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ANALYSIS OF WASTEWATER QUALITY AT THE INDONESIAN RED CROSS (PMI) IN CILACAP REGENCY

Nita Sofia Rakhmawati*, Tessa Sukma Febrianti, Hasri Widuri
Occupational Safety and Health Study Program, STT Migas Cilacap, Indonesia
*Corresponding Author: Email: rakhmawati.ns@gmail.com

Abstract
Introduction: Increasing volume of medical wastewater presents a significant challenge for environmental management, particularly in healthcare facilities such as the Blood Donor Unit (UDD) of the Indonesian Red Cross (PMI). Inadequate wastewater treatment can lead to environmental pollution and pose serious public health risks. This study aimed to evaluate the performance of a Wastewater Treatment Plant (WWTP) at the UDD PMI in the Cilacap Regency by analyzing key physical, chemical, and biological parameters.
Methods: This study employed a descriptive, quantitative approach. Wastewater samples were collected from the WWTP outlet using random sampling. The samples were placed in sterile bottles, stored at low temperatures, and analyzed at Cilacap Environmental Agency Laboratory using standardized methods for water and wastewater examination (APHA, 2017). The parameters tested included pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), oil and grease, ammonia, and total coliform.
Results: The physical parameter (TSS: 18 mg/L) and chemical parameters (pH: 8.0; BOD: 7 mg/L; COD: 10 mg/L; oil and grease: 1.9 mg/L; ammonia: <0.01 mg/L) were all within acceptable regulatory limits. However, the biological parameter of total coliforms exceeded the permissible threshold (>24,000 MPN/100 mL), indicating possible fecal contamination. This result highlights a significant risk to both public health and the environment.
Conclusion: Although WWTP are equipped with standard treatment units, their disinfection process is insufficient, posing the potential risk of waterborne disease transmission (e.g., cholera). Therefore, immediate improvements in disinfection systems are recommended.

Keywords: Wastewater Treatment Plant (WWTP), medical wastewater, physical parameters, chemical parameters.

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Introduction

Wastewater quality is a critical issue with significant implications for both the environment and public health. Wastewater generated from various activities, including industrial and domestic sources, contains hazardous substances that can contaminate water resources, soil, and air. Without proper management, such pollution disrupts ecological balance and poses serious health risks. Consequently, a thorough understanding of wastewater conditions and their impacts is essential to ensuring long-term environmental sustainability and public health.[1]

In Indonesia, industrial wastewater management is governed by multiple legal instruments anchored by Law No.32/2009 on Environmental Protection and Management.[2] This framework mandates sustainable waste practices and designates the government as both a regulator and enforcer of industrial compliance. Detailed technical requirements are specified in Government Regulation No.101/2014 on Hazardous and Toxic Waste (B3) management, including obligatory wastewater quality testing before discharge across all the industrial sectors. At the regional level, these national regulations are operationalized through Cilacap Regent Regulation No. 52/2011 concerning Wastewater Discharge and/or Utilization Permits, which sets localized technical standards, licensing procedures, and monitoring obligations for facilities in Cilacap Regency. These combined regulations underscore Indonesia's commitment to ecological sustainability and public health through controlled wastewater treatment. [3]

The Local Environmental Agency (DLH) under Indonesia's Ministry of Environment and Forestry (KLHK) enforces industrial compliance with environmental regulations by mandating the implementation of Wastewater Treatment Plants (WWTPs).[4] DLH Cilacap operationalizes this mandate through Cilacap Regent Regulation No. 52/2011, which requires industries to obtain discharge permits and conduct regular wastewater quality testing. This regulatory measure ensures proper wastewater treatment prior to discharge, significantly reducing ecological damage and public health risks. Waste, particularly in liquid form, represents a serious environmental hazard owing to its mobility and contamination potential, typically containing harmful constituents such as heavy metals, organic compounds, and pathogenic microorganisms. [5]

Liquid waste management involves three key stages: collection, treatment, and disposal. Each stage required strict control measures to prevent environmental harm. [6] Poor water management can lead to surface and groundwater pollution. Therefore, regular testing of wastewater quality is essential to identify potential environmental risks from inadequate treatment processes.[7] Liquid waste quality testing is a fundamental component of environmental impact assessment for industrial operations. Key physicochemical parameters, including pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS), serve as critical pollution indicators. Regular monitoring of these parameters allows for a thorough evaluation of wastewater quality before discharge or soil infiltration, thus supporting evidence-based waste management decisions.

This study specifically analyzes wastewater quality at the Indonesian Red Cross (PMI) facility in Cilacap Regency, a unique site that combines industrial and healthcare operations. Selected for its environmental and social significance, PMI facilities produce wastewater from multiple sources: treatment room sinks, kitchen facilities, laboratories (with potential chemical and biological contaminants, requiring compliance with the Minister of Health Regulation No.18/2020 on Regional-Based Management of Medical Waste in Healthcare Facilities), laundry operations, sanitation facilities, and vehicle washing stations. As a humanitarian organization, the PMI carries particular responsibility for ensuring that its waste management practices protect both community health and local ecosystems. However, while national regulations provide a strong foundation, their implementation at the regional level often faces practical constraints.

Cilacap Regency, a highly industrialized coastal area in Central Java (oil refining, fertilizer production, shipping), faces growing ecosystem pressures. Rising water pollution levels (Cilacap Environmental Report, 2023) underscore the importance of monitoring wastewater management at PMI healthcare facilities, as even non-industrial discharges may pose environmental risks if not properly treated. While current documentation of PMI's WWTP compliance with local regulations remains limited, a data-based assessment would help verify and

potentially improve existing wastewater management practices.

The Environmental Service (DLH) of the Cilacap Regency will conduct standardized wastewater quality testing as a core component of this study. As the official regulatory authority, the DLH's involvement ensures methodological rigor and compliance with national standards, providing a reliable assessment of the wastewater impacts from the PMI facility.

To contextualize this study within existing wastewater management research, a comparative analysis was conducted with prior studies. [8] examined wastewater quality in Pasar Bahagia and identified the exceedances of BOD, COD, TSS, and ammonia levels beyond regulatory standards, highlighting pollution risks if untreated wastewater enters aquatic ecosystems. Their recommendations, proper wastewater treatment, and routine monitoring provided valuable benchmarks for assessing the challenges faced by PMI facilities. Similarly,[9] revealed suboptimal performance in hospital wastewater treatment, in which persistently high BOD, COD, and TSS levels pose significant health and environmental hazards. Their study advocated for systemic improvements including enhanced disinfection monitoring, increased chlorination, and WWTP system upgrades.

Building on these findings, this study extends wastewater quality assessment to include critical additional parameters such as pH, oil and grease, ammonia, and total coliforms, all of which are essential for a more thorough evaluation of pollution risks. Although traditional indicators (BOD, COD, and TSS) maintain their importance, these expanded metrics provide a more complete picture of the water quality conditions. Initial investigations at the Indonesian Red Cross (PMI) facility in Cilacap Regency uncovered a significant implementation gap: while institutional policy mandates semiannual wastewater testing, no actual testing has occurred since March 2022. The wastewater at PMI originates from multiple sources, including sinks, kitchens, laboratories, laundry facilities, and vehicle washing areas. When laboratory testing was not performed, the use of aquatic organisms as bioindicators was considered a temporary alternative. However, this approach proved ineffective because of the mortality caused by wastewater exposure.

This study evaluates WWTP performance by analyzing wastewater quality at the PMI in Cilacap Regency to assess pollution levels and their potential risks to the environment and public health. The specific objectives are: (1) to evaluate the compliance of the Wastewater Treatment Plant (WWTP) with established standards, (2) to examine the physical parameters (Total Suspended Solids/TSS) against environmental quality standards, (3) to test chemical parameters (pH, BOD, COD, Oil and Grease, and NH_4) according to quality standards, and (4) to analyze the biological parameter (Total Coliform) based on applicable regulations. The findings are expected to provide recommendations for improving liquid waste management, including regular monitoring, to ensure compliance with effluent standards before environmental discharge.

Methods

This quantitative descriptive study employed a cross-sectional approach to evaluate wastewater quality at the Wastewater Treatment Plant (WWTP) of the Indonesian Red Cross (PMI) in Cilacap Regency. The independent variables included the WWTP system and operational units, and the wastewater quality parameters were categorized into three groups: physical, chemical, and biological parameters. The physical parameter analyzed was Total Suspended Solids (TSS), while the chemical parameters included pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), oil and grease, and ammonia (NH_3). The biological parameter measured was Total Coliform. The dependent variables consisted of two key components: (1) compliance of the WWTP system with Indonesian Minister of Health Regulation No.7/2019 on Hospital Environmental Health and (2) wastewater quality against Class III effluent standards as specified in Government Regulation

No.22/2021 on Environmental Protection and Management.

The study was conducted at the PMI Blood Donor Unit (March–April 2025). Wastewater samples were collected from WWTP outlet points using simple random sampling.. This location was selected because it represents the final effluent discharged into the environment, ensuring that the assessment reflects the actual risks. Sampling at the outlet minimizes spatial variability and directly evaluates the treatment efficacy. Each sample (±2,500 mL) was collected in sterile bottles and transported to the DLH laboratory within 24 h to ensure analytical accuracy. Data collection involved field observations, reviews of WWTP technical documentation, structured interviews with operators, and laboratory analyses for each parameter. The interviews assessed the operators' understanding of wastewater treatment procedures and identified operational challenges. The information obtained from the interviews was used to evaluate WWTP performance, particularly to identify factors contributing to treatment inefficiencies, especially in the disinfection process. All data were analyzed descriptively and quantitatively by comparing the measurement results with the quality standards specified in the relevant regulations.

Results

Performance Evaluation of WWTP at PMI Cilacap's Blood Donor Unit.

The Wastewater Treatment Plant (WWTP) at the Blood Donor Unit (UDD) of the Indonesian Red Cross (PMI) Cilacap Regency is designed to treat non-infectious domestic wastewater generated from activities such as blood collection, equipment cleaning, and laboratory operations. The system comprised the following integrated treatment units: collection tank, equalization tank, bioreactor, aeration contact, quality test pond, disinfection tank, and infiltration well. With a maximum capacity of 10 m^3 per day, the WWTP is capable of processing approximately 2.96 m^3 of wastewater daily. All structural components were constructed using durable materials and complied with the standards outlined in the Regulation of the Minister of Health No. 7/2019. Routine maintenance performed by qualified personnel includes cleaning, sludge removal, and equipment services. Although the treatment system meets technical specifications, maintaining effluent quality that consistently meets regulatory standards remains a challenge. Consequently, the routine monitoring of critical parameters (particularly chlorine residuals) is necessary to maintain treatment performance and meet regulatory requirements.

Physical Parameter Analysis Result (Table 1)

The laboratory analysis results showed that the effluent TSS concentration (18 mg/L) was below the 30 mg/L regulatory limit under Indonesian Government Regulation No.82/2001. These findings demonstrate the effective pollution control performance of the treatment system, while contributing to the protection of soil quality and surrounding ecosystems.

Chemical Parameter Analysis Results (Table 2)

Laboratory analysis of the wastewater samples confirmed full compliance of all chemical parameters with applicable environmental quality standards. The results showed that the pH level of the wastewater was 8.0, which falls within the permissible range of 6.0 to 9.0. In addition, the concentrations of BOD, COD, Total Suspended Solids (TSS), Oil and Grease, and Ammonia (NH_3) are 7 mg/L, 10 mg/L, 18 mg/L, 1.9 mg/L, and <0.01 mg/L, respectively. All these values are below the maximum thresholds set by regulations, which are 30 mg/L for BOD, 100 mg/L for COD, 30 mg/L for TSS, 5 mg/L for Oil and Grease, and 10 mg/L for ammonia (NH_3). These findings confirm that wastewater complies with the standards set forth in Government Regulation No.22/2021 on the Implementation of Environmental Protection and Management, as well as the Regulation of the Minister of Environment and Forestry No. P.68/Menlhk/Setjen/Kum.I/8/2016 on Domestic Wastewater Quality Standards (Regulation No. 68/2016 of the Ministry of Environment and Forestry).

Biological Parameter Analysis Result (Table 3)

Biological parameter analysis detected critical Total Coliform contamination (>24,000 MPN/100mL), exceeding Indonesia's regulatory limit (3,000 MPN/100mL) by 8-fold. This level indicates serious bacteriological contamination of wastewater, requiring further corrective action to ensure environmental safety and sustainability. The Total Coliform levels in wastewater were non-compliant with regulatory standards. These excessive bacterial concentrations fail to meet the legal requirements (Law No.32/2009 on Environmental Protection and Management) to maintain environmental quality and prevent water pollution.

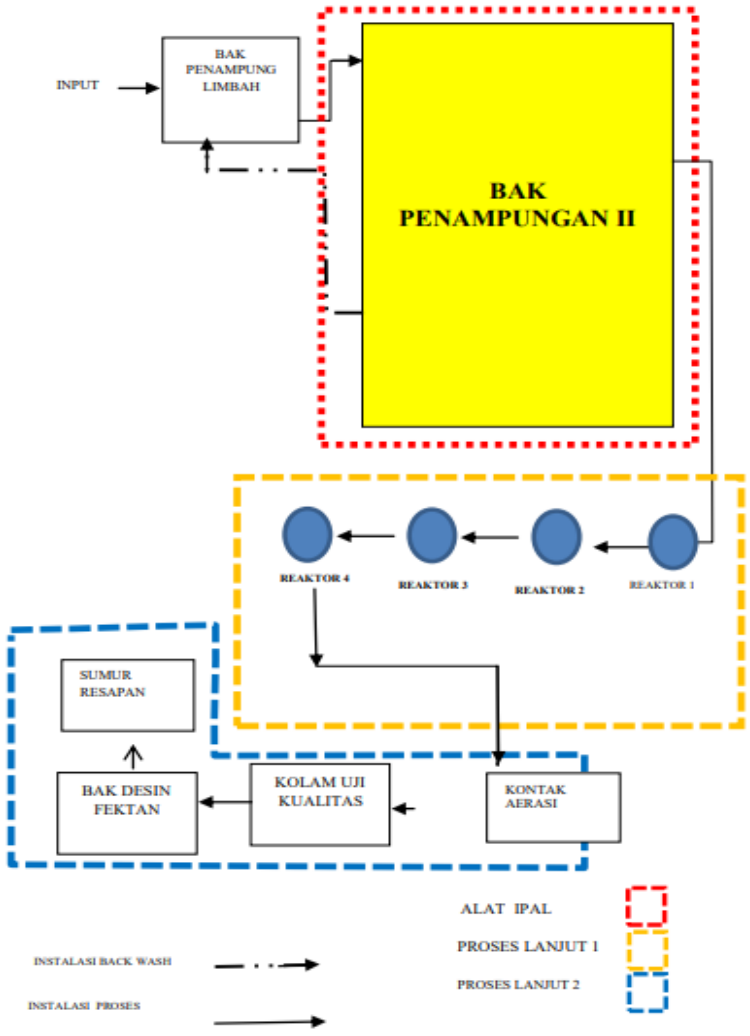

Figure 1. Flow Diagram of Wastewater Treatment Unit Operations at PMI Cilacap Regency

Figure 2. Wastewater Collection Tank and Equalization Tank

Figure 3. Bioreactor

Figure 4. Aeration Contact

Figure 5. Effluent Quality Testing Pond

Figure 6. Disinfection Tank

Figure 7. Infiltration Well

Table 1. Laboratory Test Results for Physical Parameters

No	Parameter	Unit	Quality Standard	Test Result	Remark
1	Total Suspended Solids (TSS)	mg/L	30	18	Meets the Standard

Table 2. Laboratory Test Results of Chemical Parameters

No	Parameter	Unit	Quality Standard	Test Result	Remark
1	pH	-	6.0 – 9.0	8.0	Within Standard
2	BOD (Biological Oxygen Demand)	mg/L	30	7	Within Standard
3	COD (Chemical Oxygen Demand)	mg/L	100	10	Within Standard
4	Oil and Grease	mg/L	5	1.9	Within Standard
5	Ammonia (NH_3)	mg/L	10	<0.01	Within Standard

Table 3. Laboratory Test Results of Biological Parameters

No	Parameter	Unit	Quality Standard	Test Result	Remark
1	Total Coliform	MPN/100mL	3,000	>24,000	Does Not Meet Standard

Discussion

Evaluation of WWTP Performance at UDD PMI Cilacap Regency

The operational units of the Wastewater Treatment Plant (WWTP) at the UDD PMI Cilacap Regency demonstrate the effective treatment of wastewater from facility activities. While most physical and chemical parameters comply with environmental standards, the alarmingly high total coliforms (>24,000 MPN/100 mL) indicate critical failure in disinfection processes. This level of bacteriological contamination poses significant public health risks, and threatens aquatic ecosystems if discharged untreated. These findings contradict the initial assumptions of bacterial removal efficacy and point to systemic issues, such as inadequate chlorine dosing, insufficient contact time, pipeline leaks, or suboptimal hygiene practices.

The WWTP at UDD PMI Cilacap Regency has been operated based on Standard Operating Procedures (SOP) following prevailing regulations, including Government Regulation No.22/2021 concerning the Implementation of Environmental Protection and Management, Regulation No. 68/2016 of the Minister of Environment and Forestry concerning Domestic Wastewater Quality Standards, and Minister of Health Regulation No.7/2019 concerning Environmental Health, to ensure that the operation of the WWTP runs properly and safely.

Furthermore, the consistently high Total Coliform levels suggest a systemic issue rather than an isolated one, warranting investigation into the disinfection system design and operational procedures. Key factors such as chlorine dosing accuracy, contact time, equipment maintenance, and operator training require evaluation to identify the root causes. To enhance the disinfection process, advanced technologies, such as ultraviolet (UV) radiation or ozonation, both proven effective against pathogenic microorganisms, could address these failures.

Physical Parameter Result and Analysis

The Total Suspended Solids (TSS) in the effluent measured 18 mg/L, which is well below the 30 mg/L regulatory limit (Government Regulation No.82/2001). This confirms the efficacy of sedimentation in the equalization tank and biological filtration in the bioreactor at PMI Cilacap's WWTP in reducing particulate pollution. Elevated TSS levels increase the oxygen demand for organic matter decomposition, making it essential to minimize TSS through methods such as filtration, sedimentation, or chemical flocculation.

Prior studies support these findings: [10] achieved 95% TSS removal in dairy

wastewater using dissolved air flotation, whereas [11] achieved a 99.34% reduction at a pulp and paper plant. Conversely, [12] reported non-compliant TSS levels (85–137 mg/L) in domestic wastewater, where coagulation-flocculation systems were poorly maintained.

These studies demonstrate that numerous research efforts have successfully reduced the Total Suspended Solids (TSS), albeit with varying methodologies. While some have employed innovative technologies, others have encountered challenges when applying conventional approaches. It is important to note that seasonal or operational variations could influence TSS levels and other parameters such as BOD and COD. For instance, during rainy seasons or peak facility usage, fluctuations in wastewater composition and volume may challenge the capacity of WWTPs to maintain consistent effluent quality. Incorporating contextual factors into ongoing monitoring and operational adjustments is crucial for ensuring sustained compliance. By considering seasonal and operational factors, such as heavy rainfall or surges in facility usage, WWTP managers can make dynamic operational adjustments to ensure that the quality of wastewater consistently meets environmental standards.

Chemical Parameter Result and Analysis

1. pH

The analysis results indicate that the pH of wastewater at the UDD WWTP of the Indonesian Red Cross in Cilacap Regency is 8.0, complying with the quality standard (6.0–9.0) under Regulation No.68/2016 of the Minister of Environment and Forestry. This neutral pH range suggests that wastewater is neither corrosive nor harmful to aquatic organisms, aligning with the Regulation of the Indonesian Minister of Health No.7/2019 on Hospital Environmental Health, which emphasizes proper liquid waste management to maintain environmental quality, as well as the wastewater treatment theory, where stable pH supports biological processes such as nitrification and denitrification in WWTPs. Comparable studies, such as [13] in Sukoharjo, also reported compliant domestic wastewater pH levels, while [14] identified a negative correlation between pH and outpatient numbers, a finding that was not explored here. Effective pH maintenance at the UDD WWTP demonstrates efficient wastewater treatment, reducing the risk of environmental pollution.

2. Biological Oxygen Demand (BOD)

The wastewater BOD level at the UDD PMI Cilacap WWTP was 7 mg/L, which is well below the national standard (30 mg/L) (Regulation No. 68/2016 of the Minister of Environment and Forestry), indicating minimal organic pollutants that could degrade water quality. This low BOD aligns with Indonesia's Water Quality Management Regulation (Government Regulation No. 82/2001), which mandates organic load control and reflects efficient biological treatment processes in which microorganisms effectively decompose organic matter [15]. In contrast to studies reporting elevated BOD in polluted rivers, which were conducted by [16], we observed ecosystem disruption in the Pesanggrahan River due to high organic loads. This study highlights the efficacy of WWTPs in reducing BOD through optimized treatment. These findings underscore the role of the facility in sustainable wastewater management, ensuring compliance with environmental standards, while mitigating aquatic ecosystem risks.

3. Chemical Oxygen Demand (COD)

The wastewater COD concentration of 10 mg/L at the UDD PMI Cilacap WWTP was significantly below the regulatory threshold (100 mg/L) under Regulation No. 68/2016 of the Minister of Environment and Forestry, demonstrating the effective removal of oxidizable organic and inorganic compounds. This compliance aligns with Law No.32/2009 on Environmental Protection and Management, which mandates pollution control in wastewater discharge and reflects well-optimized chemical oxidation processes during treatment. Comparable results have been reported by [17] for PT. X's WWTP, although employing different treatment technologies, suggests that multiple approaches can successfully

achieve COD reduction. The performance of the WWTP confirms its operational efficiency in meeting demanding effluent standards while minimizing environmental impacts, supporting its role as a model for domestic wastewater management in healthcare facilities.

4. Oil and Grease

The measured oil and grease concentrations in the wastewater were 1.9 mg/L, significantly below the 5 mg/L standard limit set by Regulation No. 68/2016 of the Ministry of Environment and Forestry on Domestic Wastewater Quality Standards. This finding indicates that the WWTP at the UDD PMI Cilacap effectively removes these persistent organic compounds, which could otherwise interfere with treatment processes and cause environmental pollution. The removal efficiency can be attributed to the physical and biological mechanisms of the WWTP that separate and degrade these compounds, producing effluents that meet environmental standards and support aquatic ecosystem preservation.

Supporting evidence comes from [18], who demonstrated that grease traps and rubber sawdust biochar filters can achieve 99.99% oil and grease removal. While employing different technologies, both studies confirmed that physical separation and adsorption processes effectively eliminate these contaminants from domestic wastewater. This consistency in results, despite methodological differences, enriches the available technological options for sustainable domestic wastewater management, allowing local adaptation while maintaining treatment efficacy.

5. Ammonia (NH_3)

The ammonia concentration was <0.01 mg/L, far below the 10 mg/L maximum limit under Government Regulation No.22/2021 on Environmental Protection and Management. These results confirm the effectiveness of WWTPs in reducing this toxic nitrogen compound, effectively minimizing its potential ecological impacts. A low concentration indicates successful nitrogen pollution control, which is crucial for preventing water quality degradation and maintaining environmental sustainability through eutrophication and toxicity prevention.

These findings align with the [19] study of restaurant wastewater in Ajibarang, Purwokerto, which similarly met quality standards. Both studies demonstrated that proper domestic wastewater treatment can consistently maintain safe ammonia levels across different local contexts despite variations in waste sources and treatment scales. This supports the implementation of sustainable water resource management principles under Indonesian Law No.17/2019.

Biological Parameter Result and Analysis

The measurement of total coliforms in wastewater samples at UDD PMI Cilacap Regency revealed a concentration exceeding 24,000 MPN/100 mL, far surpassing the permissible limit set by the Indonesian Ministry of Health Regulation No.2/2023 (standard: 0 MPN/100 mL). This finding directly contradicts the initial hypothesis that a local Wastewater Treatment Plant (WWTP) effectively eliminates indicator bacteria. The exceptionally high Total Coliform levels suggest significant fecal contamination and the potential presence of harmful pathogens, which pose substantial risks to public health and aquatic ecosystem degradation. The suboptimal performance of WWTPs likely results from inadequate system design, inconsistent maintenance, or insufficient treatment capacity relative to the incoming wastewater load.

Theoretically, the reduction of total coliforms requires an advanced treatment process, particularly disinfection processes, such as chlorination or ultraviolet (UV) radiation, which are effective in killing pathogenic microorganisms. The persistence of microbial contamination in WWTP effluent, as demonstrated by [20] in their study at Universitas Islam, Indonesia, directly correlates with current suboptimal disinfection practices, where high levels of total coliforms indicated limitations in the wastewater treatment system's ability to remove indicator bacteria. This similarity in findings underscores that without proper management and adequate disinfection

technology, the risk of microbiological contamination remains high, even in different geographical contexts and wastewater sources.

Given these systemic challenges, a comprehensive evaluation of WWTP design and operations at the UDD PMI Cilacap Regency is urgently required. Critical improvements should include the addition of standardized disinfection units, increased treatment capacity, and intensive training of wastewater treatment operators. These measures are essential not only to reduce Total Coliform concentrations to safe levels, but also to comply with Law No.32/2009 concerning Environmental Protection and Management, which mandates sustainable and environmentally friendly waste management. The implementation of these steps would significantly strengthen the domestic wastewater treatment system, ensuring both public health protection and sustainable preservation of aquatic ecosystems.

To achieve these improvements, an integrated approach must address several key issues. First, disinfection optimization should be carried out by evaluating the existing system, optimizing the chlorine dosage, and considering the use of UV or ozonation disinfection technologies for greater effectiveness. In addition, the filtration system must be evaluated and, if necessary, replaced with more effective media, along with the addition of filtration stages, to enhance efficiency. Tracing contamination sources is also crucial, including pipeline inspections to detect leaks, use of tracer techniques, and assessments of sanitation practices around the WWTP. Regular water quality monitoring and a planned maintenance program must be implemented to ensure that all WWTP components function properly. Finally, enhancing the capacity of operators through comprehensive training and continuous learning initiatives is vital to ensuring that they possess the necessary knowledge and skills.

It is important to discuss in greater depth the environmental and public health risks posed by high levels of Total Coliform. The potential contamination of surrounding water bodies and its impact on the health of the local community should be emphasized as a primary reason for the need for improvements in wastewater treatment systems. This will increase the urgency and support of strategic measures for managing domestic wastewater in healthcare facilities.

Conclusion

The Wastewater Treatment Plant (WWTP) at the Blood Donor Unit (UDD PMI) in the Cilacap Regency complies with infrastructure standards (Minister of Health Regulation No. 7/2019), featuring all essential operational units, including an equilization tank, reactor, aeration contact system, and disinfection tank. However, while physical parameters (TSS: 18 mg/L) and chemical parameters (pH, BOD, COD, oil and grease, NH_3) met regulatory limits (Government Regulation No. 22/202; Ministry of Environment and Forestry Regulation No. 68/2016), the disinfection process exhibited critical inefficiency.

The most significant concern was the biological parameters, with total coliforms (>24,000 MPN/100 mL) far exceeding the permissible limit (3,000 MPN/100 mL), indicating severe microbiological contamination. These findings indicate that although the WWTP system is equipped with standard operational units, the disinfection process remains ineffective and consequently requires comprehensive improvement. Specifically, immediate upgrades to disinfection systems, enhanced operator training, and advanced treatment technologies are needed to ensure compliant effluent and prevent environmental health risks.

Furthermore, the study highlights the broader implications for public health and environmental sustainability, especially in regions with dense industrial and coastal activities, such as Cilacap. Strengthening disinfection performance is not only critical for institutional compliance but is also essential to prevent long-term ecological damage and waterborne disease outbreaks (e.g., cholera). These findings may inform local policy development and serve as a reference for improving liquid waste management in healthcare facilities in Indonesia. In addition, this study

contributes to environmental science education by providing real-world data on the performance and challenges of hospital-based wastewater treatment systems. These findings can be utilized in academic settings to support learning on wastewater treatment technologies, public health risk assessment, and environmental policy implementation.

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Author Contribution

Author 1 served as the principal investigator responsible for the overall research process, including problem formulation, research design, data analysis, and final manuscript preparation. Author 2 contributed significantly to the field data collection, laboratory testing, and quantitative data processing. Author 3 was involved in the literature review, theoretical and regulatory analyses, and final editing of the manuscript to ensure academic rigor and adherence to scientific writing standards. All the authors have read and approved the final version of the manuscript.

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