BIODIVERSITAS
Volume 26, Number 12, December 2025
Pages: 5964-5976

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d261201

Using macrozoobenthos bioindicators to assess the impact of land use on water quality in Citumang River, Pangandaran District, West Java, Indonesia

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Manuscript received: 16 June 2025. Revision accepted: 21 November 2025.

Abstract. *Chazanah N, Suharyanto, Karepesina NL, Ilmi F, As-Syarif IA, Tarigan ID, Shevina S. 2025. Using macrozoobenthos bioindicators to assess the impact of land use on water quality in Citumang River, Pangandaran District, West Java, Indonesia. Biodiversitas 26: 5964-5976.* This study focuses on analyzing macrozoobenthos bioindicators in relation to land use variation along the Citumang River, within the Ciwulan-Cilaki watershed, Pangandaran District, West Java, Indonesia. Previous research has shown that land use along a watershed can influence water quality and macrozoobenthos diversity, as reflected by changes in the diversity index (H'), which tends to be higher in more natural areas (H': 1.06-2.13) and lower in areas under anthropogenic pressure (H': 0.52-1.16). This helps in understanding the relationship between macrozoobenthos diversity and environmental factors driven by land use impacts. Five sampling sites representing natural forest, plantation, agriculture, and residential areas were sampled periodically in May, June, and October 2024. Statistical analyses using PAST version 4.03 included One-Way ANOVA, Hierarchical Cluster Analysis (HCA), Similarity Percentage Analysis (SIMPER), and Canonical Correspondence Analysis (CCA). Significant differences in water quality parameters ($p<0.05$) were observed among sites with different land use types. HCA and SIMPER revealed distinct macrozoobenthos assemblages corresponding to these variations. *Faunus* sp., an estuarine species, dominated downstream residential areas with high salinity and organic matter, indicating its role as a potential bioindicator of degraded water quality. In contrast, *Clithon* sp. and *Melanoides* sp. were prevalent in upstream natural and agricultural areas, associated with higher dissolved oxygen, water clarity, and nutrient levels, suggesting their suitability as indicators of mildly to moderately polluted conditions. These findings demonstrate that macrozoobenthos communities respond sensitively to land use changes and can effectively indicate variations in riverine environmental quality.

Keywords: Benthic macrozoobenthos, bioindicators, Citumang River, land use

INTRODUCTION

Previous studies have shown that land use activities along river basins affect water quality and macrozoobenthos diversity (Camara et al. 2019; Aweng et al. 2021; Shamaskin et al. 2022; Goodarzi et al. 2023; Pratiwi et al. 2024). Each type of land use can exert specific pressures on river ecosystems (Keke et al. 2021; Adesakin et al. 2023). In areas dominated by natural forest, anthropogenic pressures are relatively low, allowing habitat quality and ecosystem functions to remain intact (Cornejo et al. 2019). In contrast, agricultural land use, through the application of fertilizers and pesticides, can increase nutrient loading and introduce chemical residues into river systems (Guellaf and Kettani 2025). Agricultural fields located adjacent to riverbanks are also prone to soil erosion, which can trigger sedimentation and elevate total suspended solids (Ebsa et al. 2022; Pratiwi et al. 2024). Meanwhile, in residential areas, domestic waste consisting of both organic and inorganic materials can increase organic pollution loads, thereby reduce dissolved oxygen levels and alter the balance of aquatic ecosystems (Bhaskar 2020; Dębska et al. 2021; Al-Ali and Al-Dabbas 2022; Isroni et al. 2023). Such pressures can modify the physicochemical properties of water and sediment characteristics, ultimately leading to changes in macrozoobenthic community structure (Hughes et al. 2019; Islamy and Hasan 2020; Delves et al. 2023; Goodarzi et al. 2023).

One common ecological response is the dominance of pollution-tolerant species accompanied by a decline in diversity within the affected area (Eriksen et al. 2021; Arias et al. 2022). This pattern is consistent with findings from several studies showing variations in the Shannon Wiener diversity index (H') across different land use types, with the highest values observed in natural areas and a significant decline in areas more strongly influenced by anthropogenic activities (Gholizadeh et al. 2021; Pratiwi et al. 2024; Octavina et al. 2025). In upstream sections dominated by natural forest, river ecosystems generally support higher biodiversity (Al et al. 2022; Zhao et al. 2024). Conversely, in downstream sections affected by intensive agriculture and settlements, water quality tends to deteriorate, accompanied by reduced biodiversity while tolerant species become dominant. The macrozoobenthic community and environmental factors are interrelated, enabling the prediction of disturbances caused by anthropogenic activities (Shabani et al. 2019; Wang et al. 2020; Aweng et al. 2021; Tayung et al. 2022; Semenchenko et al. 2024).

Integrating physicochemical and biological parameters in assessing water quality changes provides a more holistic and sustainable understanding of aquatic ecosystem conditions (Chazanah et al. 2020; Muntalif et al. 2023; Farhan et al. 2024). This approach further aids in identifying detailed macrozoobenthic species characteristics in relation to different land-use types. Macrozoobenthos are highly valuable tools for monitoring environmental quality in aquatic ecosystems (Al-Izhar and Tanjung 2023; Okoro et al. 2024). Numerous studies have demonstrated their effectiveness as efficient bioindicators in evaluating the ecological health of river ecosystems (Harahap et al. 2018; Eriksen et al. 2021; Al et al. 2022). Their sensitivity to changes in water quality, combined with their relatively sedentary nature, makes macrozoobenthos particularly useful for identifying the condition of aquatic ecosystems subjected to pollution (Boudeffa et al. 2020; Adesakin et al. 2023; Sany et al. 2023).

Although numerous studies have examined river water quality in Indonesia, research specifically addressing the relationship between land use and the presence of macrozoobenthic species in the Citumang River, Pangandaran District, remains limited. Consequently, scientific understanding of how land use influences macrozoobenthic diversity in this area has not yet been fully developed. The impacts of land use within a watershed on biotic components represent a critical issue in ecosystem management (Scotti et al. 2020; Shamaskin et al. 2022), posing a challenge for ecologists in understanding the effects of land use on biodiversity and in developing reliable assessment methods to accurately measure such responses. Therefore, this study aims to determine the impacts of different land-use types on macrozoobenthic distribution and to explore how macrozoobenthic diversity integrates with various physicochemical and sediment parameters, particularly in the Citumang River. We focus on four land-use types along the Citumang River: natural forest, plantation, agriculture, and settlement. These four categories were selected as they represent the predominant land-use variations along the Citumang River and constitute the most representative human-managed land-use types.

MATERIALS AND METHODS

Study area

The Citumang River, located approximately 14 km from the center of Pangandaran District, is one of the leading tourist attractions in West Java, Indonesia. This river has received special attention as it is designated as part of the National Tourism Strategic Area (KSPN) (Putri and Nurusholih 2019). Its main attraction is body rafting, supported by natural landscapes consisting of rock formations and small caves along the river's course (Hermansah 2019; Sahidin et al. 2021). In addition to serving as a regional economic asset, the development of this area has driven land use along the river toward plantations, agriculture, and settlements. Six sampling stations were selected purposively to represent the land use gradient along the Citumang River, ranging from natural forest (Site I), plantation (Site II), agriculture (Site III), to settlements in the downstream section (Site IV to Site VI). The selection of sampling locations considered variations in land use from upstream to downstream, with relatively similar aquatic physical characteristics, substrate types, and environmental pressures, thereby representing the dominant conditions of each site (Figure 1).

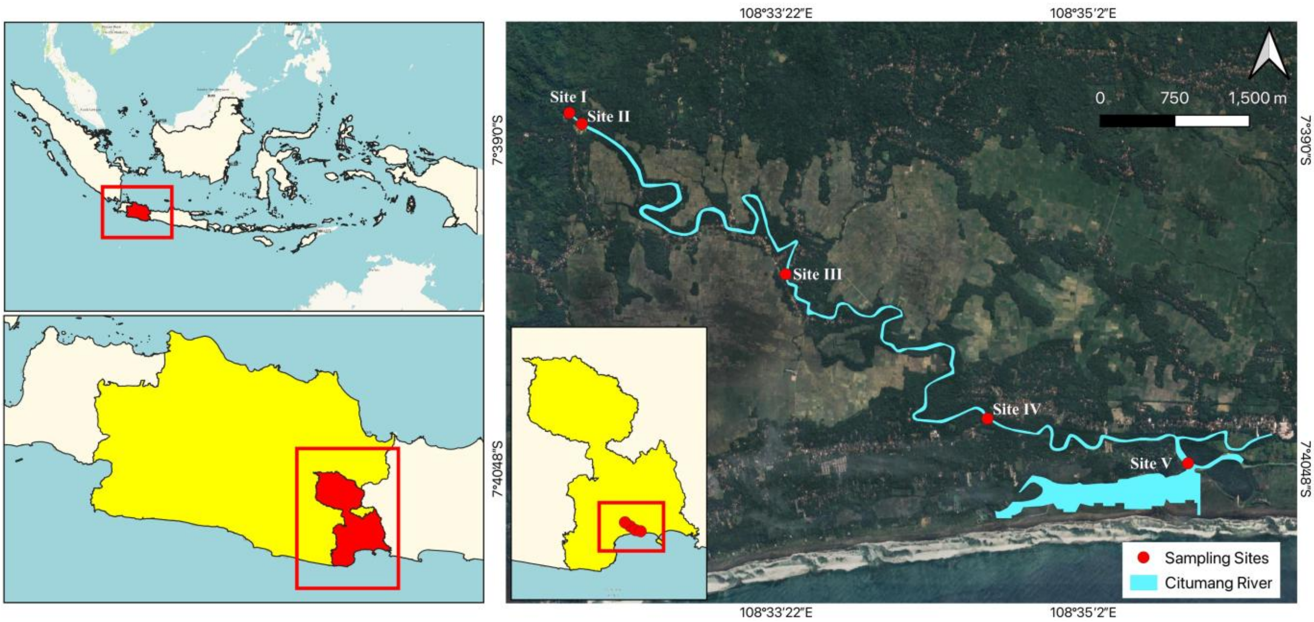

Figure 1. Flow map of the Citumang River in West Java, Indonesia, that crosses areas such as Parigi, Sidamulih, and Sukaresik, until it approaches the coastal area (research stations are marked with red dots)

To ensure the determination of research stations, land use analysis in this study was conducted spatially using a buffering technique by creating a 100 m buffer zone on both the left and right sides of the river, as shown in Table 1. This buffer zone serves as the main study area representing the riparian zone, which has the potential for direct interaction with the water body. Land use within this distance strongly influences water quality and the ecological condition of the river (Allan and Castillo 2007; Koskey et al. 2021). The results of this analysis were then used as the basis for determining stations to assess the potential impacts of land use on water quality and aquatic ecosystems, while also considering researcher safety. This consideration was necessary given that the Citumang River has strong currents in the upstream section and varying depths, with the downstream section generally deeper than the upstream. Sampling was conducted during three different periods, specifically May, June, and October 2024, to represent both dry and rainy season conditions. To strengthen the seasonal considerations in the research design, monthly rainfall data from the Meteorology, Climatology, and Geophysics Agency (BMKG) of Indonesia were used as a reference. The lowest rainfall was recorded in May (47.79 mm), representing the dry season, whereas higher rainfall was recorded in June (190.16 mm) and October (194.5 mm), reflecting the rainy season.

Procedures

Sample

Macrozoobenthos sampling refers to SNI 13-4718-1998 (BSN 1998) using a 25×40 cm² Surber net with a pore size of 0.5 mm (Muntalif et al. 2023). At each sampling point, there are 5 sub-sampling locations spaced approximately 5 m apart which are then combined to represent one station (Wakhid et al. 2021). The Surber net is used in the opposite direction to the current and placed on the bottom of the water for approximately five minutes at each sampling point. Macroinvertebrates that were carried away by the water current entered the net (Ochieng et al. 2020). The benthic macroinvertebrates were then placed in tubes, labelled, and preserved in 70% ethanol solution (Scotti et al. 2020). Macrozoobenthos were identified morphologically up to the genus level using a binocular microscope and referring to literature Pennak (1953), Mellanby (1963), Ward (1992), Bouchard (2004), and Dharma (2005).

Water sampling was conducted based on SNI 6989:57:2008 concerning Surface Water Sampling Methods (BSN 2008). Water samples were collected once at each coordinate point using the grab sampling method to represent the water quality of the water body. The river water quality was then assessed by comparing it with the Indonesian Government Regulation No. 22 of 2021 for Class II waters intended for recreational water infrastructure, freshwater aquaculture, and sources for livestock and agricultural use as well as the Regulation of the Indonesian Ministry of Health No. 2 of 2023.

In situ measurements were carried out for various parameters, including water transparency (cm) using a Secchi disk, Dissolved Oxygen (DO, mg/L) using a DO meter (Lutron PDO-519), water temperature (°C) using a thermometer, and pH using a pH meter (Kedida CT-6020), at each sampling station. Ex situ measurements were conducted for parameters such as Total Suspended Solids (TSS, mg/L), Total Dissolved Solids (TDS, mg/L), Biochemical Oxygen Demand (BOD, mg/L), Chemical Oxygen Demand (COD, mg/L), ammonia (mg/L), nitrate (NO_3-N, mg/L), and nitrite (NO_2-N, mg/L).

Table 1. Research station coordinates

Area	Coordinate	River width (m)	River discharge (m^3/s)	NF	P	A	R	Description
Site I	7°38'39.87"S 108°32'09.96"E	3.83±1.04	0.15	58%	29%	12%	1%	1) The dense riparian vegetation, along with the presence of moss on the soil surface, rocks, and creeping plants, indicates a wet ecosystem characterized by high humidity. 2) The riverbed is composed of medium-sized rocks and predominantly sand along its course.
Site II	7°38'54.62"S 108°32'17.87"E	9.83±1.44	1.67	34%	46%	18%	2%	1) The riverbed is composed of medium-sized rocks and predominantly sand along its course.
Site III	7°39'43.99"S 108°33'24.78"E	10.6±1.04	2.73	0%	18%	70%	12%	1) The river is surrounded by dense vegetation and shrubs, as well as agricultural areas including plantations and rice fields along its course. 2) The riverbed is primarily composed of sand, with medium-sized rocks distributed throughout the stream.
Site IV-V	7°40'31.43"S 108°34'31.00"E	10.22±0.26	5.4	0%	27%	19%	54%	1) The riparian vegetation is dominated by palm or nipa trees along the riverbanks and is exposed to direct wastewater discharge.

Note: NF: Natural Forest, P: Plantation, A: Agricultural, R: Residential

Ex situ water quality analysis was performed using river water samples collected from both the riverbank and the midstream using a water sampler, with a total volume of approximately ±1.5 liters per composite sample. Samples were stored in cool boxes containing ice packs before being transported to the laboratory for further analysis. All water quality analyses followed the APHA (1999) standard procedures.

For sediment parameter analysis, approximately 2 kg of sediment samples were collected from each station and stored in plastic containers. The analysis included sediment grain size distribution, total organic carbon, total phosphate, and total nitrogen, all performed ex situ. Total organic carbon was analyzed using the Walkley-Black method, total phosphate using the Stannous Chloride-Spectrophotometry method, and total nitrogen using the Kjeldahl method SNI 4146:2013 (BSN 2013).

Data analysis

Biotic index

The abundance of macrozoobenthic individuals can be calculated as the ratio of the number of individuals to a specific unit area (Southwood and Henderson 2000):

$$\boldsymbol{A = \frac{X_i}{L}}$$

Where, A represents the abundance (ind/m²), X_i is the number of individuals of the i-th macrozoobenthic species, and L is the sampled area (using a Surber net) in square meters (m²).

Macrozoobenthic diversity refers to the number of species present within a given area and can be determined using the Shannon-Wiener Diversity Index (H'), based on the formula proposed by Shannon and Weaver (1949):

$$\mathbf{H'} = -\sum \boldsymbol{P_i \, ln \, P_i}$$

Where, H' represents the Shannon-Wiener diversity index, and Pi is the proportion of individuals of the *i*-th species (ni) to the total number of individuals (N), calculated as ni/N. The criteria for interpreting the diversity index (H') are as follows: H'<1 indicates low diversity, 1<H'<3 indicates moderate diversity, and H'>3 indicates high diversity.

Species dominance, used to determine the presence of dominant macrozoobenthic taxa in the aquatic environment, is assessed using the Simpson's Dominance Index, which is expressed as:

$$\boldsymbol{D = \sum \left(\frac{ni}{N}\right)^2}$$

Where, D is the dominance index, ni represents the number of individuals of the *i*-th macrozoobenthic species, and N is the total number of individuals across all genera. The dominance index ranges from 0 to 1. A value of D approaching 1 indicates the presence of a dominant group and typically corresponds to a lower evenness index. Conversely, a value of D approaching 0 suggests that no single taxon dominates the community, which is usually associated with a higher evenness index.

The evenness index is used to describe the relative distribution of individuals within a community and is calculated using the following formula:

$$\boldsymbol{E = \frac{H'}{In\, s}}$$

The categories for the evenness index values are as follows: when E<0.6, the population exhibits high evenness, with individuals relatively evenly distributed; values of E between 0.4 and 0.6 indicate moderate evenness, suggesting variation in individual distribution; while E<0.4 indicates low evenness, where the distribution of individuals is uneven, often with the dominance of a few specific species.

This study integrates various statistical analysis methods to examine environmental factors and macrozoobenthic diversity influenced by variations in land use along the Citumang River. Differences in water quality among the different land use types were analyzed using One Way ANOVA (P<0.05). Tukey's HSD post hoc test was applied when significant differences were detected between the means of each treatment. Macrozoobenthic diversity and abundance were analyzed using ecological indices such as the Shannon Wiener diversity index, evenness index, and Simpson dominance index to assess the condition of the aquatic ecosystem based on the distribution and proportion of macrozoobenthic taxa, which reflect the degree of ecological stress in the habitat. Macrozoobenthic structure was determined through Hierarchical Cluster Analysis (HCA) using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based on the Bray Curtis dissimilarity index to group macrozoobenthos according to differences in land use types (Roger et al. 2017). The key species contributing to differences in macrozoobenthic composition among land use types were identified using Similarity Percentage (SIMPER) analysis. Relationships between physicochemical and sediment parameters with macrozoobenthic diversity were examined using Canonical Correspondence Analysis (CCA) to identify environmental factors influencing macrozoobenthic distribution across different land use types (Scotti et al. 2020). In the CCA, only genera with dominant distributions were prioritized, whereas those with wide or irregular distributions were excluded from the analysis. All statistical analyses were performed using PAST software version 4.03 (Hammer et al. 2001). The data obtained in this study are presented in tables and figures and analyzed descriptively by relating the results to relevant references.

RESULTS AND DISCUSSION

Results

Distribution and diversity index of macrozoobenthos

Based on the observation results of macrozoobenthos in the Citumang River, it was found that variations in the composition and abundance of macrozoobenthos (Table 2, Figure 2) were influenced by differences in land use along the river. The macrozoobenthos diversity index ranged from 1.06 to 1.65 with an average of 1.39. Based on the Shannon Wiener diversity index, the average diversity level in the Citumang River was classified as moderate with a moderate ecological pressure. The highest evenness index in natural forest land use was 0.84 indicating that the distribution of macrozoobenthos individuals in this location was relatively even among various species. Meanwhile, the highest species dominance was recorded in residential land use located at the mouth of the Citumang River at 0.34. This value indicates the dominance of one or more species in an area, as reflected in the high abundance of *Faunus* sp., amounting to 380 ind/m² dominating the area, although the dominance index category is still considered low. Nevertheless, this dominance contributed to the overall variation in macrozoobenthos abundance in each type of land use in the Citumang River, which ranged from 74 to 808 ind/m². The highest abundance was found in residential land use with 808 ind/m², followed by plantation and agricultural land uses with the same abundance of 157 ind/m². Meanwhile, the lowest abundance was recorded in natural forest land use with 74 ind/m². Although residential areas showed the highest macrozoobenthos abundance, these areas were dominated by estuarine taxa tolerant to salinity and pollution, such as *Faunus* sp., *Clibanarius* sp., and *Uca* sp.. This indicates that although the number of macrozoobenthos found was high, the species diversity in these areas was low, suggesting that the environmental conditions only support certain species.

Table 2. Presence of benthic macroinvertebrate in each location

Taxon	NF	P	A	R
Ostreida				
Ostreidae				
Saccostrea sp.	-	-	-	+
Caenogastopoda				
Pachychilidae				
Faunus sp.	-	-	-	+
Cycloneritida				
Neritidae				
Clithon sp.	+	+	+	+
Sorbeoconcha				
Thiaridae				
Melanoides sp.	+	+	+	+
Decapoda				
Ocypodidae				
Uca sp.	-	-	-	+
Diogenidae				
Clibanarius sp.	-	-	-	+
Penaeidae				
Metapenaeus sp.	-	-	+	+

Note: NF: Natural Forest, P: Plantation, A: Agricultural, R: Residential, +: Present, -: Absent. Orders are represented in bold capital letters, families are shown in bold font, and genera are neither bolded nor in capital letters

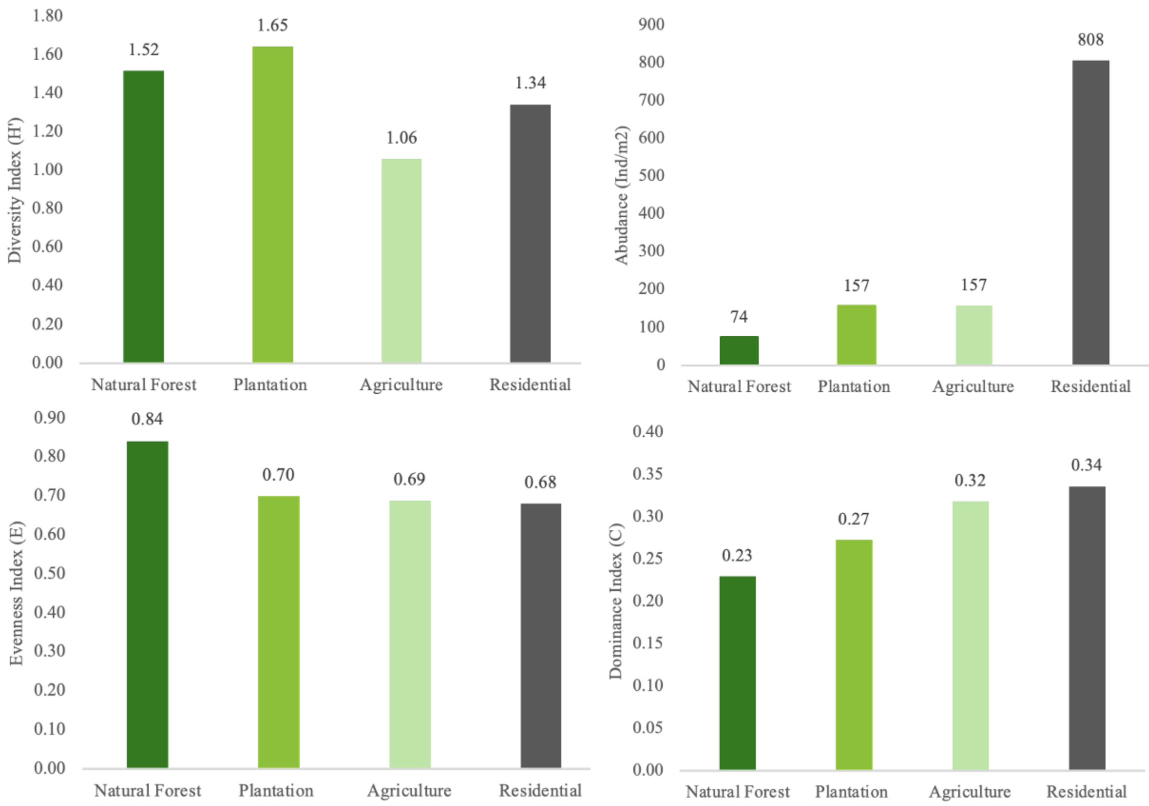

Figure 2. Macrozoobenthos ecological indices by land use type in the Citumang River, Pangandaran District, West Java, Indonesia

Consistent with the ANOSIM analysis results (p<0.01), there were significant differences in macrozoobenthic species composition, with key species identified for each land use category in the Citumang River. These findings were further supported by the HCA results, which revealed a clustering pattern in the dendrogram (Figure 3) where natural forest, plantation, and agricultural land uses were grouped into a single cluster with a high level of similarity. This indicates that these three locations shared relatively similar macrozoobenthic compositions. However, the natural forest tended to form a distinct subgroup, likely due to better water quality and lower pollution levels, as reflected in the relatively high macrozoobenthic diversity recorded in this area. In contrast, the settlement land use formed a separate group due to pronounced differences in macrozoobenthic structure. This was consistent with the water quality analysis results, which indicated polluted aquatic conditions in this area, leading to dominance by pollution-tolerant species. Table 3 presents the results of the SIMPER analysis, which details the taxa identified as bioindicators driving these differences.

The SIMPER analysis revealed that differences in macrozoobenthic distribution among land use types (Table 3) were primarily driven by the dominance of *Faunus* sp., (Av. Dissim: 22.11; Contrib. 33.93%), which was predominantly found in residential areas and absent from other land use types. This finding suggests that *Faunus* sp., may serve as a potential bioindicator of pollution in residential land-use areas located in the downstream section of the river. In contrast, *Clithon* sp. and *Melanoides* sp. exhibited a decline in abundance in residential areas compared to other land uses. This pattern is supported by the abundance analysis, which showed relatively high abundances of these two species in natural forest, plantation, and agricultural land uses, indicating their potential role as bioindicators of good to moderate water quality.

Table 3. Similarity Percentage (SIMPER) analysis results for macrozoobenthos abundance in the Citumang River, Pangandaran, West Java, Indonesia

Genus	Speciment photo	Av. dissim	Cont. %	Mean natural forest	Mean plantation	Mean agricultural	Mean residential
Faunus sp.		22.11	33.93	0	0	0	380
Melanoides sp.		12.47	19.14	20.7	57.3	54	41.3
Clithon sp.		11.14	17.09	24.7	44.7	65.3	12.3
Clibanarius sp.		8.944	13.73	0	0	0	147
Uca sp		6.891	10.58	0	0	0	116
Saccostrea sp.		2.75	4.221	0	0	0	52.7
Metapenaues sp.		0.8541	1.311	0	0	1.33	10.3

Note: Av. dissim: Average dissimilarity, Cont: Contribution

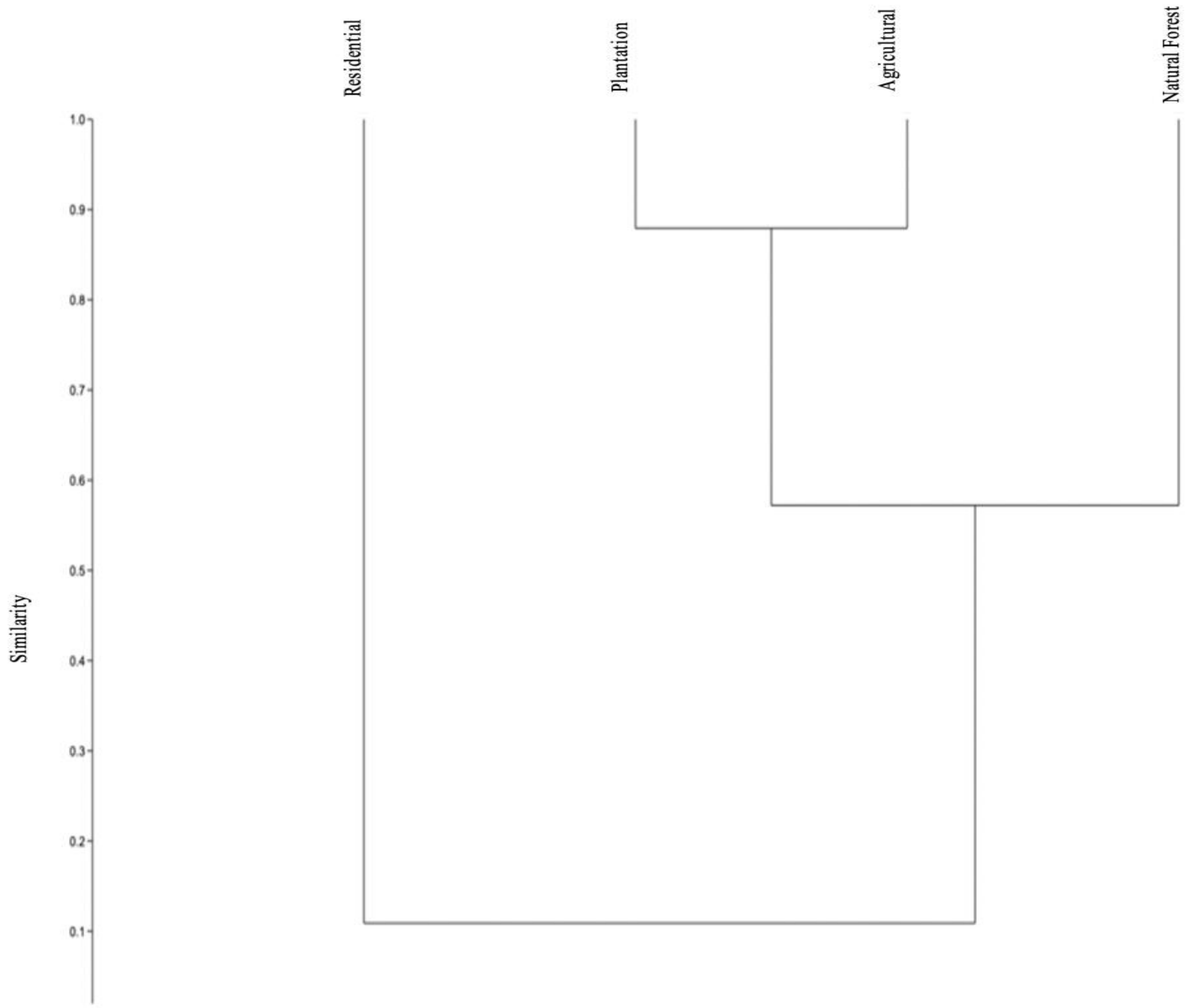

Figure 3. Hierarchical Cluster Analysis (HCA) based on Bray-Curtis similarity showing macrozoobenthos sample grouping

Physicochemical parameters of water

Table 4 presents the mean (±SD) of the physicochemical parameters of water at each sampling site. The post hoc test results showed a significant difference in temperature ($p<0.05$) between natural forest and residential land uses. The increase in water temperature from natural forest to residential areas ranged from 25.79 to 27.72°C with significantly different dissolved oxygen levels ($p<0.05$) among the various land use types, ranging from 4.26 to 5.75 mg/L. These findings are consistent with previous studies, which reported that dissolved oxygen concentration in aquatic ecosystems is inversely related to temperature, where higher dissolved oxygen levels are generally associated with lower water temperatures (Tennakone et al.1989; Harvey et al. 2011). Based on the temperature measurements conducted, it can be concluded that the water temperature in the Citumang River remains within the normal range according to water quality standards and is still within the optimal limits to support the survival of macrozoobenthos.

Conductivity and salinity parameters showed a significant increase in residential land use areas. This increase was attributed to seawater intrusion which tends to occur in downstream river regions. In contrast, TDS and TSS did not exhibit significant differences, although both showed an increasing trend from natural forest to residential areas (Yolanda et al. 2023). The increase in suspended material load was consistent with the significant rise in COD and BOD values in residential land-use areas indicating organic pollution resulting from domestic activities (Stepenuck et al. 2002; Wang et al. 2020; Arias et al. 2022). The influence of land use can accelerate water quality degradation and alter the physicochemical characteristics of the aquatic environment. This is in line with the findings of Dębska et al. (2021) and Pratiwi et al. (2024), which demonstrated that land use surrounding river basins can affect river water quality.

Table 4. ANOVA test results and physicochemical characteristics of water in the Citumang River, Pangandaran, West Java, Indonesia, presented as mean±standard deviation. Bold p-values indicate statistically significant differences (p<0.05). Tukey's post hoc test results indicate significant pairwise differences between locations

Parameter	Natural Forest	Plantation	Agricultural	Residential	P Value
Temperature (ºC)	25.79±0.62	26.49±0.68	26.69±0.86	27.72±0.56	<0.05
TDS (mg/L)	158.33±121.64	119.11±92.38	128±98.29	7235.41±2850.19	0.06
TSS (mg/L)	14.62±1.83	23.14±8.53	28.7±5.03	25.03±3.85	0.13
Conductivity (µS/cm)	401.44±91.31	310.33±59.78	302.3±41.68	15637.89±6822.17	<0.05
Brightness (cm)	230±34.64	185±13.23	153.33±29.29	152.78±0.59	<0.05
DO (mg/L)	5.62±0.59	5.75±0.85	4.26±0.7	4.38±0.6	<0.05
COD (mg/L)	12.2±8.88	9.19±3.81	17.15±0.34	37.03±24.43	<0.05
BOD (mg/L)	2.73±0.4	3.5±0.7	3.27±0.58	5.41±0.011	<0.05
pH	7.632±0.23	8±0.25	7.84±0.21	7.67±0.15	0.19
Salinity (mg/l)	211.56±32.84	153.22±29.17	169±27.61	8916.52±4096.82	<0.05
Nitrite (mg/L)	0.001±0.0001	0.0015±0.0005	0.003±0.003	0.01±0.005	0.77
Nitrate (mg/L)	0.4±0.19	0.57±0.5	0.3755±0.34	0.25±0.152	0.68
Ammonia (mg/L)	0.0158±0.03	0.01±0.02	0.01±0.001	0.02±0.017	0.97

Table 5. Spatial variation of sediment physicochemical parameters in the Citumang River, Pangandaran District, West Java, Indonesia

Sediment Parameters	Natural Forest	Plantation	Agricultural	Residential
Clay (%)	3	11	9	32
Silt (%)	14	17	19	37
Gravel (%)	60	2	2	3
Sand (%)	23	71	70	30
N Total (%)	4.16	5.49	9.16	13.88
C-Organik (%)	0.79	0.53	0.79	0.87
Phospat (%)	0.0000351	0.0000269	0.0000365	0.00002

Sediment particle distribution and physicochemical characteristics

The analysis of particle distribution and organic content in the Citumang River in this study also revealed significant variations among different land uses. Land use with natural conditions, such as natural forest, was dominated by the gravel fraction at 60% with a lower nutrient content of 4.16% (Table 5). The higher percentage of coarse sediment indicates that the natural forest area located in the upstream section of the Citumang River has a relatively high-water flow velocity, thereby supporting the dominance of the gravel fraction. In contrast, areas with more intensive human activities, such as plantations, agriculture, and residential areas were dominated by the same sediment fraction, namely sand, with a proportion ranging from 30% to 71%.

The dominance of silt and clay fractions along with the high content of total nitrogen, organic carbon, and phosphate in sediments from residential land-use areas is influenced by their downstream location in the river, which allows the accumulation of fine particles due to sedimentation from upstream (Malek and Frontalini 2024). Additionally, the reduced flow velocity causes fine particles to settle on the riverbed (Jansen 2016; Mobasher et al. 2023). On the other hand, Arias et al. (2022) stated that finer-grained substrates such as silt and clay have a higher capacity to adsorb organic matter compared to coarse substrates. The dominance of estuarine-tolerant species in this location reflects their ecological adaptation to the estuarine habitat and indicates that salinity is one of the key environmental factors influencing the macrozoobenthos community structure in the residential downstream area of the Citumang River.

Canonical Correspondence Analysis (CCA) revealing the relationships between environmental variables and macrozoobenthos in the Citumang River

The ordination diagram from Canonical Correspondence Analysis (CCA) in the Citumang River illustrates the relationship between environmental parameters and macrozoobenthos diversity across different land use types. This analysis resulted in four distinct quadrants that reflect ecological quality differences among natural forest, plantation, agricultural, and residential land uses (Figure 4).

In the natural forest, plantation, and agricultural land uses located in the upstream part of the river, species such as *Clithon* sp. and *Melanoides* sp. were associated with high dissolved oxygen levels, water clarity, and relatively elevated concentrations of nitrate and phosphate. Additionally, the distribution of sediment particles, specifically gravel and sand, was correlated with the presence of these two species, indicating relatively pristine aquatic conditions with low anthropogenic pressure. Meanwhile, in residential land-use areas, species such as *Faunus* sp., *Uca* sp., *Clibanarius* sp., and *Saccostrea* sp. were associated with water quality parameters including salinity, Total Dissolved Solids (TDS), conductivity, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), nitrite concentration, and increased water temperature. These species were also linked to the distribution of fine sediment particles such as clay and silt, accompanied by relatively high organic and nitrogen content. These conditions reflect a more degraded aquatic environment influenced by anthropogenic activities in the downstream section of the river.

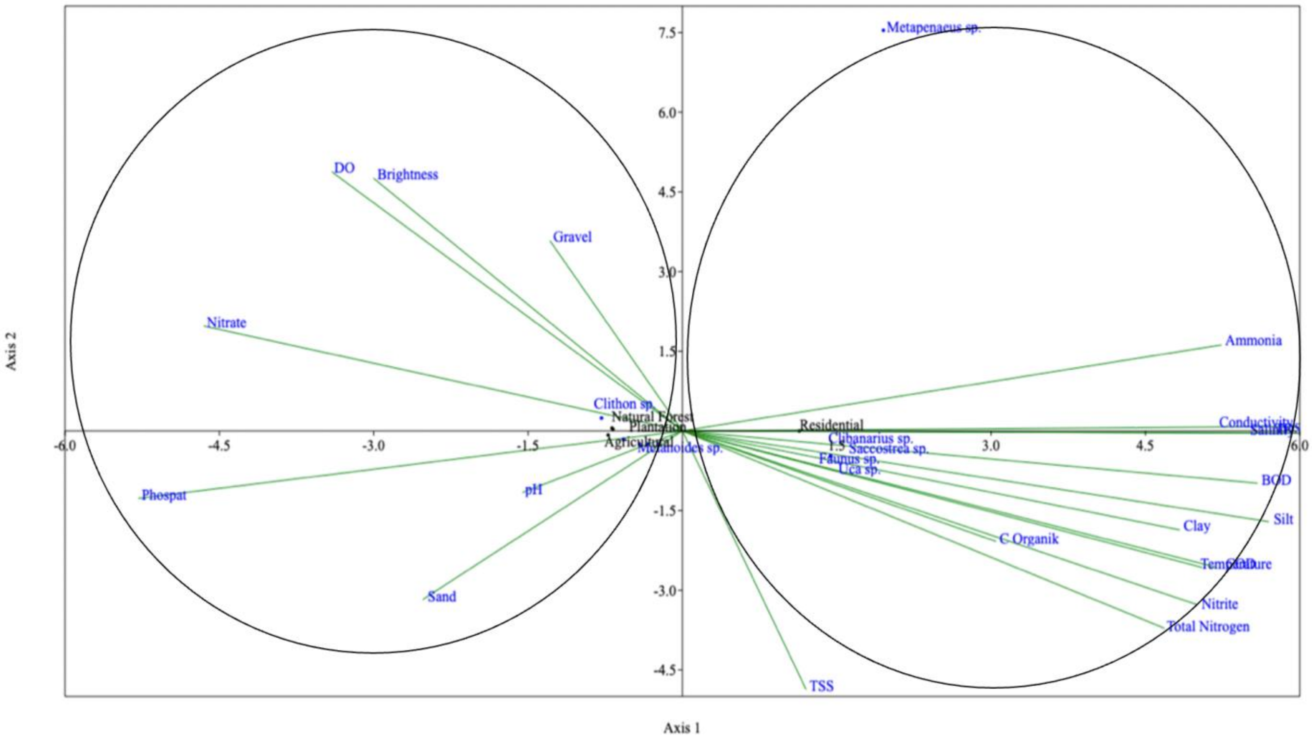

Figure 4. Triplot of Canonical Correspondence Analysis (CCA) of macrozoobenthos in relation to water and sediment quality parameters across different land use types

Discussion

Distribution and biotic index of macrozoobenthos

Land use variation along the Citumang River is associated with shifts in macrozoobenthic community structure characterized by an increased dominance of tolerant species in residential areas subjected to higher anthropogenic pressures (Al et al. 2022; Arias et al. 2022). One indication of changes is the higher abundance of tolerant species such as *Faunus* sp. in residential areas compared to natural forest, plantation, and agricultural land which demonstrate relatively stable and pristine aquatic conditions (Theodoropoulos et al. 2015). These results are consistent with the findings of Ardyatma et al. (2020) and Sahidin et al. (2021) who show that *Faunus* sp. tends to dominate estuarine habitats with high salinity and organic content influenced by domestic activities. Similarly, Oyeku et al. (2023) show that in areas with relatively pristine aquatic conditions, macrozoobenthic communities are generally dominated by sensitive species, in contrast to residential areas that are more frequently inhabited by tolerant taxa.

Other estuarine species, such as *Clibanarius* sp., *Uca* sp., *Saccostrea* sp., and *Metapenaeus* sp. were also found exclusively in residential areas, although the abundance was significantly lower than that of *Faunus* sp. These species have characteristics that facilitate tolerance to salinity fluctuations and adaptation to estuarine environments influenced by tidal variations and seawater intrusion (Ardyatma et al. 2020; Sahidin et al. 2021; Oyeku et al. 2023). Similar pattern were reported by Pratiwi et al. (2023) who found *Faunus* sp. and *Clibanarius* sp. as dominant gastropods in tidally influenced estuarine habitats characterized by muddy substrates rich in organic matter. This condition is supported by the characteristics of residential areas located downstream, where flow velocity tends to be low and the substrate is dominated by clay and silt which tend to accumulate organic matter (Stepenuck et al. 2002) thereby supporting the persistence of tolerant species in these zones (Arias et al. 2022; Baharuddin et al. 2023). Consistent with Fuller et al. (2022), changes in substrate characteristics along the river flow influence the distribution and abundance of macrozoobenthos which tend to decrease on large rock substrates. Furthermore, domestic waste in residential areas contributes to increased organic content (Pohlmann et al. 2018; Han et al. 2019) leading to water quality degradation (Minshall et al. 2014; Souza et al. 2021; Delgado et al. 2023) and consequently reducing macrozoobenthos abundance in these areas. This condition arises because each species has varying tolerance ranges to substrate characteristics and other environmental parameters (Al-Izhar and Tanjung 2023; Oyeku et al. 2023).

Clithon sp. and *Melanoides* sp. were more dominant in land uses with natural characteristics, including natural forest, plantation, and agriculture, suggesting these species serve as bioindicators of water quality ranging from good to mildly polluted. These results are consistent with studies indicating that *Clithon* sp. is associated with natural habitats characterized by hard substrates and stable currents (Purnama and Anwar 2022), whereas *Melanoides* sp. exhibits broad tolerance and is commonly found in waters with elevated organic matter and low dissolved oxygen, although it does not dominate under conditions of severe pollution (Patang et al. 2018). According to Dufrêne and

Legendre (1997), species bioindicator assessment involves species distribution patterns and frequency of occurrence in habitats, generally related to their abundance. A species can be categorized as a bioindicator if it meets several characteristics, including sensitivity to environmental changes, wide distribution, and an important ecological role. The dominance of these two species suggests their tolerance to moderate environmental changes, although they still depend on relatively better water quality compared to residential land use areas (Scotti et al. 2020; Shamaskin et al. 2022; Liang et al. 2025).

The results are reinforced by SIMPER analysis, showing that *Faunus* sp. contributed the most to the differences in macrozoobenthos communities among land use categories. This species was dominantly identified only in residential land-use areas, making it a potential bioindicator of poor water quality. According to studies by Solé et al. (2009) and Coelho et al. (2014), a healthy estuary should be inhabited by *Nereis diversicolor*, an estuarine species tolerant to salinity but sensitive to organic pollution and heavy metals. However, this study found dominance by *Faunus* sp. which is known for its high tolerance to salinity and its ability to adapt to estuarine environments influenced by seawater intrusion caused by tidal fluctuations in the downstream river (Sahidin et al. 2021). Conversely, in natural forest, plantation, and agricultural land uses, there was an increased dominance of *Clithon* sp. and *Melanoides* sp., positioning these species as potential bioindicators of water quality with light to moderate pollution. This condition is supported by water quality analysis results showing clear water with high oxygen content and a hard substrate such as rocky areas in flowing zones, which provide suitable habitats for these species.

Physicochemical parameters of river water and sediment

Environmental changes can affect the physicochemical conditions of aquatic habitats (Table 2) that serve as living environments for aquatic organisms (Stepenuck et al. 2002; Yuan et al. 2019; Xu et al. 2021; Al et al. 2022; Arias et al. 2022). The impacts are evident in increased organic pollution, temperature changes, and water quality degradation, which lead to alterations in species composition and abundance (Aweng et al. 2021; Xu et al. 2021; Adesakin et al. 2023). These changes, in turn influence the habitat conditions of macrozoobenthos (Muntalif et al. 2023; Farhan et al. 2024) as reflected by the differences in macrozoobenthos distribution across various land uses along the Citumang River. Residential areas represent one of the land-use types with the most significant impact on water quality and macrozoobenthic communities (Pratiwi et al. 2024).

Spatially, residential land use exhibits poorer water quality compared to other land uses, as reflected by elevated levels of TDS, conductivity, COD, BOD, and salinity that exceed water quality standards. This condition aligns with previous studies reporting that residential land use tends to generate higher organic and inorganic pollution, thereby adversely affecting water quality and failing to meet environmental standards (Xu et al. 2021). Furthermore, the highest salinity concentration was recorded in residential areas, reaching 7,950.89 mg/L, attributed to tidal influences that allow seawater intrusion into the river system (Yuan et al. 2019; Adjovu et al. 2023; Chen et al. 2023). According to Rahimi-Movaghar et al. (2019) and Pushpalatha et al. (2022), coastal residential land use tends to increase salinity concentrations compared to other land uses located further inland (Yuan et al. 2019; Mama et al. 2022; Pushpalatha et al. 2022). In this study, organic matter content in residential land-use areas ranged from 0.53% to 0.87%, indicating accumulation of organic matter in the downstream section of the river. This organic matter accumulation is caused by domestic activities and slowed river flow conditions, which facilitate the deposition of fine particles and organic matter on the riverbed (Jansen 2016; Mobasher et al. 2023). Such conditions can trigger eutrophication processes, potentially reducing dissolved oxygen levels in the water. This, in turn, impacts the macrozoobenthos community structure and disrupts ecosystem balance (Asadisharif et al. 2024; Farhan et al. 2024).

Relationship between macrozoobenthos distribution and environmental factors

Land use variation along the Citumang River influences macrozoobenthos diversity as a reflection of aquatic environmental conditions. CCA confirmed the relationship patterns between physicochemical parameters and macrozoobenthos groups, as well as clear associations with different land use types (Arias et al. 2022). It was observed that in natural forest, plantation, and agricultural land uses, *Clithon* sp. and *Melanoides* sp. showed strong associations with water quality parameters such as dissolved oxygen, water clarity, and slightly increased nitrate concentrations. This reflects relatively pristine aquatic conditions with minimal disturbance from domestic activities. According to Pratiwi et al. (2024), areas with natural characteristics generally have better water quality. The distribution of sediment particles specifically gravel and sand was also correlated with these species, indicating ecologically stable waters in these land uses that allow more sensitive species to thrive amid changes in water quality (Farhan et al. 2024). Asadisharif et al. (2024) found that agricultural activities tend to increase nutrient loads into water bodies, ultimately causing water quality degradation. The results showed a decline in water quality in agricultural land use, however the decrease was not significant compared to natural forest and plantation land uses, indicating that aquatic conditions in agricultural areas of the Citumang River still support macrozoobenthos presence despite some changes in water quality composition.

Conversely, in residential land use areas, species such as *Faunus* sp., *Uca* sp., *Clibanarius* sp., and *Saccostrea* sp., were associated with water quality parameters including salinity, Total Dissolved Solids (TDS), conductivity, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), nitrite, and increased water temperature, indicating water quality degradation in these areas. This phenomenon was supported by abundance index analysis showing the dominance of *Faunus* sp. in residential land uses suggesting that salinity is a key environmental factor influencing macrozoobenthos community structure in the downstream residential zones of the Citumang River. The increased salinity in the downstream region, caused by tidal influence and seawater intrusion, creates environmental conditions unsuitable for most freshwater macrozoobenthos, but favors the abundance of estuarine species such as *Faunus* sp.. According to Wang et al. (2020), residential land use contributes to environmental changes that affect interactions between macrozoobenthos and abiotic aquatic factors. This is consistent with water quality analysis results in residential areas, which showed increased water temperature contributing to low macrozoobenthos individual abundance (Sulaeman et al. 2020). Based on the results, individual abundance tended to be low at higher water temperatures.

According to Mely et al. (2023), temperature changes can affect physical, chemical, and biological processes in aquatic environments including algal dynamics as a primary food source which in turn influences food availability for macrozoobenthos (Belle et al. 2021; Kunze et al. 2022). Baharuddin et al. (2023), further stated in their study that residential areas experiencing higher domestic activity pressures tend to be dominated by species tolerant to environmental changes compared to other species. Species more sensitive to environmental changes tend to decline in number or even disappear due to their inability to adapt effectively. Conversely, species with high tolerance to extreme conditions such as increased salinity in estuarine areas are more likely to survive and reproduce. Under these conditions, pollution tolerant species such as *Faunus* sp. persist and even become more dominant. The dominance of certain pollution tolerant macrozoobenthos species reflects adaptation to environments with elevated salinity levels resulting from tidal influences in residential land use areas.

ACKNOWLEDGEMENTS

We would like to thank Institut Teknologi Bandung, Indonesia, for their support in funding this research through the P2MI funding programme.

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