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Monitoring of Aquaculture Wastewater in Gerokgak Subdistrict, North Bali

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Abstract

Gerokgak Subdistrict, Buleleng Regency, Bali, is a major center for marine and brackish-water aquaculture whose intensive activities generate wastewater rich in nutrients. This study evaluates the characteristics of aquaculture wastewater by analyzing carbon (C), nitrogen (N), and phosphorus (P) concentrations in water and sediment, assessing key physical, chemical, and biological water quality parameters, and determining pollution index (PI) values. Wastewater from shrimp and grouper aquaculture was sampled using a purposive approach at two representative stations. Results show that shrimp aquaculture wastewater contains higher organic carbon and microbial abundance than grouper wastewater, indicating greater organic loading. Nitrate (0.396–0.597 mg/L) and ammonia (up to 0.794 mg/L) concentrations exceeded marine biota quality standards, contributing to PI values ranging from 2.63 to 3.17, classified as lightly polluted. The higher PI values observed in shrimp aquaculture wastewater reflect increased nutrient enrichment and microbial activity, which may elevate eutrophication risk in receiving coastal waters. These findings highlight the need for improved nutrient and wastewater management to support the long-term sustainability of aquaculture in Gerokgak.

Keywords: Coastal Aquaculture; Environmental Monitoring; Nutrient Loading; Pollution Index; Wastewater Quality.

1. Introduction

Gerokgak Subdistrict, located in Buleleng Regency, Bali, is a strategic area for marine and brackish-water aquaculture, including shrimp and grouper farming. Intensive aquaculture activities in this region generate substantial wastewater that is directly discharged into surrounding coastal waters. Such discharges commonly contain elevated levels of organic matter and nutrients, particularly carbon (C), nitrogen (N), and phosphorus (P), which can alter water quality and ecological conditions.

Previous studies have reported declining water quality in several coastal villages of Gerokgak, characterized by reduced dissolved oxygen levels and elevated concentrations of ammonia and nutrients exceeding marine aquaculture standards (Mustofa *et al.*, 2020; Nasukha *et al.*, 2019). Excessive nutrient inputs from uneaten feed, metabolic waste, and sediment accumulation increase the risk of eutrophication and degradation of benthic habitats. Given the expansion of intensive and super-intensive aquaculture systems in Indonesia, systematic monitoring of wastewater characteristics and pollution levels are essential.

This study aims to (1) analyze the C, N, and P composition in water and sediment derived from shrimp and grouper aquaculture wastewater, (2) evaluate water quality conditions based on physical, chemical, and biological parameters, and (3) assess pollution levels using the pollution index. The results are expected to provide a scientific basis for environmental management and sustainable aquaculture development in Gerokgak coastal waters.

2. Materials and Methods

2.1. Data Collection

This research was conducted in the coastal waters of Gerokgak, Buleleng Regency, Bali, Indonesia, a major center for marine and brackish-water aquaculture. Sampling was performed using a purposive sampling method to represent two different aquaculture wastewater sources (Sugiyono, 2016). Two primary stations were established:

1. Station 1 (Teluk Pegametan): representative of shrimp farming effluent
2. Station 2 (Patas Village): representative of grouper farming effluent

At each station, water and sediment samples were collected from three replicate sampling points. In situ measurements of water quality parameters

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were conducted directly at the sampling sites. Water temperature was measured using a calibrated thermometer, salinity using a calibrated refractometer, pH using a portable pH meter, and dissolved oxygen (DO) using a portable DO meter.

2.2. Data Analysis

Water quality and sediment parameter data obtained during the study were analyzed using SPSS to generate quantitative statistical outputs. The analysis focused on descriptive statistics, including mean and standard deviation, to summarize the measured parameters (SPSS, 2017; Zein *et al.*, 2019).

3. Results and Discussion

3.1. Results

A. Nutrient Content and Total Microbes in Wastewater

The results showed variations in the nutrient and microbial composition of grouper and shrimp aquaculture wastewater. Grouper wastewater contained 0.53 ± 0.02% organic carbon, 0.03 ± 0.008% nitrogen, 3.29 ± 1.37 mg/L phosphorus, and 2.23 ± 0.78 CFU/mL total microbes. In contrast, shrimp wastewater exhibited higher organic carbon (0.61 ± 0.08%) and phosphorus (4.04 ± 3.15 mg/L) contents. Although nitrogen levels were lower (0.02 ± 0.002%), total microbial abundance in shrimp wastewater was substantially higher (5.77 ± 1.17 CFU/mL), indicating greater organic loading and microbial activity.

B. Nutrient Content and Total Microbes in Sediments in Gerokgak Waters

Sediment analysis showed differences in the composition of aquaculture waste. Organic carbon content was higher in shrimp farming sediments (2.62 ± 0.04%) than in grouper farming sediments (1.39 ± 0.33%). In contrast, grouper sediments contained higher nitrogen (0.42 ± 0.04%) and phosphorus (24.95 ± 4.84 mg/L) concentrations compared to shrimp sediments (0.35 ± 0.05% and 22.22 ± 6.95 mg/L, respectively). Total microbial abundance was substantially higher in shrimp sediments ($3.2 \times 10^7 \pm 1.55 \times 10^7$ CFU/g) than in grouper sediments ($0.04 \times 10^7 \pm 0.06 \times 10^7$ CFU/g).

C. Water Quality and Pollution Index Values

The results of the water quality measurements taken from grouper and shrimp aquaculture wastewater are presented in Table 5.3. Based on measurements of several water quality parameters, it was found that the values of most parameters in grouper aquaculture wastewater were in accordance with the quality standards set out in Bali Governor Regulation No. 16 of 2016. However, the temperature and nitrate values exceeded these standards, which are intended to protect marine life. In shrimp aquaculture wastewater, several parameters did not comply with these standards, including temperature, nitrate and ammonia.

Table 1. Characteristics of Aquaculture Wastewater

No	Parameter	Grouper Farming	Shrimp Farming
1	C Organik (Karbon)	0,53±0,02 %	0,53±0,02 %
2	N (Nitrogen)	0,03±0,008 %	0,03±0,008 %
3	P (Phosphorus)	3,29±1,37 mg/L	3,29±1,37 mg/L
4	Total Microbes (x 10^3)	2,23±0,78 CFU/mL 5,77±1,17 CFU/mL	2,23±0,78 CFU/mL 5,77±1,17 CFU/mL

Table 2. Karakteristik Sedimen Budidaya

No	Parameter	Grouper Waste	Shrimp Waste
1	C Organik (Karbon)	1,39 ± 0,33%	2,62 ± 0,04%
2	N (Nitrogen)	0,42 ± 0,04%	0,42 ± 0,04%
3	P (Phosphorus)	24,95 ± 4,84 mg	24,95 ± 4,84 mg/L
4	Total Microbes (x 10^3)	0,04 ± 0,06 CFU/g	0,04 ± 0,06 CFU/g

Table 3. Water Quality Parameter Measurement Results

No	Parameter	Grouper	Shrimp	Quality Standards (Governor Regulation No. 16, 2016)
1	Temperature (°C)	30-30,2	30-31,2	28-30
2	pH	7,95-8,18	7,68-7,9	7-8,5
3	DO (ppm)	5-5,8	4,8-5,1	5
4	Turbidity	0,35-0,68	2,3-3,68	5
5	Salinity (ppt)	30-33	30-31	33-34
6	BOD (ppm)	0.6	1,01-6,04	20
7	Nitrate (ppm)	0,396-0,597	0,456-0,594	0.06
8	Ammonia (ppm)	0,063-0,137	0,114-0,794	0.3
9	Sulfide (ppm)	0.01	0.01	0.01

The highest Pollution Index (PI) value in grouper aquaculture wastewater was recorded at sampling point 3 (3.164), followed by point 1 (2.692) and point 2 (2.625). In shrimp aquaculture wastewater, the Pollution Index values at points 1 to 3 were 3.172, 2.925, and 2.807, respectively.

Table 4. Pollution Index in Grouper Farming Wastewater

Point	Pollution Index	Average±SD	Category
1	2.692	2.827±0.294	Slightly polluted
2	2.625		
3	3.164		

Table 5. Pollution Index in Shrimp Farming Wastewater

Point	Pollution Index	Average±SD	Category
1	3.172	2.968±0.186	Slightly polluted
2	2.925		
3	2.807		

Based on the marine biota quality standards, the Pollution Index values indicate that wastewater from both grouper and shrimp aquaculture was classified as lightly polluted. However, pollution levels in shrimp aquaculture wastewater were generally higher than those observed in grouper aquaculture wastewater.

3.2. Discussion

A. Nutrient Content and Total Microbes in Wastewater

The total microbial abundance in waters surrounding the shrimp farming site was 5.77 ± 1.17 CFU/mL, which was higher than that observed around the grouper farming site (2.23 ± 0.78 CFU/mL). This difference is closely related to the higher organic matter content in shrimp aquaculture waters. Microbial density in shrimp farming areas tends to be higher due to the greater availability of organic material, which serves as a substrate for microbial growth. Yuningsih et al. (2014) reported that elevated organic matter concentrations in floating net cage systems originate primarily from feed waste. In terms of feeding intensity, shrimp farming generally requires a higher feed input than grouper farming. Moreover, fish utilize feed more efficiently than shrimp, resulting in greater accumulation of organic matter in waters surrounding shrimp ponds. Organic matter supports microbial metabolism by providing an energy source for growth and development (Kristiawan *et al.,* 2014). Kliene (2006) also noted that microbial growth increases in waters with high organic matter content. Consequently, higher organic matter availability promotes increased microbial abundance in aquaculture waters. Palimirmo (2016) further explained that improved organic matter supply accelerates bacterial life processes, leading to an increase in microbial populations.ues and survival rates of shrimp larvae fed P. cruentum either as a sole diet or in combination with artificial feed.

B. Nutrient Content and Total Microbes in Sediment

The average organic carbon content at both research sites indicates that the sediments fall into the moderate organic carbon category. Based on the EPA (2002) classification, sediments with organic carbon content ranging from 1% to 3% are considered moderate. The organic carbon present in sediments affected by shrimp and grouper aquaculture waste is primarily derived from organism excretion and the accumulation of organic residues. This is supported by Dewanti et al. (2016), who stated that organic carbon in aquatic sediments originates from the decomposition of organic matter and the remains of dead organisms.

The nitrogen content of sediments in Gerokgak waters is higher than that reported for Punduh Bay, Lampung, which is influenced by shrimp pond activities and has nitrogen levels ranging from 0.05% to 0.25% (Paena *et al.,* 2017). According to Silva et al. (2011), nitrogen concentrations exceeding 0.2% are classified as high. The elevated nitrogen levels in Gerokgak sediments are likely associated with additional organic inputs from aquaculture activities at the study site, including fixed cages and floating net cages used for shrimp and grouper farming.

Phosphorus concentrations in sediments were higher than those in the water column. This observation is consistent with Paena et al. (2017), who reported that phosphorus accumulates in sediments over longer periods. Phosphorus in aquatic sediments originates from the degradation of uneaten feed (Prasetiyono *et al.,* 2022), while phosphate in both water and sediment from aquaculture waste is derived from feed residues and the excretion of cultured fish and shrimp (Suguira, 2018).

The total microbial abundance in sediments associated with aquaculture waste is influenced by the accumulation of organic matter on the substrate. Organic matter derived from excretion products and uneaten feed supports microbial growth. As organic waste input increases, microbial abundance also rises. Microorganisms play a crucial role in the decomposition of organic matter; therefore, higher microbial activity accelerates the decomposition process (Purnomo *et al.,* 2016).

C. Water Quality and Pollution Index

Several water quality parameters in grouper and shrimp aquaculture wastewater still comply with the marine biota quality standards stipulated in Bali Governor Regulation No. 16 of 2016, except for temperature, nitrate, and ammonia. In both types of aquaculture wastewater, water temperature slightly exceeded the recommended threshold. The temperature in grouper farming wastewater ranged from 30.0 to 30.2 °C, while that in shrimp farming wastewater ranged from 30.0 to 31.2 °C. According to Bali Governor Regulation No. 16 of 2016, the optimal temperature range for marine biota is 28–30 °C. The elevated temperatures observed in this study may be related to daytime sampling under high ambient temperatures.

Previous studies indicate that such temperature ranges are still tolerable for aquaculture species. Suwoyo (2011) reported temperature values of 25.0–30.6 °C in tiger grouper aquaculture, which remain suitable for grouper survival. Similarly, Supito et al. (1998) found that tiger groupers can survive at temperatures ranging from 26 to 30.5 °C. For shrimp aquaculture, vaname shrimp have been reported to grow optimally at water temperatures between 28 and 32 °C (Krummenauer *et al.,* 2011). Therefore, when considering the specific cultured commodities, the temperature range observed in both grouper and shrimp aquaculture wastewater is still acceptable.

Nitrate concentrations in wastewater from both grouper and shrimp farming exceeded the quality standards set out in Bali Governor Regulation No. 16 of 2016, indicating that the aquaculture waste is nutrient-rich. Although elevated nitrate levels may negatively affect receiving waters over the long term, natural mixing and circulation in marine environments can help reduce nitrate concentrations. Nitrate serves as a nutrient source for phytoplankton and aquatic plants; however, excessive accumulation may trigger eutrophication. Setijaningsih and Suryaningrum (2015) noted that nitrate is a stable and highly soluble form of nitrogen in water.

Nitrate concentrations are also influenced by dissolved oxygen (DO) levels, as oxygen facilitates the oxidation of nitrite to nitrate. In this study, DO concentrations of approximately 5 ppm indicate that nitrification processes were occurring effectively. In addition, high ammonia concentrations originating from uneaten feed and metabolic waste of cultured fish and shrimp contribute to increased nitrate levels in aquaculture wastewater.

Based on pollution index calculations, wastewater from both grouper and shrimp aquaculture is classified as lightly polluted. The pollution index value for shrimp farming wastewater was higher than that for grouper farming wastewater, reflecting elevated values of several contributing parameters, particularly temperature, nitrate, and ammonia. These parameters were consistently higher in shrimp farming wastewater. According to Hamuna et al. (2018), elevated concentrations of ammonia and nitrate are of concern, as they are nutrient-rich environmental parameters that can promote eutrophication when continuously accumulated in marine waters, posing risks to other marine organisms.

4. Conclusion

Based on the results of this study, it can be concluded that grouper and shrimp aquaculture waste exhibit distinct characteristics. Shrimp farming waste is characterized by higher carbon content and greater total microbial abundance than grouper farming waste. Although the overall water quality for both aquaculture commodities remains generally acceptable, nitrate and ammonia concentrations exceed the established quality standards. These elevated nutrient levels contribute to higher pollution index values, indicating that wastewater from both grouper and shrimp aquaculture is classified as lightly polluted, with pollution levels being higher in shrimp aquaculture wastewater.

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