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RESEARCH ARTICLE

Land Cover Quality, Pollution, and Macrozoobenthos Diversity in the Brantas River: Implications for Tropical River Management

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ABSTRACT

Land cover changes and water pollution significantly impact tropical river ecosystems. This study explored the relationship between land cover quality, water pollution, and macrozoobenthos diversity in the Brantas River sub-watershed, East Java. Spatial analysis assessed land cover, while water quality was evaluated using physico-chemical parameters and pollution indices. Macrozoobenthos diversity, measured as a bioindicator, revealed an increase downstream despite higher pollution levels, indicating a shift from sensitive to tolerant taxa under ecological stress. Poor land cover quality, predominantly agricultural and plantation areas, contributed to sediment runoff and nutrient pollution, classifying water quality as "lightly polluted." Habitat characteristics such as substrate type and organic matter availability influenced diversity. The findings underscore the importance of integrated watershed management, including reforestation and sustainable land use, to balance ecological conservation with socio-economic development. This study offers valuable insights into tropical watershed dynamics and strategies for sustainable river management.

1. INTRODUCTION

Land cover changes have emerged as a critical global issue, with profound implications for river ecosystems. These changes, driven by urbanization and agricultural expansion, alter land use patterns, significantly impacting water quality and biodiversity (Basuki, 2024; Guo, 2024). In tropical regions, where ecosystems are particularly vulnerable to anthropogenic pressures, the transformation of natural vegetation into built-up areas intensifies pollution and degrades aquatic habitats. Rivers in these regions often experience increased sedimentation, nutrient loading, and contamination, disrupting ecological balance and reducing biodiversity. Understanding the interplay between land cover changes and their ecological consequences is essential for effective management of river systems, particularly in areas of high environmental and socio-economic importance.

The Brantas River watershed, located in East Java, Indonesia, exemplifies the challenges faced by tropical river systems. Covering a significant portion of the region, the Brantas River supports diverse ecological, agricultural, and industrial activities, making it vital to both local communities and the broader environment. However, rapid urbanization, agricultural expansion, and industrial development within the watershed have contributed to severe ecological degradation (Hertika et al., 2023; Budirahayu, 2024). The conversion of forested and vegetated lands into agricultural fields and urban settlements has led to increased surface runoff, sedimentation, and pollution. These processes introduce heavy metals, pesticides, and organic pollutants into the river, exacerbating water quality deterioration and threatening aquatic life (Hertika et al., 2021; Valiant et al., 2020).

One of the most concerning ecological consequences of land cover change is its impact on aquatic biodiversity. Macrozoobenthos, which include benthic invertebrates such as insects, crustaceans, and mollusks, are highly sensitive to environmental changes and pollution levels. As bioindicators, they provide crucial insights into the health of aquatic ecosystems (HERTIKA, 2024; Nurainah & Hanafiah, 2022). These organisms are directly affected by physical, chemical, and biological conditions in their habitats, making them invaluable for assessing the ecological status of rivers. Macrozoobenthos diversity often declines in response to pollution, habitat degradation, and other anthropogenic pressures, highlighting the need for strategies to mitigate these impacts.

The Brantas River watershed presents unique challenges in this context. Research has shown that industrial activities and agricultural runoff contribute significantly to heavy metal contamination and nutrient pollution in the river, leading to adverse effects on aquatic ecosystems (Hertika et al., 2021; Hertika et al., 2023). These factors not only reduce macrozoobenthos diversity but also disrupt ecosystem functions, such as nutrient cycling and organic matter decomposition, which are critical for maintaining water quality. Furthermore, the decline in biodiversity within the river has socio-economic implications, as the Brantas River plays a crucial role in supporting fisheries, irrigation, and local livelihoods (Budirahayu, 2024; Valiant et al., 2020). This underscores the importance of addressing ecological degradation within the watershed to ensure the sustainability of its resources.

Despite the increasing recognition of these challenges, knowledge gaps remain regarding the intricate relationships between land cover quality, pollution levels, and macrozoobenthos diversity. While studies have established the general impact of urbanization and agricultural activities on river health, few have comprehensively examined these factors in the context of tropical rivers like the Brantas. The interplay between land use patterns, pollution sources, and biodiversity outcomes is complex, influenced by both local and regional dynamics. For instance, while heavy metal contamination and nutrient pollution are well-documented in the Brantas River, the specific pathways through which these pollutants affect macrozoobenthos diversity require further investigation. Additionally, the role of land cover quality in mediating these impacts is not fully understood, particularly in sub-watersheds where land use intensity varies significantly (Hertika et al., 2023; Handayani et al., 2023).

Addressing these gaps is essential for developing effective watershed management strategies. Integrated approaches that consider both ecological and socio-economic factors are increasingly recognized as the most effective means of mitigating watershed degradation (Pambudi, 2019; Handayani et al., 2023). Such strategies must account for the cumulative effects of land cover change, pollution, and biodiversity loss while balancing the needs of local communities. For instance, promoting sustainable agricultural practices, improving waste management, and restoring natural vegetation can reduce pollution and enhance habitat quality. Additionally, involving local stakeholders in decision-making processes can help ensure that management interventions are both equitable and effective.

In this study, we aim to investigate the relationship between land cover quality, water pollution, and macrozoobenthos diversity in the Brantas River watershed. By integrating multiple indices and analytical methods, including the Pollution Index, Biotic Index, and Shannon-Wiener Diversity Index, we seek to provide a comprehensive assessment of ecosystem health in this region. Our research focuses on three key objectives: (1) evaluating the current state of land cover and its implications for water quality, (2) assessing the impact of pollution on macrozoobenthos diversity, and (3) identifying patterns of biodiversity along the river's pollution gradient. Through this approach, we aim to fill critical knowledge gaps and provide actionable insights for watershed management.

The findings of this study are expected to contribute to the broader understanding of how land cover changes and pollution affect aquatic ecosystems in tropical regions. By highlighting the ecological consequences of human activities in the Brantas River watershed, this research underscores the urgent need for sustainable land use practices and pollution control measures. Furthermore, our study emphasizes the importance of preserving biodiversity as a key component of ecosystem resilience. Macrozoobenthos, as indicators of aquatic health, offer a valuable perspective on the impacts of environmental degradation, enabling the development of targeted interventions to restore ecosystem functions and improve water quality.

In conclusion, the degradation of river ecosystems due to land cover change and pollution is a pressing global issue, particularly in tropical regions where biodiversity is highly vulnerable to anthropogenic pressures. The Brantas River watershed, with its complex ecological and socio-economic dynamics, provides a critical case study for understanding these challenges. By examining the relationships between land cover quality, pollution levels, and macrozoobenthos diversity, this study aims to advance the scientific basis for integrated watershed management. Ultimately, the findings will support efforts to mitigate ecological degradation, promote sustainable development, and enhance the resilience of river systems in Indonesia and beyond.

2. MATERIALS AND METHODS

2.1 Study area description

The study was conducted in the tributaries of the Brantas River watershed, located in East Java, Indonesia. This watershed encompasses diverse land use activities, including agriculture, residential settlements, and plantations, which vary significantly across sub-watersheds. Sampling locations were selected to represent a gradient of anthropogenic impacts, capturing variations in land cover quality and pollution levels. Three primary sampling points were chosen: one near agricultural fields, another adjacent to residential areas, and a third within a plantation-dominated landscape. These locations were identified using spatial analysis and ground verification to ensure they reflect distinct land use characteristics. The specific details of the sampling locations, including flow rates and geographic coordinates, are summarized in **Table 1,** providing a clear representation of the study area's diverse land use characteristics and hydrological conditions.

Table 1: Study area and sampling locations

Sampling Point	Flow rate (m^3/s)	Coordinate point
Point 1	0,246	7°56'17"S 112°47'17"E
Point 2	0,858	7°56'45"S 112°47'12"E
Point 3	4,166	7°55'50"S 112°47'33"E

The Brantas River, characterized by its tropical climate, experiences significant seasonal variability, with distinct wet and dry periods influencing hydrology and water quality. Sampling was conducted during the rainy season to capture the heightened influence of surface runoff and precipitation on pollutant loads and macrozoobenthos communities, aligning with the seasonal relevance of tropical river studies (Basyuni et al., 2018).

2.2 Sampling design and data collection

2.2.1 Macrozoobenthos sampling

Macrozoobenthos specimens were collected using a combination of standardized techniques, including hand sorting, sediment sieving, and substrate scraping, **Table 2**. These methods were employed to capture diverse macrozoobenthos communities across different habitats, such as rocky substrates, muddy banks, and aquatic vegetation. Transects measuring 100 meters were established at each sampling point, with collection efforts distributed systematically along the transect to minimize bias and enhance data comparability (Elpiyani et al., 2023).

Specimens were collected in duplicate before and after rainfall events to account for short-term variations. Each sample was preserved in 70% ethanol and transported to the laboratory for identification. Specimens were identified to the family level using a regional identification key, with reference to established protocols for tropical river systems. To ensure reliability, a minimum of 100 individuals per site were analyzed.

Table 2: Sampling design and environmental parameters

Sampling Point	Dominant Land Cover	Sampling Method	Key Parameters
Point 1	Agriculture	Transects	pH, Temperature (°C), Dissolved Oxygen (mg/L), Biological Oxygen Demand (mg/L), Chemical Oxygen Demand (mg/L), Total Suspended Solids (mg/L),
Point 2	Residential	Transects	pH, Temperature (°C), Dissolved Oxygen (mg/L), Biological Oxygen Demand (mg/L), Chemical Oxygen Demand (mg/L), Total Suspended Solids (mg/L),

Point 3	Plantation	Transects	pH, Temperature (°C), Dissolved Oxygen (mg/L), Biological Oxygen Demand (mg/L), Chemical Oxygen Demand (mg/L), Total Suspended Solids (mg/L)

2.2.2 Water quality assessment

Water samples were collected concurrently with macrozoobenthos sampling, following national standards (SNI 6989.57:2008). Physico-chemical parameters, including pH, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS), were measured. Sampling was performed using sterile containers, and samples were stored in a cooler box during transport to the laboratory for analysis. In-situ measurements of current velocity were conducted using a calibrated current meter, providing additional context for water quality assessments.

2.3 Indices and analytical tools

2.3.1 Land cover quality assessment

Land cover quality was analyzed using the Land Cover Quality Index (IKTL), calculated based on satellite imagery and spatial data processed in ArcGIS software. The analysis incorporated metrics such as forested area, agricultural fields, and urban settlements to classify land cover quality at each sampling site. Calculations followed standardized formulas, as outlined in Indonesian Ministry of Environment and Forestry regulations.

2.3.2 Pollution and biotic indices

Pollution index analysis

Pollution levels were evaluated using physical, chemical, and biological parameters. The Pollution Index (IP), based on the Minister of Environment Decree No. 115 of 2003, was employed to classify pollution levels at each site. The index calculated the relative pollution load using maximum and average concentrations of individual pollutants against regulatory thresholds. Additionally, the Biotilik Index was applied to assess biological water quality, with macrozoobenthos families categorized by their tolerance to pollution. This dual approach provided a holistic understanding of water quality conditions. The physical-chemical parameters were assessed using the Pollution Index (IP) method, based on the Minister of Environment Decree No. 115 of 2003. The IP method is represented in Equation 1.

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)^2 M + \left(\frac{C_i}{L_{ij}}\right)^2 R}{2}} \qquad (1)$$

Description:

PI_j = Pollution Index for use category j

C_i =Concentration of water quality parameter i

L_{ij} =Concentration of water quality parameter I specified in the standard for use category j

M = Maximum value of C_i/L_{ij}

R = Average value of C_i/L_{ij}

Biological parameters were analyzed using Biotilik Index method, based on the Ecoton Biotilik Guide for River Basin Health Assessment (2022). The Biotilik Index method is represented in Equation 4.

$$\text{Indeks Biotilik} = X/N \qquad (2)$$

Description:

X = Σ (biotilik score x number of individuals)

N = number of individuals

Macrozoobenthos diversity analysis

The Shannon-Wiener Diversity Index (H') was employed to quantify macrozoobenthos diversity. This index captures the richness and evenness of taxa at each site, reflecting the ecological complexity of macrozoobenthos communities. The proportion of individuals in each family relative to the total number sampled was used to calculate diversity, enabling a robust comparison across sites.

Macrozoobenthos diversity was analyzed using the Shannon-Wiener Diversity Index, as represented in Equation 5.

$$H' = -\Sigma \text{ Pi x ln Pi} \qquad (3)$$

Description:

H' = Shannon-Wiener Diversity Index

Pi =Proportion of individuals in a particular family relative to the total number of families (ni/N)

ln = Natural logarithm

2.4 Statistical analysis

Data analysis included descriptive statistics to summarize land cover, water quality, and macrozoobenthos diversity. Pearson correlation analysis was performed to explore relationships among the variables, including land cover quality, pollution levels, and macrozoobenthos diversity. The strength and direction of these correlations provided insights into the interdependencies of environmental stressors and biological responses. Multiple regression models were applied to validate observed patterns and control for confounding factors, ensuring robust interpretation. To address potential limitations in seasonal sampling, findings were contextualized using historical data from similar studies on tropical river systems. This integrative approach enhanced the generalizability of results and provided a broader temporal perspective.

2.5 Limitations and generalizability

While this study provides valuable insights into the impacts of land cover quality and pollution on macrozoobenthos diversity, it is limited by its focus on the rainy season. Seasonal variations, particularly during the dry season, may influence water quality and macrozoobenthos communities differently. Additionally, the study's reliance on family-level identification, while practical, may obscure finer-scale ecological dynamics observable at the species level.

3. RESULTS

3.1 Land cover quality and distribution

The analysis of land cover in the Brantas River sub-watershed revealed substantial degradation, with low-quality land cover dominating the study area. The Land Cover Quality Index (IKTL) scores for the three sampling points—Point 1 (agriculture), Point 2 (residential), and Point 3 (plantation)—were 25.449, 24.658, and 24.248, respectively. These scores categorize the land cover as "poor," consistent with findings in other tropical river systems experiencing deforestation and urbanization (Hakiki et al., 2017; Haeruddin et al., 2019). The dominance of agricultural and plantation areas, combined with minimal forest cover, underscores the anthropogenic pressures on the watershed.

Spatial analysis using ArcGIS showed that forested areas were confined to a small region near Desa Taji, while plantations and agricultural lands constituted the majority of the landscape. The prevalence of these land uses has likely exacerbated soil erosion, leading to increased sedimentation in the river. This degradation is further compounded by the lack of vegetative buffers along riverbanks, which limits the filtration of surface runoff before entering the river system.

3.2 Water quality metrics

The water quality analysis, conducted through physico-chemical measurements and pollution indices, highlighted variations in pollution levels across the three sampling points. **Table 3** summarizes the key water quality parameters measured at each location.

Table 3: Physico-chemical water quality parameters across sampling points

Parameter	Point 1	Point 2	Point 3
pH	7.6	8.1	8.0
Temperature (°C)	24.3	24.5	26.0
Dissolved Oxygen (mg/L)	5.2	5.4	5.2
Biological Oxygen Demand (mg/L)	7.5	8.2	8.4
Chemical Oxygen Demand (mg/L)	24.3	27.0	26.2
Total Suspended Solids (mg/L)	13.6	15.5	23.1

The Pollution Index (IP) values were 2.23, 2.38, and 2.43 for Points 1, 2, and 3, respectively, categorizing the river water as "lightly polluted." These findings align with previous studies demonstrating a correlation between degraded land cover and increased pollutant loads in aquatic systems (Hakiki et al., 2017; Haeruddin et al., 2019). Point 3 exhibited the highest pollution levels, likely due to cumulative impacts from upstream agricultural and residential areas, as well as plantation-related activities.

3.3 Macrozoobenthos diversity and community composition

Macrozoobenthos diversity, as assessed using the Shannon-Wiener Diversity Index (H'), demonstrated a gradient across the sampling points. **Table 4,** presents the diversity indices and community composition at each site.

Table 4: Macrozoobenthos diversity and community composition

Sampling Point	Shannon-Wiener Index (H')	Dominant Orders	Sensitive Families (EPT)	Tolerant Families
Point 1	0.650	Ephemeroptera, Trichoptera	Baetidae, Hydropsychidae	Simuliidae
Point 2	1.430	Ephemeroptera, Diptera	Baetidae, Hydropsychidae	Chironomidae
Point 3	1.517	Odonata, Mesogastropoda	Hydropsychidae	Coenagrionidae

Diversity was lowest at Point 1 and increased downstream. At Point 1, macrozoobenthos communities were dominated by pollution-sensitive families such as Baetidae and Hydropsychidae, with limited representation from tolerant taxa. In contrast, Point 3 exhibited higher diversity but was dominated by tolerant families, including Coenagrionidae and Thiaridae. This shift in community composition reflects the replacement of sensitive taxa by more pollution-tolerant species along the pollution gradient (Leopardas et al., 2016; Herawati et al., 2020).

3.4 Statistical Relationships Among Land Cover, Water Quality, and Biodiversity

Pearson correlation analysis revealed significant relationships among land cover quality, water pollution levels, and macrozoobenthos diversity. **Table 5** summarizes the correlation coefficients between these variables.

Table 5: Correlation analysis of key variables

Variable Pair	Correlation Coefficient (r)	Significance (p-value)
Land Cover Quality - Pollution	-0.996	0.140
Pollution - Diversity	0.976	0.140
Land Cover Quality - Diversity	-0.951	0.201

The analysis showed a strong negative correlation between land cover quality and water pollution, indicating that poor land cover contributes to increased pollution levels. Similarly, there was a strong positive correlation between pollution and diversity, suggesting that higher pollution levels are associated with a shift toward more tolerant macrozoobenthos taxa. However, the negative correlation between land cover quality and diversity was less pronounced, possibly due to the combined influence of habitat heterogeneity and organic matter availability downstream (Boutoumit et al., 2021; Fitriani et al., 2021).

3.5 Spatial patterns of Macrozoobenthos diversity

The results depicted in the figure highlight the spatial trends in macrozoobenthos diversity and the relative abundance of sensitive and tolerant taxa along the Brantas River gradient (**Figure 1)**. The Shannon-Wiener Diversity Index (H') increased downstream, starting from 0.65 at Point 1 to 1.52 at Point 3, indicating greater diversity in downstream habitats. This trend reflects a shift from pollution-sensitive taxa, such as Ephemeroptera, Plecoptera, and Trichoptera (EPT), which dominated upstream, to pollution-tolerant taxa, such as Coenagrionidae and Thiaridae, which prevailed downstream. Sensitive taxa comprised 81% of the community at Point 1, decreasing significantly to 49% at Point 2 and 23% at Point 3, whereas tolerant taxa showed the opposite trend, increasing from 19% at Point 1 to 77% at Point 3.

These findings align with previous studies suggesting that macrozoobenthos diversity and community composition respond predictably to pollution gradients and habitat changes (Chandrathilake, 2023; Leopardas et al., 2016). Habitat complexity, such as rocky substrates upstream and sedimentary environments downstream, further influenced diversity patterns. Downstream regions provided more nutrient-rich conditions, favoring the dominance of tolerant taxa (Boutoumit et al., 2021; Fitriani et al., 2021). The study underscores the importance of integrated management strategies to mitigate upstream pollution and maintain ecological balance in riverine systems, as highlighted in previous works (Mohammed et al., 2018; Wahyuni, 2023).

Figure 1: Spatial trends in Macrozoobenthos diversity and dominant taxa along the brantas river gradient

3.6 General observations and implications

The results of this study highlight the significant impacts of land cover quality on water quality and macrozoobenthos diversity in the Brantas River sub-watershed. The progressive increase in diversity downstream, despite higher pollution levels, underscores the role of habitat heterogeneity and organic matter availability in shaping community composition. However, the dominance of tolerant taxa at Point 3 raises concerns about the long-term ecological health of the river, as it indicates a shift away from pollution-sensitive species that are critical for maintaining ecosystem functions. These findings align with the broader literature on tropical rivers, which emphasizes the importance of integrated watershed management to mitigate the impacts of land cover degradation and pollution on aquatic ecosystems (Boutoumit et al., 2021; Fitriani et al., 2021). Statistical modeling provided valuable insights into the relationships among key variables, offering a foundation for future research and management interventions.

4. DISCUSSION

The findings of this study reveal the intricate relationships among land cover quality, water pollution, and macrozoobenthos diversity in the Brantas River sub-watershed. The results demonstrate how degraded land cover, primarily due to agricultural and plantation dominance, contributes to increased pollution levels and shifts in macrozoobenthos community composition. These patterns are consistent with broader observations in tropical watersheds, where land cover changes significantly impact water quality and biodiversity (McDonald et al., 2016; Sertel et al., 2019). This discussion explores the implications of these findings, contextualizes them within existing literature, and highlights their relevance for watershed management.

4.1 Impact of land cover quality on water pollution

The poor land cover quality observed at all three sampling points aligns with previous studies that identify deforestation and urbanization as critical drivers of water quality degradation in tropical watersheds (McDonald et al., 2016; Sertel et al., 2019). The Land Cover Quality Index (IKTL) values for the study area were consistently low, with agricultural and plantation activities dominating the landscape. This pattern exacerbates sediment runoff and introduces nutrients and pollutants into the river system, as reflected in the Pollution Index (IP) scores categorizing the water as lightly polluted.

For instance, Point 1, situated near agricultural fields, exhibited relatively lower pollution levels compared to Points 2 and 3. However, the presence of fertilizers likely contributed to elevated Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS). At Point 2, located near residential areas, pollution was influenced by domestic waste and livestock runoff, consistent with studies linking population density to higher contaminant loads in water bodies (Widjonarko & Maryono, 2022). Point 3, downstream from agricultural and residential zones, recorded the highest Pollution Index score, emphasizing the cumulative impacts of upstream activities. These findings reinforce the necessity of land cover conservation and targeted pollution control measures to mitigate the impacts of anthropogenic activities on water quality.

4.2 Macrozoobenthos responses to pollution gradients

The responses of macrozoobenthos to pollution gradients in the Brantas River provide critical insights into ecological stress and ecosystem health. The study observed a progressive increase in diversity downstream, despite higher pollution levels. This finding can be attributed to the replacement of sensitive taxa, such as Baetidae and Hydropsychidae, by pollution-tolerant families, such as Coenagrionidae and Thiaridae. These shifts align with established mechanisms of macrozoobenthos community responses to pollution, where tolerant species thrive under degraded conditions, reflecting ecological stress (Chandrathilake, 2023).

The Shannon-Wiener Diversity Index (H') values corroborate this trend. Point 1, with its cleaner water and rocky substrate, supported higher proportions of sensitive families, resulting in lower overall diversity due to limited representation from other taxa. In contrast, Points 2 and 3 exhibited more even community structures, as tolerant taxa became dominant in response to increased nutrient loads and habitat heterogeneity. This pattern reflects the dual role of pollution and habitat structure in shaping macrozoobenthos diversity, emphasizing the need for holistic assessments that consider both biological and environmental parameters.

4.3 Spatial and habitat influences on diversity patterns

Spatial variations in macrozoobenthos diversity were influenced by habitat characteristics, including sediment type, flow velocity, and organic matter availability. Point 1, characterized by rocky substrates and moderate flow, provided suitable conditions for sensitive families, such as Ephemeroptera and Trichoptera, which require clean, oxygen-rich environments. However, the dominance of these families resulted in lower overall diversity, as the habitat supported limited taxa.

At Point 3, the presence of sandy substrates and slower flow rates facilitated the accumulation of organic matter, creating a nutrient-rich environment favorable to tolerant taxa, such as Thiaridae. These findings align with studies indicating that complex habitats with diverse substrates tend to support higher macrozoobenthos diversity (Boutoumit et al., 2021; Fitriani et al., 2021). However, the dominance of tolerant taxa raises concerns about the long-term ecological health of the river, as it indicates reduced resilience and ecosystem functionality.

Figure 1, illustrating the spatial trends in diversity and community composition, highlights the shift from sensitive to tolerant taxa along the river gradient. This transition underscores the critical role of habitat management in mitigating the impacts of pollution and maintaining biodiversity in tropical rivers.

4.4 Socio-economic drivers and management implications

The degradation of land cover and subsequent water quality issues in the Brantas River sub-watershed are closely linked to socio-economic drivers, including population growth, agricultural expansion, and plantation activities. Increased demand for land has led to deforestation and the conversion of natural habitats into cultivated areas, exacerbating sediment runoff and pollutant loads (Widjonarko & Maryono, 2022; Rabo, 2021). These findings highlight the interplay between socio-economic pressures and ecological degradation, emphasizing the need for integrated approaches to land and water management.

Effective management strategies should prioritize reforestation, the establishment of riparian buffers, and sustainable agricultural practices to mitigate sedimentation and nutrient runoff. Integrated watershed management, as advocated by Mohammed et al. (2018) and Wahyuni (2023), offers a framework for balancing ecological conservation with human needs. For instance, promoting agroforestry systems can enhance land cover quality while maintaining agricultural productivity. Similarly, involving local communities in conservation initiatives can ensure the sustainability of interventions and foster a sense of stewardship over natural resources.

4.5 Study Limitations and Future Directions

While this study provides valuable insights into the relationships among land cover quality, water pollution, and macrozoobenthos diversity, several limitations must be acknowledged. The focus on the rainy season limits the generalizability of findings to other seasons, particularly the dry season, which may exhibit different hydrological and ecological dynamics. Future studies should adopt a longitudinal approach, incorporating data from multiple seasons to capture temporal variations in water quality and macrozoobenthos communities.

Additionally, the reliance on family-level identification, while practical for broad assessments, may obscure finer-scale ecological patterns observable at the species level. Incorporating species-level analyses and advanced molecular techniques could provide a more nuanced understanding of community responses to environmental stressors. Furthermore, this study did not explicitly quantify the socio-economic drivers of land cover change, such as population growth rates and agricultural practices. Integrating socio-economic data into future research could enhance the relevance of findings for policy development.

4.6 Broader implications for tropical watershed management

The findings of this study underscore the interconnectedness of land cover quality, water pollution, and biodiversity in tropical watersheds, with implications for global conservation efforts. The observed shifts in macrozoobenthos communities along pollution gradients highlight the critical role of these organisms as bioindicators of ecosystem health (Chandrathilake, 2023). Monitoring macrozoobenthos diversity can provide early warnings of ecological stress, guiding adaptive management strategies.

The degradation of the Brantas River watershed reflects broader trends in tropical river systems, where socio-economic pressures drive ecological change. Addressing these challenges requires integrated approaches that consider the ecological, social, and economic dimensions of watershed management. By emphasizing the conservation of natural habitats, sustainable land use practices, and stakeholder engagement, policymakers can mitigate the impacts of land cover change and pollution on aquatic ecosystems (Mohammed et al., 2018; Wahyuni, 2023).

In conclusion, this study contributes to the understanding of how land cover quality influences water quality and biodiversity in tropical rivers. By integrating ecological and socio-economic perspectives, the findings offer a foundation for developing sustainable management strategies that balance environmental conservation with human needs. Future research should build on these insights, exploring the interactions among land use, water quality, and biodiversity across spatial and temporal scales to inform evidence-based policies for watershed resilience.

5. CONCLUSION

This study provides an in-depth understanding of the interplay between land cover quality, water pollution, and macrozoobenthos diversity in the Brantas River sub-watershed. The findings reveal that poor land cover quality, predominantly shaped by agricultural and plantation activities, significantly contributes to sediment runoff and nutrient pollution, leading to a degradation of water quality. Pollution levels, as assessed by the Pollution Index, were categorized as "lightly polluted," with downstream areas experiencing cumulative impacts from upstream land use.

Macrozoobenthos diversity exhibited a gradient along the pollution levels, with sensitive taxa dominating in less polluted upstream areas and tolerant taxa becoming prevalent downstream. This shift highlights the utility of macrozoobenthos as bioindicators of aquatic ecosystem health, reflecting the ecological stress imposed by pollution. Habitat characteristics such as substrate type and organic matter availability further influenced diversity patterns, emphasizing the importance of habitat complexity in maintaining biodiversity.

The study underscores the need for integrated watershed management to mitigate land cover degradation and pollution. Strategies such as reforestation, sustainable agricultural practices, and community engagement are essential for balancing ecological conservation and socio-economic development. While the study advances the understanding of ecological dynamics in tropical watersheds, future research should incorporate seasonal variations and species-level analyses to provide a more comprehensive perspective. These insights contribute to global efforts in managing tropical river systems sustainably and maintaining aquatic biodiversity.

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