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Evaluation of Operational Waste Management System at the Belawan Ocean Fishing Port

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ABSTRACT
Belawan Ocean Fishing Port plays a strategic role in the capture fisheries management system in western Indonesia. The high intensity of port operations contributes to increased waste generation, which may adversely affect environmental quality and the sustainability of fisheries. This study aimed to evaluate the operational waste management system at Belawan Ocean Fishing Port and to examine its implications for fisheries management. An exploratory descriptive approach supported by quantitative estimation was applied. Data were collected through field observations, semi-structured interviews with 10 key informants, and document analysis of relevant regulations and official reports. Waste generation was estimated based on the number of vessels landing daily and the average waste generated per vessel. The results indicate that operational waste at Belawan Ocean Fishing Port consists of solid, liquid, and hazardous waste. The estimated daily waste generation reached approximately 800 kg of solid waste, 2.5 m³ of liquid waste, and 10 litres of hazardous (B3) waste. These figures represent indicative estimates based on vessel activity during the study period. The existing waste management system has not been standardised, as reflected by the absence of source segregation, non-operational wastewater treatment facilities, and dedicated facilities for hazardous waste handling. In addition, stakeholder awareness and community participation in waste management remain limited. This study concludes that operational waste management at Belawan Ocean Fishing Port has not been fully integrated into fishing port governance. Strengthening infrastructure, institutional capacity, and participatory approaches is therefore essential to support sustainable fisheries management in the port area.

Keywords: Belawan Ocean Fishing Port; Fisheries management; Operational waste; Sustainability

INTRODUCTION

Fishing ports play a strategic role in capture fisheries management, particularly in tropical regions, as they function as central nodes for fish landing, distribution, processing, and marketing activities (Gumilang & Susilawati, 2020; Rahmayanti, 2018). Within fisheries management systems, ports are not merely physical infrastructure, but also operational control points that influence supply chain efficiency, fish quality, and the sustainability of aquatic resources and surrounding environments (Hutapea *et al.*, 2017; Susanto *et al*., 2020). Consequently, the environmental performance of fishing ports constitutes an integral component of sustainable fisheries management.

In Indonesia, fishing ports serve as socio-economic hubs involving a wide range of stakeholders, including fishers, port workers, fish processors, and traders (Shaadikin *et al.,* 2022). The high intensity of daily operations in port areas inevitably generates various types of waste, including solid, liquid, and hazardous waste. When inadequately managed, the accumulation of operational waste may degrade port water quality and adjacent coastal ecosystems, thereby posing sanitation risks and potentially affecting fish handling hygiene, product quality, and market competitiveness (Lasut, 2020; Ferreira *et al.,* 2022). These environmental issues directly relate to fisheries management priorities, particularly in maintaining resource sustainability and ensuring compliance with food safety and export standards.

Belawan Ocean Fishing Port is one of the major fishing ports in western Indonesia,

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supporting large-scale capture fisheries activities (Reza *et al*., 2020; Siahaan *et al*., 2016). As a class A fishing port, Belawan handles substantial volumes of fish landings and conducts intensive operational activities daily (Fadhilah *et al*., 2024). These conditions contribute to increased operational waste generation, potentially placing environmental pressure on surrounding coastal waters. In the context of tropical fisheries management, environmental degradation in port areas is a critical issue, as it may directly affect the sustainability of fish resources and the quality of landed catches (Muninggar *et al.,* 2020; Mutmainah *et al*., 2018).

In response to increasing environmental pressures at fishing ports, the eco-fishing port concept has been introduced as an integrated framework that incorporates environmental management into port governance. The eco-fishing port approach emphasises waste reduction at source, wastewater treatment functionality, hazardous (B3) waste control, sanitation and hygiene standards, and stakeholder participation as key sustainability indicators (Muninggar *et al*., 2020; Ferreira *et al*., 2022). Within this framework, operational waste management becomes a critical performance component of sustainable fisheries-port management.

Previous studies have reported that many fishing ports in Indonesia continue to face challenges in managing operational waste, including limited waste segregation facilities, underperforming wastewater treatment systems, and weak environmental management institutions (Firdayanti & Darjati, 2021; Muninggar *et al.*, 2022). In several cases, direct disposal of waste into port waters remains a common practice, contributing to increased pollution loads and declining coastal water quality (Lasut, 2020; Risnawati *et al.,* 2024). These conditions indicate a persistent gap between environmental management principles and their implementation in port-level fisheries management systems.

From a regulatory perspective, Indonesia has established a relatively comprehensive legal framework governing environmental protection and fishing port management, including Law No. 32 of 2009 on Environmental Protection and Management and Ministerial Regulation No. 8 of 2012 of the Ministry of Marine Affairs and Fisheries on Fishing Ports. Nevertheless, previous studies suggest that integrating environmental policies into operational fisheries management at fishing ports remains suboptimal (Azizi *et al*., 2017; Wicaksono & Effendi, 2019). Despite the strategic role of Belawan Ocean Fishing Port, systematic evaluations of its operational waste management system remain limited.

In this study, the operational waste management system is defined as a sequence of activities covering waste generation within the port area (including vessel-related activities conducted at berth), source segregation, temporary storage, collection, transport, treatment, and final disposal under port jurisdiction. Offshore waste disposal beyond the port boundary is not included in this evaluation. The evaluation framework adopted in this study refers to regulatory standards and eco-fishing port indicators, including: (1) availability of source segregation facilities; (2) adequacy of collection and temporary storage infrastructure; (3) functionality of wastewater treatment facilities (IPAL/WWTP); (4) availability of designated hazardous (B3) waste storage; (5) existence of standard operating procedures (SOPs); and (6) stakeholder participation and monitoring mechanisms. These indicators are used to assess the extent to which operational waste management practices align with sustainable fisheries-port governance principles.

Based on these considerations, this study aims to evaluate the operational waste management system at Belawan Ocean Fishing Port and to analyse its implications for fisheries management in the port area. The evaluation focuses on identifying waste types and sources, estimating daily waste generation, assessing the effectiveness of existing waste management practices, and examining stakeholder perceptions related to environmental management. The findings are expected to provide a scientific basis for strengthening eco-fishing port implementation and improving sustainable fisheries management in tropical fishing ports.

MATERIAL AND METHOD

Time and Study Area

This study was conducted at Belawan Ocean Fishing Port, located in Medan Belawan District, Medan City, North Sumatra Province, Indonesia. The study area was purposively selected because Belawan Ocean Fishing Port is a class A fishing port with high operational intensity and a strategic role in supporting capture fisheries activities in western Indonesia (Reza *et al*., 2020; Siahaan *et al.,* 2016). Field data were collected from January to February 2025 under normal operational conditions, outside extreme weather periods and peak fishing seasons. Therefore, the results represent indicative waste generation under

moderate operational intensity and may differ during peak or low fishing seasons.

Definition and System Boundary

In this study, "operational waste" refers to waste generated from activities occurring within the port area, including:

1. Fish landing and unloading activities
2. Fish sorting and auction activities
3. Vessel deck washing and equipment cleaning
4. Fish handling and processing within the port
5. Vessel maintenance was conducted at the berth

The evaluation includes waste generation, source segregation, temporary storage, collection, transport, treatment, and final disposal within the port jurisdiction. Offshore waste disposal occurring outside port boundaries is not included in this study.

Operational waste is categorised into three types:

- Solid waste
- Liquid waste
- Hazardous (B3) waste

These categories are analysed separately to avoid conflating different waste streams.

Tools and Materials

The tools used in this study included structured observation sheets, semi structured interview guidelines, field note forms, audio recording devices, and cameras for documentation purposes. Data processing was supported by basic qualitative and quantitative data analysis software. The research materials consisted of primary data obtained from field observations and interviews, as well as secondary data derived from relevant regulations, port operational reports, and scientific publications (Firdayanti & Darjati, 2021; Muninggar *et al*., 2022).

Research Design

This study employed an exploratory descriptive research design with a qualitative approach supported by quantitative estimation. The qualitative component assessed existing waste management practices, institutional arrangements, and stakeholder participation; the quantitative component provided indicative estimates of daily waste generation using a vessel-based approach. The study was non-experimental and focused on evaluating operational systems and practices observed during the study period (Muninggar *et al*., 2020; Ferreira *et al*., 2022).

Data Collection Methods

Data were collected through field observations, semi-structured interviews, and document analysis. Field observations focused on port operational activities with potential waste generation, including fish landing and unloading, vessel and equipment cleaning, fish processing, and shipyard and vessel maintenance. Observations were conducted to identify waste types, sources of waste generation, disposal patterns, and the availability and condition of waste management facilities within the port area (Mutmainah *et al.*, 2018; Muninggar *et al.*, 2022). In this study, operational waste refers specifically to waste generated by activities within the port area, including vessel-related activities conducted at berths. It excludes offshore waste disposal outside port jurisdiction.

Semi-structured interviews were conducted with ten purposively selected informants, including two port authority officers, three vessel captains or owners, two fish processing unit operators, one auction facility manager, and two port cleaning staff. These informants represented institutional, operational, and user perspectives within the port system. All informants provided verbal consent prior to the interviews, and the collected information was used solely for research purposes (Shaadikin *et al.,* 2022; Masjhoer, 2025).

Document analysis was performed on national regulations and official documents related to waste management and fishing ports, including Law No. 32 of 2009 on Environmental Protection and Management, Ministerial Regulation of Marine Affairs and Fisheries No. 8 of 2012 on Fishing Ports, and Regulation of the Ministry of Environment and Forestry No. 5 of 2021. These documents were used as references to assess the conformity between observed waste management practices and existing regulatory requirements (Azizi *et al*., 2017; Wicaksono & Effendi, 2019).

Estimation of Operational Waste Generation

The estimation of daily operational waste generation was conducted to obtain a quantitative overview of waste loads generated at Belawan Ocean Fishing Port. In this study, operational waste refers to waste generated from activities within the port area, including fish landing and unloading, vessel and equipment cleaning, fish handling, and vessel maintenance conducted at the berth. Waste generated outside the port jurisdiction was not included in the estimation.

Waste generation was estimated based on the average number of vessels landing per day and the

average amount of waste generated per vessel. During the observation period (January–February 2025), approximately 20 vessels landed at Belawan Ocean Fishing Port per day. The estimation was calculated using the following equation:

$$TL = N \; x \; L$$

where:
TL = total daily waste generation;
N = number of vessels landing per day;
L = average waste generation per vessel.

The average solid waste generation per vessel (40 kg) and liquid waste generation per vessel (125 litres) were derived from field observations of waste accumulation patterns and cross-validated through interviews with port users and cleaning staff. Direct weighing instruments were not used; therefore, these values represent indicative approximations rather than exact measurements.

Based on this calculation, the estimated daily generation of solid waste was approximately 800 kg (40 kg × 20 vessels), while liquid waste generation was approximately 2,500 litres per day (125 litres × 20 vessels), equivalent to 2.5 m³ per day. Hazardous (B3) waste generation was estimated separately due to its different generation pattern. Interview results indicated that light vessel maintenance activities produce approximately 2 litres of used oil or related hazardous residues per vessel per week. During the study period, approximately 35 vessels underwent light maintenance per week in the port area. Accordingly, total hazardous (B3) waste generation was calculated as follows:
2 liters × 35 vessels = 70 liters per week
This weekly value was then converted into a daily estimate:
70 liters ÷ 7 days = 10 liters per day

This conservative estimation approach was applied as an indicative measure rather than an absolute quantification, in line with common practices in waste management planning and environmental load assessment (World Bank, 2018). Therefore, all estimated values presented in this study should be interpreted as indicative estimates intended to describe the magnitude of operational waste loads within the port area.

Data Analysis

The collected data were analysed using descriptive qualitative analysis, supported by quantitative estimates. Qualitative data from observations and semi-structured interviews were analysed using thematic analysis. Themes were developed deductively based on evaluation indicators derived from relevant regulations and eco-fishing port parameters, including source segregation, availability of collection and storage facilities, functionality of wastewater treatment (IPAL), hazardous (B3) waste handling, standard operating procedures (SOPs), and stakeholder participation. Quantitative waste-generation estimates were used to describe the magnitude of operational waste loads and to support the interpretation of qualitative findings. Data validity was strengthened through source triangulation by comparing information obtained from observations, interviews, and document analysis (Ferreira *et al*., 2022; Muninggar *et al*., 2020).

RESULT AND DISCUSSION

Result

The following findings are based on field observations conducted from January to February 2025, supported by interview data and document analysis. Waste generation figures presented in this section are indicative estimates derived from the vessel-based calculation approach described in the methods section.

Types and Sources of Operational Waste

Based on field observations and semi-structured interviews, operational waste generated at Belawan Ocean Fishing Port was classified into three main categories: solid, liquid, and hazardous waste. These waste types originated from routine port operational activities, including fish landing and unloading, vessel and equipment cleaning, fish processing, and shipyard and vessel maintenance.

Solid waste was identified as the most dominant waste type in the port area. This waste was primarily generated from fish landing and sorting activities at the fish auction facility. Solid waste components consisted of organic fractions, such as fish remains, offal, scales, and bones, as well as inorganic fractions, including plastic packaging, ice bags, damaged fishing nets, and ropes. Liquid waste was generated from vessel deck washing, cleaning of fish handling equipment, and melting ice mixed with blood and fish mucus. Hazardous waste originated mainly from vessel maintenance activities, such as oil changes, hull painting, and engine servicing.
The classification of operational waste types and their sources at Belawan Ocean Fishing Port is presented in Table 1.

Table 1. Classification of Operational Waste Types and Sources at Belawan Ocean Fishing Port

Waste Type	Source of Activities	Examples of Waste
Solid waste	Fish landing, auction activities, deck cleaning	Fish remains, offal, plastic packaging, damaged nets
Liquid waste	Vessel and equipment cleaning, fish processing	Water mixed with blood, mucus, and detergents
Hazardous waste	Vessel maintenance and repair	Used oil, paint residues, lubricants, and batteries

Information/source: Field observations and interviews, 2025

Estimated Daily Operational Waste Generation

During the observation period, approximately 20 vessels landed at Belawan Ocean Fishing Port per day. Based on vessel-based estimates, daily solid waste generation was approximately 800 kg, while liquid waste generation was approximately 2,500 litres per day (equivalent to 2.5 m^3). These values were derived from field observations of waste accumulation patterns and cross-validated through interviews with port users and cleaning staff, as explained in the methods section.

Hazardous (B3) waste was estimated separately due to its different generation pattern. Interview findings indicated that light maintenance activities generate approximately 2 litres of hazardous waste per vessel per week. With an estimated 35 vessels undergoing maintenance per week, total hazardous (B3) waste generation was calculated at approximately 70 litres per week, equivalent to around 10 litres per day. This value represents accumulated maintenance-related hazardous waste generated within the port area.

Detailed estimates of daily operational waste generation at Belawan Ocean Fishing Port are presented in Table 2.

Table 2. Estimated Daily Operational Waste Generation at Belawan Ocean Fishing Port

Waste Type	Average Waste per Vessel	Number of Vessels per Day	Estimated Daily Waste
Solid waste	40 kg	20	±800 kg
Liquid waste	125 liters	20	±2,500 litres (2.5 m^3)
Hazardous waste	±2 litres/week/vessel	–	±10 litres/day*

Note: Hazardous waste estimates were derived from accumulated light maintenance activities involving approximately 30–40 vessels per week.

Existing Waste Management Conditions at the Port

Field observations indicated that operational waste management at Belawan Ocean Fishing Port had not been implemented based on waste type separation. Solid, liquid, and hazardous waste were not segregated at the source, and most waste was collected at a general temporary storage facility or discharged into open drainage channels within the port area. During the observation period, approximately 15 general waste bins were available in the auction area, supported by one temporary storage facility (TPS) for mixed solid waste. One wastewater treatment facility (IPAL) was present but found to be non-operational. No designated hazardous (B3) waste storage facility was observed within the port area.

Interview findings suggest that many port users have a limited understanding of waste classification and appropriate handling procedures. Several informants indicated that waste separation was not routinely practised and that mixed waste collection was common. Port cleaning activities were conducted intermittently and were not integrated into a structured waste management system.

Discussion

Implications of Operational Waste Generation for Fisheries Management

The magnitude of operational waste generated at Belawan Ocean Fishing Port confirms that fishing ports serve as critical control points within capture fisheries management systems. Solid and liquid waste generated from fish landing, vessel

cleaning, and fish handling activities may affect port water quality, which is closely linked to the efficiency of fish handling and the quality of landed catches. Similar conditions have been reported in previous studies, indicating that unmanaged waste accumulation in port areas contributes to environmental degradation in coastal waters (Lasut, 2020; Mutmainah *et al*., 2018).

At large-scale fishing ports such as Belawan, high operational intensity results in higher waste loads than at smaller ports. Muninggar *et al.* (2020) and Muninggar *et al*. (2022) emphasised that ports with high activity levels require integrated environmental management approaches to prevent negative impacts on fisheries productivity and port performance. However, this study did not include direct measurements of water quality or fish quality; therefore, the implications discussed represent potential risks rather than empirically verified impacts.

Gaps Between Regulatory Frameworks and Waste Management Practices

The findings of this study reveal a gap between existing regulatory frameworks and on-site waste management practices at Belawan Ocean Fishing Port. Although national regulations mandate proper handling of solid, liquid, and hazardous (B3) waste in port areas, implementation at the operational level remains limited. This is reflected in the absence of source segregation, the non-operational wastewater treatment facility, and the lack of designated hazardous (B3) waste storage. Table 3 summarises the main gaps identified between regulatory requirements and observed conditions.

Table 3. Identified Gaps in Operational Waste Management at Belawan Ocean Fishing Port

Regulatory Requirement	Observed Condition	Identified Gap
Source segregation	Not implemented	Non-compliance
Functional IPAL	Non-operational	Infrastructure gap
Hazardous (B3) storage	Not available	Risk of improper handling
SOP & monitoring	Limited implementation	Institutional weakness

These findings are consistent with previous research highlighting institutional weaknesses and insufficient enforcement as key barriers to effective environmental management in the fisheries sector (Azizi *et al.,* 2017; Wicaksono & Effendi, 2019; Firdayanti & Darjati, 2021; Risnawati *et al.,* 2024).

Role of Port Stakeholders in Sustainable Waste Management

Limited stakeholder awareness and participation further underscore the social dimension of environmental management at fishing ports. Effective waste management requires coordinated roles among port authorities (policy and supervision), auction facility management (operational control), vessel owners and crews (waste handling at source), traders and processors (management of processing waste), cleaning staff (collection and transport), and local environmental agencies (regulatory oversight). Without coordinated responsibility among these actors, waste management efforts are likely to remain fragmented. This observation aligns with Shaadikin *et al.* (2022) and Masjhoer (2025), who emphasised the importance of participatory approaches in supporting sustainable port management for fishing.

Managerial Implications and Directions for Future Research

From a managerial perspective, this study's results highlight the need to integrate operational waste management into the overall governance of fishing ports. This approach is consistent with the *eco-fishing port* concept, which emphasises incorporating environmental considerations into fisheries port management systems (Muninggar *et al*., 2020; Ferreira *et al.,* 2022). Enhancing waste management performance requires not only the provision of physical infrastructure but also institutional strengthening, inter-agency coordination, and continuous stakeholder engagement.

Future research should focus on quantitative assessments of the relationship between port waste management practices, water quality parameters, and capture fisheries performance. In addition, evaluating the effectiveness of *eco-fishing port* implementation at large-scale fishing ports would provide valuable insights for improving sustainable fisheries management in tropical regions.

CONCLUSION

This study shows that operational waste generated at Belawan Ocean Fishing Port consists of solid waste, liquid waste, and hazardous (B3) waste, with estimated daily volumes of approximately 800 kg of solid waste, 2.5 m^3 of liquid waste, and 10 litres of hazardous waste. Despite these significant waste loads, operational waste management has not yet been implemented in an integrated and standardised manner. Source segregation is not practised, the wastewater treatment facility (IPAL) is non-operational, and no designated hazardous (B3) waste storage facility is available.

These findings indicate a gap between regulatory requirements and on-site implementation, highlighting the need to strengthen operational waste management as part of fishing port governance. Priority actions include: (1) implementation of mandatory source segregation for different waste types; (2) re-operationalisation and routine maintenance of the IPAL; (3) provision of a dedicated hazardous (B3) waste temporary storage facility; and (4) development of standard operating procedures (SOPs) accompanied by regular monitoring and stakeholder involvement. This study is limited by the use of indicative vessel-based waste estimation and the absence of direct environmental quality measurements. Future research should incorporate quantitative water quality assessments and evaluate eco-fishing port performance to support sustainable fisheries management.

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