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Analysis of Marine Water Quality to Facilitate Management in Support of Mangrove Conservation in Kayo Batu Village, Jayapura

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ABSTRACT

Purpose of the study: this investigation aimed to assess the quality of marine water by analyzing a range of physico-chemical parameters, such as pH, dissolved oxygen (DO), total dissolved solids (TDS), dissolved hydrogen ions (DHL), salinity, and temperature, in addition to determining its importance in promoting mangrove conservation initiatives.

Materials and methods: A quantitative approach was used by measuring water quality at eight sampling points during morning and afternoon sessions, combined with a questionnaire distributed to 88 respondents to capture community perceptions of environmental changes.

Results: The results indicate that marine water quality in Kayo Batu Village is classified as lightly polluted but remains within the permissible threshold according to the Minister of Environment Decree No. 51 of 2004. Some parameters, such as DO and pH, slightly exceed the optimal range for healthy mangrove ecosystems. Community perceptions reveal concerns about declining water quality due to poor sanitation and domestic pollution. Therefore, a mangrove conservation strategy based on adaptive and participatory approaches is necessary, particularly through the control of pollution sources, environmental education, and improved sanitation infrastructure.

Conclusions: The findings of this study are expected to serve as a scientific basis for policy formulation to sustainably preserve the coastal ecosystem.

Keywords
conservation, marine water quality, coastal ecosystem, management in support, mangrove conservation.

INTRODUCTION

Indonesia, as the world's largest archipelago with the second longest coastline after Canada, possesses vast coastal areas with tremendous natural resource potential (Yoswaty et al., 2024). Among these resources, mangrove ecosystems hold particular strategic importance across ecological, economic, and social dimensions. Ecologically, mangroves serve as natural barriers against coastal erosion, stabilize muddy substrates, provide critical habitat for marine life as nursery, spawning, and feeding grounds, and function as effective blue carbon storage systems that contribute to climate change mitigation (Luo et al., 2024). Economically, these forests support coastal community livelihoods through fisheries, nature-based tourism, and provision of local raw materials (Hilmi et al., 2017).

Kayo Batu Village, situated in North Jayapura District, Jayapura City, Papua, represents a unique coastal settlement characterized by houses built directly over the sea (floating village) and immediate adjacency to mangrove forest areas. This geographical configuration creates both opportunities and challenges for sustainable coastal management, particularly given the village's potential for marine tourism development and community-based economic activities.

Previous research has established the fundamental relationship between water quality parameters and mangrove ecosystem health. Hartati & Pin, (2021) and Saru et al., (2019) demonstrated the utility of multivariate statistical analysis in identifying mangrove water quality characteristics, emphasizing the importance of physico-chemical parameters in ecosystem assessment. Similarly, Yoswaty et al., (2024) highlighted the significance of seawater quality parameters in mangrove conservation areas, providing methodological frameworks for water quality evaluation.

Studies on mangrove restoration have indicated that water quality conditions significantly influence rehabilitation success rates. Amalo et al., (2025) assessed mangrove restoration feasibility using water quality and substrate parameters, revealing that suboptimal environmental conditions can lead to restoration failure. Hilmi et al., (2017) further established correlations between seawater intrusion and mangrove ecosystem dynamics, underscoring the complex interactions between hydrological conditions and vegetation health.

Research on pollution impacts in coastal ecosystems has shown that anthropogenic activities, particularly inadequate sanitation systems and domestic waste discharge, significantly degrade marine water quality. (Luo et al., 2024) documented the positive impact of conservation efforts on water quality improvement over a twenty-year period, demonstrating that targeted

management interventions can effectively restore coastal ecosystem health.

Despite the substantial body of research on mangrove ecosystems and water quality, several critical gaps remain in the literature. First, there is limited research specifically addressing the relationship between water quality parameters and mangrove conservation success in Indonesian coastal villages, particularly those with unique floating settlement configurations. Second, most existing studies focus on either water quality assessment or conservation strategies independently, lacking integrated approaches that combine scientific water quality analysis with community-based conservation planning.

Third, while pollution index methodologies have been applied in various coastal contexts, their specific application to mangrove conservation planning in remote Indonesian coastal communities remains underexplored. Finally, there is insufficient research examining the combined effects of multiple anthropogenic factors—including inadequate sanitation infrastructure, domestic pollution, and community activities—on mangrove ecosystem sustainability in small-scale coastal settlements.

The failure of previous mangrove rehabilitation efforts in Kayo Batu Village, despite government and community initiatives, suggests that environmental conditions, particularly water quality, may not support optimal mangrove growth. This situation necessitates a comprehensive scientific investigation to understand the extent of marine water quality degradation and its implications for mangrove conservation success. Given the unique characteristics of Kayo Batu Village as a floating settlement with direct interaction between residential activities and mangrove ecosystems, there is an urgent need to establish baseline water quality conditions and develop evidence-based conservation strategies. The village's potential for sustainable tourism and community-based economic development further emphasizes the importance of successful mangrove conservation as a foundation for long-term environmental and economic sustainability.

The increasing recognition of mangroves' role in climate change mitigation and coastal protection makes this research particularly relevant to broader environmental management goals. Understanding the specific water quality constraints affecting mangrove health in this unique coastal setting can inform both local conservation efforts and broader policy frameworks for coastal ecosystem management.

This study aims to analyze marine water quality conditions in Kayo Batu Village and assess their implications for mangrove conservation success. Specifically, the research seeks to evaluate marine water quality conditions based on physico-chemical parameters including pH, dissolved oxygen, total dissolved solids, electrical conductivity, salinity, and temperature, while determining pollution levels using standardized pollution index methodologies in accordance with Minister of Environment Decree No. 51 of 2004. Additionally, the study aims to assess community perceptions regarding environmental changes and water quality degradation through structured questionnaire surveys to identify key factors influencing water quality from the community perspective. The research further analyzes the relationships between identified environmental factors—including sanitation infrastructure, marine transportation activities, socio-economic conditions, and government policies—and marine water quality conditions using multiple linear regression statistical analysis methods. By determining the suitability of current marine water quality conditions for supporting optimal mangrove growth and ecosystem health based on established environmental standards, the study ultimately seeks to develop evidence-based mangrove conservation strategies that integrate water quality improvement measures with community participation and adaptive management approaches specifically tailored to the unique floating village conditions of Kayo Batu. The findings of this research are expected to provide a scientific foundation for policy formulation aimed at sustainable preservation of coastal ecosystems while supporting community-based economic development in similar coastal settlement contexts.

MATERIALS AND METHODS

Study Organization

The research was conducted in Kayo Batu Village, North Jayapura District, Jayapura City, Papua Province. Using a descriptive quantitative approach (Yoswaty et al., 2024) (Satheeshkumar & Khan, 2012), this study aims to measure and describe marine water quality based on physico-chemical parameters and examine its relationship with mangrove conservation in Kayo Batu Village, North Jayapura District, Jayapura City.

Water Quality Analysis

The measurement data of physico-chemical parameters were compared with the Marine water Quality Standard for marine biota (KepmenLH, 2004) based on:

Decree of the Minister of the Environment No. 51 of 2004 concerning Marine water Quality Standards for marine biota.

Environment Ministerial Regulation No. 27 of 2021 and Government Regulation No.22 of 2021 for Pollution Index analysis.

The analysis was carried out by calculating the Pollution Index (IP) value using the formula:

$$IP_j = \sqrt{\frac{(C_i / L_{ij})_M^2 + (C_i / L_{ij})_R^2}{2}}$$

Description:

- IP = Pollution Index
- Ci and Cj = measured parameter concentration values
- Si and Sj = parameter quality standard values

Pollution Index Category:

- IP ≤ 1.0: Not polluted
- 1.0 < IP ≤ 5.0 : Lightly polluted
- 5.0 < IP ≤ 10.0 : Moderately polluted

- IP > 10.0 : Heavily polluted

Community Perception Data Analysis

Questionnaire data were processed by descriptive statistics (mean, mode, frequency) to determine the level of understanding and concern of the community towards the quality of the aquatic environment and mangrove conservation efforts.

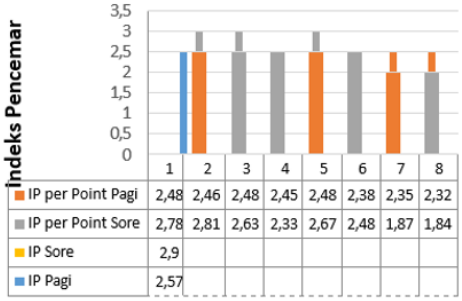
Development of Conservation Strategies

Mangrove conservation methodologies were formulated in accordance with the findings derived from both water quality assessments and the perceptions held by the local community. The process of strategy formulation is grounded in the following principles: Adaptive: aligned with the specific conditions of the local ecosystem; Participatory: engaging the community in an active and meaningful manner.

RESULTS

Marine Water Quality Pollution Index

Measurement results using water quality pollutant parameters namely: Temperature, TDS, pH, DO, Salinity and DHL. These parameters are then compared with Government Regulation Number 22 of 2021 Appendix VIII concerning Sea Water Quality Standards to determine the quality of river water based on the Pollution Index method. The results of the Pollution Index analysis can be seen in **Figure 1**.



	1	2	3	4	5	6	7	8
IP per Point Pagi	2,48	2,46	2,48	2,45	2,48	2,38	2,35	2,32
IP per Point Sore	2,78	2,81	2,63	2,33	2,67	2,48	1,87	1,84
IP Sore	2,9							
IP Pagi	2,57							

Figure 1. Diagram of the results of the seawater pollution index analysis in kayo batu village

Marine water quality parameters as an effort to conserve mangroves in Kayo Batu Village were obtained based on field measurements and through community perceptions using a questionnaire instrument with a Likert scale. From the data obtained, there are five parameters of seawater quality, namely: turbidity, unpleasant odour, seawater colour, domestic waste, and vegetation condition. The results of data processing can be seen in **Figure 2**.

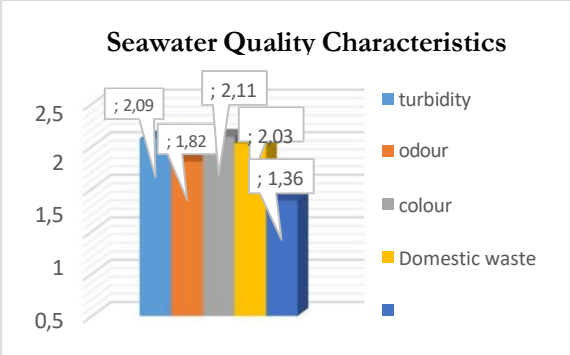


Figure 2. Seawater Quality Characteristics

Based on the results of the analysis, there are four main factors that influence changes in seawater quality in Kayo Batu Village, namely: sanitation infrastructure, sea transportation and port activities, socio-economics and government policies. as shown in Figures 3 to 6.

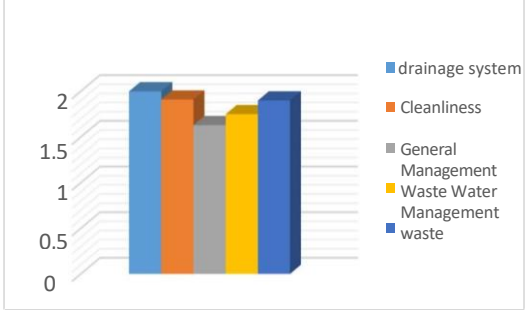


Figure 3. Sanitation Infrastructure factors

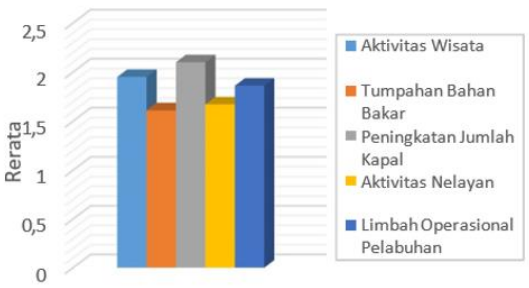


Figure 4. Sea transportation and port activities factors

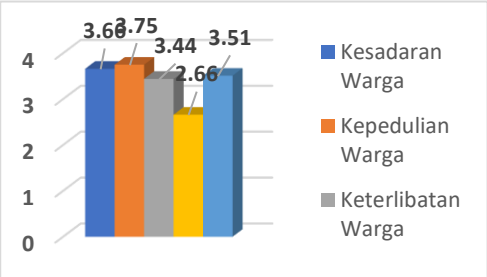


Figure 5. Socio-economics factors

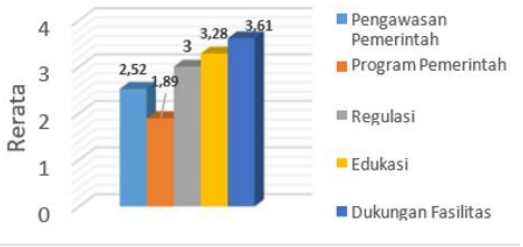


Figure 6. Government policies factors

Statistical Test

Multiple Linear Regression Test is used to determine the effect of sanitary infrastructure factors, marine transportation activities, social & economic and government policies on sea water quality in Kayo Batu village (Figure 7).

Table 1. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	0.550[a]	0.303	0.269	2.314	0.303	9.020	4	83	0.000

a. Predictors (Independent Variables): (Constant), Government Policy, Sea Transportation Activities, Socioeconomic Factors, Sanitation Infrastructure

Table 2. Coefficients of Multiple Linear Regression Analysis on Factors Affecting the Dependent Variable

Variable	Unstandardized Coefficients (B)	Standard Error	Standardized Coefficients (Beta)	t	Sig. (p-value)	95% Confidence Interval for B	
						Lower Bound	Upper Bound
(Constant)	16.302	4.235	—	3.850	0.000	7.880	24.725
Sanitation Infrastructure	0.328	0.111	0.275	2.962	0.004	0.108	0.549
Marine Transportation Activities	0.301	0.081	0.342	3.725	0.001	0.137	0.464
Social and Economic Factors	-0.477	0.218	-0.202	-2.183	0.031	-0.911	-0.043
Government Policy	-0.317	0.104	-0.282	-3.041	0.003	-0.525	-0.110

Table 3. ANOVA Results for the Effect of Government Policy, Marine Transportation Activities, Socio-Economic Factors, and Sanitation Infrastructure on Changes in Sea Water Quality

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	193.133	4	48.283	9.020	.000[b]
Residual	444.310	83	5.353		
Total	637.443	87			

Dependent Variable: Changes in Sea Water Quality b. Predictors: (Constant), Government Policy, Marine Transportation Activities, Social & Economic Factors, Sanitation Infrastructure

From the output Analysis of the Coefficient of Determination, it is known that the Adjusted R Square value is 0.27, it concludes that the contribution of the influence of the independent variable on the dependent variable simultaneously is 27%. Based on the F Test Output Analysis (simultaneous), it is known that the results of the F test (Simultaneous) show the Sig level. 0.000 <0.05, it concludes that there is a Significant Influence of the Independent Variables of Sanitation Infrastructure, Sea Transportation Activities, Social & Economic and Government Policy on the dependent variable of Sea Water Quality simultaneously.

Sanitary Infrastructure Factor with P- value 0.004 <0.05 means Significant or there is an influence between the Sanitary Infrastructure variable on changes in seawater quality to support mangrove conservation. Marine Transportation Activity Factor with P- value 0.000 <0.05 means significant or there is an influence of the marine transportation activity factor on changes in seawater quality to support mangrove conservation. Social and Economic Factors with P- value 0.032 <0.05 means Significant or there is a significant influence between Social & Economic Factors on changes in sea water quality to support Mangrove Conservation. Government Policy Factor with P- Value 0.003 <0.05 means significant or there is an influence between government policy variables on changes in seawater quality to support mangrove conservation.

The Regression Equation is obtained: 16,302 + 0,328*x*1 + 0,301*x*2 – 0.477 *x*3 – 0,317 *x*4

Based on the regression equation can be explained as follows:

The constant value obtained is 16.302, it means that if the independent variable is worth 0 (constant) then the dependent variable Seawater Quality is worth 16.302. The coefficient value of variable x1 (Sanitary Infrastructure Factor) is 0.275, it means that any increase in variable x1 (Sanitary Infrastructure Factor) will increase variable Y (Seawater Quality).The coefficient value of variable x2 (Sea Transportation Activity) has a value of 0.342 which means that if the variable x2 (Sea Transportation Activity) will also increase.The coefficient value of variable x3 (Social & Economic) has a value of -0.202 which means that if variable x3 (Social & Economic) increases, variable Y (Sea Water Quality) decreases.The coefficient value of variable x4 (Government Policy Factor) is -0.282, which means that if variable x4 (Government Policy Factor) increases, variable Y (Seawater Quality) decreases.

t test: for each independent variable.

Sanitary Infrastructure Factor (p < 0.05), Marine Transportation Activity Factor (p < 0.05) significant, Social & Economic Factor (p < 0.05) significant and Government Policy Factor (p < 0.05) significant effect on Sea Water Quality in Kayo Batu Village.

F test: The significance of F = 0.000 was obtained, where p < 0.05 so that overall or together the factors of sanitation infrastructure, marine transport activities, social & economic and government policies have a significant effect on seawater quality in Kayo Batu village.

The Mangrove Conservation Strategy encompasses: 1) The rehabilitation of mangroves within the pristine water zone. The process of mangrove planting is executed incrementally, commencing from regions that, based on empirical assessments of water quality, are deemed to be closest to optimal or comparatively favorable conditions. This methodology is designed to enhance the likelihood of successful seedling rehabilitation by increasing their survival rates. Subsequent locations will be addressed following the amelioration of water quality. 2) The monitoring of sources of seawater pollution. This initiative is conducted through active community engagement utilizing a straightforward and cost-effective methodology. This oversight can be achieved via: (a) the installation of refuse nets, which serve the purpose of filtering, capturing, or obstructing the ingress of plastic and inorganic debris into mangrove habitats; (b) the implementation of floating sanitation facilities equipped with a septic drum system; public awareness campaigns aimed at diminishing the utilization of detergents and domestic chemicals detrimental to coastal ecosystems; (c) the rehabilitation of drainage systems and the mitigation of sedimentation, aimed at curtailing the runoff of contaminating substances contributing to water turbidity. 3) The integration of conservation efforts with the enhancement of aquatic ecosystems, 4) The promotion of education and community engagement, and 5) The fortification of policies and collaborative efforts.

DISCUSSION

Interpreting the Outcomes of Research Endeavors

The findings of this study reveal a complex relationship between marine water quality conditions and mangrove conservation prospects in Kayo Batu Village. The pollution index analysis indicates that while the marine waters are classified as lightly polluted (IP values ranging from 2.32 to 2.78) and remain within permissible thresholds according to Minister of Environment Decree No. 51 of 2004, several critical parameters demonstrate concerning trends that warrant immediate attention. The pH values at multiple sampling points exceeded optimal ranges for healthy mangrove ecosystems, and dissolved oxygen levels showed variations that could stress mangrove vegetation, particularly during critical growth phases.

The community perception data provides valuable insights into the lived experiences of environmental degradation, with respondents identifying turbidity (2.11), unpleasant odor (2.03), and domestic waste (1.82) as primary concerns affecting seawater quality. These perceptions align closely with the scientific measurements, validating the community's environmental awareness and highlighting their capacity to contribute meaningfully to conservation monitoring efforts. The statistical analysis revealed that four key factors—sanitation infrastructure, marine transportation activities, socio-economic conditions, and government policies—collectively explain 27% of the variance in seawater quality conditions, with all factors showing statistically significant relationships ($p < 0.05$).

The regression analysis demonstrates that sanitation infrastructure improvements and enhanced government policies can positively influence water quality, while inadequate marine transportation management and certain socio-economic pressures contribute to environmental degradation. This multifactorial causation underscores the complexity of coastal ecosystem management in small-scale communities and suggests that successful conservation strategies must address multiple interacting variables simultaneously.

Evaluating in Relation to Antecedent Studies

The current findings align with and extend previous research in several important ways. Consistent with Yoswaty et al., (2024), this study confirms that physico-chemical parameters serve as reliable indicators of mangrove ecosystem health, with temperature, salinity, and dissolved oxygen emerging as particularly sensitive measures of environmental stress(Yang et al., 2024; Zheng & Takeuchi, 2022). The pollution index methodology employed here successfully categorized water quality conditions, supporting the utility of standardized assessment frameworks established in previous coastal studies.

The relationship between water quality and mangrove restoration success, as observed in Kayo Batu Village, corroborates findings by Amalo et al., (2025), who demonstrated that suboptimal environmental conditions significantly reduce seedling survival rates in restoration projects(Ellison, 2000; Gerona-Daga & Salmo, 2022). The failure of previous mangrove rehabilitation efforts in the study area can now be understood within this scientific context, as the measured pH exceedances and dissolved oxygen fluctuations likely created stressful conditions for establishing mangrove seedlings. However, this study extends beyond previous research by integrating community perceptions with scientific measurements, revealing a more nuanced understanding of environmental change processes. While Navasakthi et al., (2023) and Ouyang et al., (2006) focused primarily on multivariate statistical analysis of water quality parameters, the current research demonstrates that community knowledge can provide temporal context and identify pollution sources that may not be captured through periodic scientific sampling alone.

The findings also build upon Hilmi et al., (2017) by demonstrating specific mechanisms through which anthropogenic activities influence mangrove ecosystem conditions. The statistical significance of sanitation infrastructure and marine transportation factors provides quantitative evidence for relationships that previous studies had identified conceptually but not measured empirically in small-scale coastal communities.

Elucidating the Ramifications of the Discoveries

The implications of these findings extend across multiple scales and domains of coastal ecosystem management. At the local level, the research provides a scientific foundation for understanding why previous mangrove restoration efforts failed and offers specific guidance for improving future conservation initiatives(Gerona-Daga & Salmo, 2022). The identification of water quality as a limiting factor suggests that rehabilitation efforts should prioritize environmental remediation before or concurrent with seedling planting activities.

From a management perspective, the statistically significant relationships between infrastructure factors and water quality conditions indicate that investments in sanitation systems and waste management could yield measurable improvements in ecosystem health(Haque et al., 2015; Ogwu & Kosoe, 2025). The positive coefficient for government policy factors in the regression analysis suggests that strengthened regulatory frameworks and enforcement mechanisms could enhance conservation outcomes, while the negative coefficient for certain socio-economic factors highlights the need for community-based approaches that address livelihood concerns alongside environmental goals(Dawson et al., 2024; Nguyen & Hung, 2020).

The findings have broader implications for coastal management policy in Indonesia and similar developing nation contexts. The successful integration of community perceptions with scientific measurements demonstrates the potential for participatory monitoring approaches that could reduce the cost and increase the effectiveness of environmental assessment programs(Danielsen et al., 2021; Parhusip et al., 2020). The pollution index methodology's ability to detect early warning signs of environmental degradation, even within officially acceptable parameter ranges, suggests that current regulatory standards may need refinement to better protect sensitive coastal ecosystems.

For mangrove conservation science, this research contributes to understanding how multiple stressors interact to influence ecosystem resilience. The finding that 27% of water quality variance can be explained by four anthropogenic factors suggests that targeted interventions addressing these specific drivers could yield disproportionate benefits for ecosystem health. This insight is particularly valuable for resource-constrained conservation programs that must prioritize interventions carefully. The study also highlights the critical importance of baseline environmental assessment in conservation planning. The classification of waters as "lightly polluted" while still experiencing conservation failures underscores the need for ecosystem-specific water quality standards that account for the particular sensitivities of mangrove species and life stages.

Recognizing the Constraints of the Research

Several important limitations must be acknowledged in interpreting these findings. The temporal scope of water quality measurements, conducted during specific morning and afternoon sessions, may not capture important seasonal variations or episodic pollution events that could significantly influence long-term ecosystem health. Mangrove ecosystems are subject to complex tidal cycles, seasonal rainfall patterns, and periodic disturbances that could alter water quality conditions substantially across different time periods. The spatial sampling design, while appropriate for the study area's scale, was limited to eight sampling points and may not fully represent the heterogeneity of water quality conditions throughout the mangrove ecosystem. Coastal environments are characterized by steep environmental gradients, and additional sampling points could reveal important spatial patterns in pollution distribution and ecosystem stress.The community perception component, though valuable, was limited to 88 respondents and may not capture the full diversity of environmental knowledge and concerns within the broader community. Cultural and social factors could influence perception reporting, and the questionnaire format may not have adequately captured traditional ecological knowledge that could inform conservation strategies.

The statistical analysis, while revealing significant relationships, explains only 27% of the variance in water quality conditions, indicating that important factors remain unidentified or unmeasured. Potential unmeasured variables could include upstream watershed activities, seasonal climatic variations, marine current patterns, and historical pollution legacies that continue to influence current conditions.

The study's focus on physico-chemical parameters, while standard in water quality assessment, does not address biological indicators of ecosystem health such as microbial communities, phytoplankton populations, or invertebrate assemblages that could provide additional insights into ecosystem functioning and stress responses.

Finally, the cross-sectional design limits the ability to establish causal relationships definitively, despite the statistical significance of observed associations. Longitudinal studies would be necessary to confirm that improvements in the identified factors would indeed lead to measurable improvements in water quality and mangrove conservation outcomes.

CONCLUSION

Based on the measurement of physical and chemical parameters of seawater (pH, DO, TDS, Salinity, DHL, and Temperature), in general, the quality of seawater in Kayo Batu Village is still within the quality standard limits set by the Decree of the Minister of Environment No. 51 of 2004. However, pH values at several points showed numbers above the normal threshold, which could be an early indication of changes in the coastal environment.

Sustainable mangrove conservation requires a holistic approach through education and community involvement in maintaining environmental sanitation. It is also recommended to strengthen regulation and supervision of domestic waste and shipping activities and revitalise mangrove rehabilitation programmes based on coastal environmental quality.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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