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Operational and Maintenance Strategy of Shrimp Aquaculture Wastewater Treatment Plant: A Case Study of CV. TBD in Belitung, Indonesia

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ABSTRACT:- Shrimp farming is a major industry in Indonesia, contributing significantly to the economy but also posing environmental risks due to untreated wastewater discharge. This study aims to evaluate the operational processes, pollutant reduction efficiency, and potential improvements of the wastewater treatment plant (WWTP) at CV. TDB, a shrimp farm located in East Belitung, Indonesia. The method used was field observation and comparison with wastewater treatment theory and applicable quality standards. The TDB pond WWTP consists of a series of sedimentation ponds and biological treatment using Chanos chanos (milkfish) to aid in the breakdown of organic matter. Water quality parameters such as pH, ammonia (NH_3), nitrite (NO_2 -), nitrate (NO_3 -), and phosphate (PO_4 $^{3-}$) are monitored twice a year to assess compliance with local environmental regulations. The results showed that the WWTP system met local regulatory standards for pH (7.30-8.41) and ammonia (0.087 mg/L), but its efficiency in reducing nitrogen and organic matter was suboptimal due to the lack of sophisticated treatment processes. Despite complying with environmental limits, the system's reliance on natural sedimentation and filtration limits its ability to manage pollutants consistently across a range of environmental conditions. Recommendations to improve the effectiveness and sustainability of the system include the introduction of secondary and tertiary treatment technologies, increased monitoring frequency, and the implementation of more frequent maintenance protocols. These improvements will enhance the operational efficiency of the WWTP, ensure long-term regulatory compliance, and reduce the environmental impact of shrimp farming operations. This study provides valuable insights into wastewater management in aquaculture and highlights the need for technological improvements to achieve sustainable production.

Keywords – Shrimp farming, Wastewater Treatment Plant, Nitrogen, Organic matter, Natural sedimentation

I. INTRODUCTION

Indonesia, as one of the largest archipelagic countries in the world, has vast marine resources, which contribute greatly to its economy, mainly through fisheries and aquaculture. Among the marine species cultivated, shrimp farming has become a major sector, with *Litopenaeus vannamei* shrimp (commonly known as Vannamei shrimp) playing an important role in meeting domestic and international demand [1], [2]. Shrimp farming, although highly profitable, poses many environmental challenges, particularly regarding wastewater management. The rapid expansion of shrimp farming has raised concerns about the discharge of untreated effluent, which poses significant risks to coastal ecosystems [3], [4]. Effective wastewater treatment, especially through wastewater treatment plants (WWTP) is crucial in mitigating the adverse impacts of aquaculture effluents on surrounding water bodies [5], [6].

Shrimp farming wastewater contains high concentrations of organic matter, nutrients such as nitrogen and phosphorus, and traces of chemicals used in disease management [3], [7]. In Indonesia, regulatory frameworks have been established, such as the Governor Regulation of Bangka Belitung Islands Number 34 of 2019, which provides guidelines for controlling surface water pollution from shrimp farms. Despite these regulations, there is a gap between policy and implementation, with many shrimp farms struggling to effectively manage their wastewater [8]. Failure to adequately manage effluents leads to eutrophication, degradation of water quality, and damage to marine biodiversity [9], [10]. Therefore, there is an urgent need to develop and implement more efficient wastewater management and treatment strategies.

In the field of aquaculture wastewater management, significant progress has been made to improve the efficiency of WWTPs. Conventional treatment systems, such as sedimentation, aeration and biological filtration, have been widely applied to reduce organic and nutrient loads from effluents [11]. However, these systems often fail in terms of maintaining long-term efficiency and adapting to varying effluent compositions. Recent research has explored the use of advanced treatment technologies, such as artificial wetlands, biofloc technology, and integrated multitrophic aquaculture (IMTA), which aim to create a more sustainable balance between production and environmental conservation [12], [13].

One of the most pressing challenges in aquaculture wastewater management is maintaining a balance between operational efficiency and environmental sustainability. Operational aspects of WWTP systems, including routine maintenance and process optimisation, have a direct impact on their effectiveness [11]. In addition, technological innovations, such as real-time monitoring of effluent quality and the use of bioindicators, have been proposed to improve treatment outcomes [14]. Despite these advances, small and medium-scale farms, such as CV. TDB, often lack the resources and expertise to implement cutting-edge technologies, relying heavily on traditional methods that may not fully comply with environmental standards.

This study aims to evaluate the operational and maintenance strategy of a wastewater treatment plant (WWTP) at CV. TDB, a shrimp farm in Belitung, Indonesia. Specifically, this research scope are (1) Investigate the operational process of the WWTP system and its compliance with local environmental regulations, (2) Assess the efficiency of wastewater treatment in reducing pollutants such as nitrogen, phosphorus, and organic matter., (3) Provide recommendations to improve the effectiveness and sustainability of WWTP systems through optimised operational practices and maintenance protocols.

By identifying key areas for improvement within the existing wastewater treatment framework, this research will contribute to a broader understanding of sustainable aquaculture practices and provide a model for other shrimp farms in Indonesia and similar regions.

II. METHODOLOGY

This study was conducted to evaluate the operational and maintenance performance of a wastewater treatment plant (WWTP) at CV. TDB, a shrimp farm located in East Belitung, Indonesia. The farm manages wastewater generated during shrimp farming through a sedimentation pond system and biological processes. The methodology used included direct observation of the operational process of the WWTP system and analysis of water quality parameters at various stages of the treatment process.

2.1 Study Area and Sampling Procedure

CV. TDB includes 36 shrimp farms spread across 40 hectares of land. Wastewater from these ponds is treated using a series of eight sedimentation ponds before being discharged into the Selungsor River. The main wastewater discharge channel is located approximately one kilometre from the main ponds.

Water samples were taken from several points throughout the system, including the inlet, various stages within the sedimentation pond, and the final outlet. Samples were analysed twice a year for levels of key pollutants, including ammonia ($NH3$), nitrite ($NO2^-$), nitrate ($NO3^-$), and phosphate ($PO4^{3-}$). Sampling was conducted in accordance with the guidelines set out in the Indonesian Ministry of Marine Affairs and Fisheries standards for shrimp pond effluent quality.

2.2 Operational Process

The wastewater treatment system at CV. TDB mainly relies on natural sedimentation and filtration processes. Sedimentation ponds are equipped with basic physical treatment mechanisms to capture suspended solids, while biological treatment is facilitated by stocking certain fish species such as *Chanos*. *Chanos* (milkfish) to help decompose organic matter.

However, no advanced filtration or chemical treatments, such as Sequencing Batch Reactors (SBR), were utilised, limiting the system's ability to handle high nitrogen concentrations and organic loads. The operation is designed to maximise natural processes, with alternating aerobic and anaerobic conditions helping to reduce nitrogen and carbon levels. Nonetheless, the operational efficiency of the pond is hampered by the lack of biosecurity infrastructure, which has yet to be installed due to limited electricity availability.

2.3 Maintenance and Monitoring

Routine maintenance of the WWTP system includes regular cleaning of the main sewer and secondary sewer to prevent blockages, especially after the shrimp harvest. The secondary sewer is located approximately 200 metres from the ponds, with the main sewer approximately one kilometre from the sedimentation ponds. The maintenance schedule includes sludge removal and cleaning of floating debris to prevent blockages. It should be noted, however, that more frequent cleaning is required to maintain system efficiency, especially during periods of heavy rainfall or shrimp harvesting, which put additional strain on the treatment system. Water quality monitoring is conducted twice a year at the in-house laboratory. Parameters such as pH, ammonia, nitrite, nitrate and phosphate are assessed to ensure compliance with local effluent standards. However, the limited frequency of these tests, along with the lack of equipment to measure other important water quality parameters such as total suspended solids (TSS) and turbidity, present challenges in maintaining accurate and consistent water quality data.

2.4 Data Analysis

The water quality data collected was compared to regulatory standards set by the Ministry of Marine Affairs and Fisheries, specifically focusing on effluent limits for pH, ammonia, and nitrogen-based compounds. Statistical analyses were used to evaluate whether the WWTP system consistently met these standards, particularly during different stages of the shrimp production cycle. In addition, the potential for improving system performance through the introduction of advanced treatment methods, such as biofiltration and chemical treatment, was assessed.

III. RESULT AND DISCUSSION

3.1 WWTP System Operational Processes and Compliance with Local Environmental Regulations

Layout of the WWTP of CV. TDB is shown in Figure 1. The farm area is 40 acre including reservoir, ponds for nursery, and aquaculture ponds. Those units were designed to support the optimal process of shrimp aquaculture.

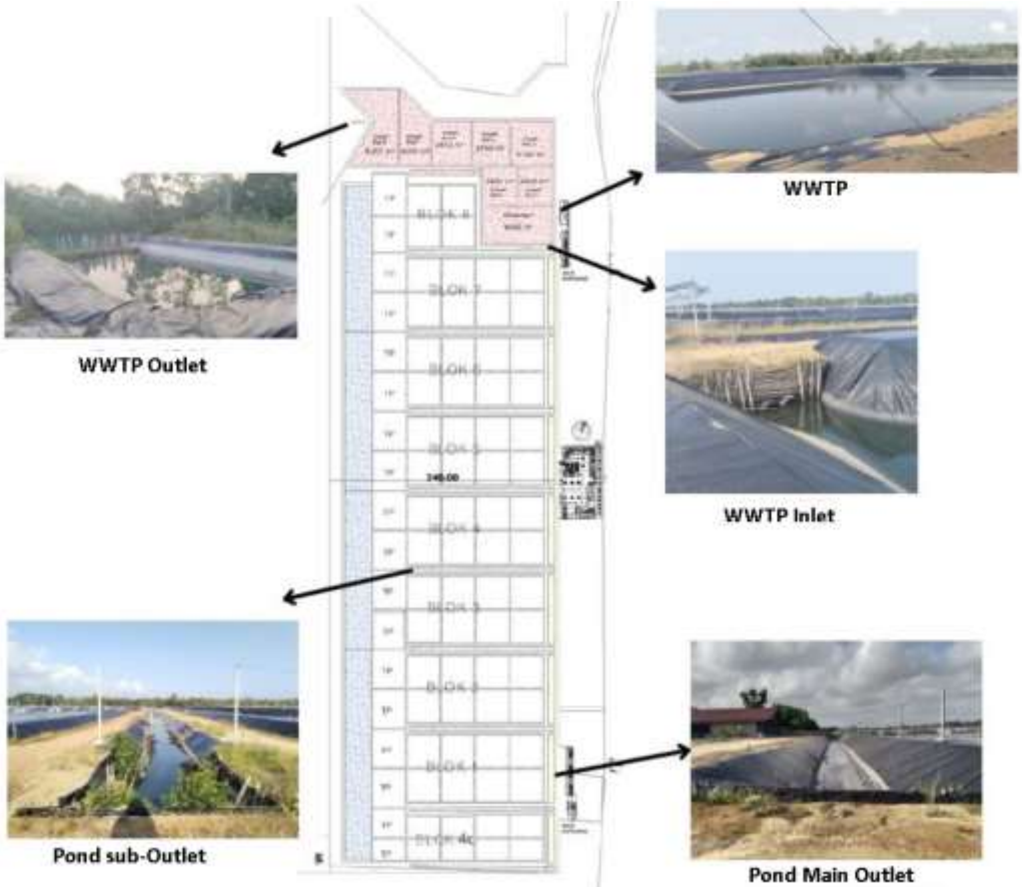

Figure 1. Layout of Shrimp Farm of CV TDB

The WWTP system at CV. TDB is designed as a series of sedimentation ponds, which handle effluent from shrimp farming operations. Wastewater flows through eight sequential ponds, which allow suspended solids to settle before final discharge to the Selungsor River. River. The system includes biological treatment mechanisms, such as the introduction of *Chanos chanos* (milkfish), to help break down organic matter. However, despite having this infrastructure, the system lacks advanced treatment technologies, such as biofiltration or chemical treatment units, which could improve the reduction of ammonia and other pollutants. Water quality monitoring, mandated by local environmental standards set by the Ministry of Marine Affairs and Fisheries (Kepmen No. 28/MEN/2004), is conducted twice a year at CV. TDB. Parameters monitored include pH, ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and phosphate ($PO_4^{\ 3-}$), all of which meet effluent quality standards. For example, the recorded pH values consistently ranged between 7.30 and 8.41, which complied with the regulatory requirement of 6.0 to 9.0. Ammonia levels, measured at 0.087 mg/L, were also within the permissible limit of 0.1 mg/L. While these values are appropriate, the absence of more frequent testing raises concerns about the long-term reliability of the system, especially during critical periods such as harvesting or heavy rains.

3.2 Efficiency in Reducing Pollutants

The efficiency of the WWTP system in reducing key pollutants-such as nitrogen, phosphorus, and organic matter-remains suboptimal. The primary reliance on natural sedimentation and filtration processes, without secondary treatment, limits the system's ability to handle more complex pollutants such as nitrogen compounds ($NO2-$ and $NO3-$) and total suspended solids (TSS). Although nitrate (10 mg/L) and nitrite (0.0158 mg/L) levels comply with environmental limits, the current system lacks the technological sophistication to consistently reduce these levels across a range of environmental conditions.

For example, the build-up of biofilm and sludge at the pond edge has been observed, indicating that natural processes are not sufficient to fully degrade organic matter. The need for more effective treatment stages, such as aerobic and anaerobic digestion, is obvious. The introduction of more advanced technologies, such as aerated ponds and Sequencing Batch Reactors (SBR), can significantly improve the efficiency of nitrogen removal and organic matter decomposition.

3.3 Recommendations for Improvement

To improve the effectiveness and sustainability of the WWTP system, several operational and maintenance recommendations can be made, i.e. application the advanced processing technology, increased monitoring frequency, improved maintenance protocol and development of standard operation and procedure.

3.3.1 Introduction to Advanced Processing Technology

Installation of secondary and tertiary treatment processes is essential. Aeration ponds can help increase oxygen levels, reduce Biological Oxygen Demand (BOD), and improve nitrification processes. Similarly, integrating Sequencing Batch Reactors (SBR) or similar systems can improve ammonia, nitrite, and nitrate removal.

3.3.2 Increased Monitoring Frequency

Given the seasonal variation in shrimp farming and the potential for effluent spikes during harvest or high rainfall, water quality monitoring should be conducted more frequently than the current biennial schedule. Monthly or even bi-weekly testing during critical periods can help identify potential inefficiencies in the system before they lead to regulatory non-compliance.

3.3.3 Improved Maintenance Protocol

Current maintenance activities, such as sludge removal and pipe cleaning, are performed every three shrimp cycles (approximately nine months). This interval is too infrequent, given the operational demands of shrimp farming. Increasing the frequency of outlet and pond maintenance to at least once per cycle, or every three months, will significantly reduce the risk of clogging and system inefficiency.

3.3.4 Development of Standard Operating Procedures (SOPs)

The farm does not have a clear set of Standard Operating Procedures (SOPs) for the operation and maintenance of the WWTP system. Establishing these guidelines will ensure that all aspects of the wastewater treatment process are carried out consistently and in compliance with environmental regulations.

IV. CONCLUSION

In summary, although CV. TDB's WWTP system complies with local environmental regulations, its current operational efficiency can be improved with advanced treatment technologies and better maintenance practices. These improvements will ensure the long-term sustainability of the aquaculture operations and the surrounding ecosystem.

This study evaluated the operational processes, pollutant reduction efficiency, and potential improvements for the wastewater treatment plant (WWTP) at CV. TDB. The results revealed that although the WWTP system currently meets local environmental regulations for basic parameters such as pH and ammonia, its reliance on natural sedimentation and filtration limits its ability to consistently reduce nitrogen, phosphorus, and organic matter. The lack of advanced treatment technologies and infrequent monitoring posed challenges in ensuring long-term compliance and operational efficiency.

To improve the effectiveness and sustainability of the WWTP system, several recommendations were made, including the introduction of secondary and tertiary treatment processes (such as aeration ponds and SBR), increased frequency of water quality monitoring, and stricter maintenance protocols. By implementing these improvements, the farm can achieve more reliable pollutant reduction, ensuring regulatory compliance and protection of the surrounding ecosystem.

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