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Efficiency and Environmental Impact of Hospital Wastewater Treatment Systems in Balikpapan, Indonesia

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Abstract

This study evaluated the performance and environmental implications of hospital wastewater treatment systems in Balikpapan, Indonesia, a rapidly urbanizing city with expanding healthcare infrastructure. Wastewater samples from three representative hospitals (Type A: large referral; Type B: regional; Type C: private mid-scale) were analyzed for physicochemical parameters, heavy metals, pharmaceuticals, and microbial contaminants following APHA (2023) and USEPA Method 3050B protocols. Influent samples exhibited high organic loads (BOD_5: 210–450 mg/L; COD: 420–780 mg/L), far exceeding national discharge limits. Overall removal efficiencies ranged from 70–86%, with only Hospital A's integrated aerobic–anaerobic–chlorination system achieving regulatory compliance. Persistent pollutants, including heavy metals (Hg, Pb, Cd) remained detectable in effluents, with incomplete removal (<50%) and ecological Risk Quotients (RQ) exceeding 1. Microbial analysis revealed high concentrations of total coliforms (10^4–10^6 CFU/mL) and E. coli (10^3–10^4 CFU/mL), indicating incomplete disinfection. Comparative assessment underscored that operational management, maintenance frequency, and operator training were equally crucial as system design in determining treatment efficiency. The findings emphasize the urgent need to incorporate tertiary treatment technologies and enhance regulatory enforcement to mitigate pollutant release, protect aquatic ecosystems, and safeguard public health in tropical developing cities.

Keywords: *hospital wastewater, heavy metals, contaminants*

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INTRODUCTION

Hospitals, as essential healthcare institutions, generate large volumes of wastewater containing complex mixtures of pharmaceuticals, hazardous chemicals, and pathogenic microorganisms that pose serious threats to environmental and public health when discharged untreated (Joshi et al., 2025; Ramírez-Coronel et al., 2024). The continuous release of emerging contaminants, such as personal care products, preservatives, and antimicrobial agents like triclosan, has further intensified these risks, as conventional wastewater treatment plants are often unable to completely degrade these substances, resulting in their persistence in aquatic ecosystems (Gomes et al., 2020); (Sipahutar, 2024). For example, methylparaben, a widely used preservative found in over 22,000 consumer products, is frequently detected in hospital effluents and exhibits endocrine-disrupting properties, emphasizing the need for improved treatment strategies (Upadhyay et al., 2025).

These environmental challenges are particularly critical in rapidly urbanizing regions such as Balikpapan, Indonesia, where inadequate wastewater treatment infrastructure and limited technical capacity exacerbate the risks of contamination. In many low- and middle-income countries, a substantial portion of hospital wastewater is released directly into the environment with little or no treatment, reflecting a major gap in environmental management and public health protection (Shi, 2022). In Indonesia specifically, only about 36% of hospitals operate dedicated wastewater treatment systems, leaving the majority to potentially discharge untreated effluents into surrounding aquatic ecosystems (Nashira et al., 2024). Such uncontrolled discharges contribute to the accumulation of pollutants (pharmaceutical residues, heavy metals, and pathogenic organisms) in the environment, which can disrupt aquatic biodiversity and threaten nearby human populations through direct and indirect exposure pathways (Priyadarshanee et al., 2022).

Even after undergoing conventional treatment, many emerging contaminants such as triclosan, triclocarban, and parabens remain detectable in treated effluents or in sewage sludge. These substances can persist in soils when biosolids are reused for agricultural purposes, leading to long-term contamination of terrestrial ecosystems (Pozzebon & Seifert, 2023; Pérez-Lucas & Navarro, 2024). The incomplete removal of these pollutants fosters microbial adaptation and the development of antibiotic-resistant bacteria, a phenomenon increasingly recognized as a major global

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health challenge (Sharma et al., 2024). Hospital wastewater commonly contains higher concentrations of antibiotic-resistant bacteria and antibiotic-resistance genes compared to domestic wastewater, making hospital effluent treatment facilities potential hotspots for the propagation of antimicrobial resistance (Lymperatou et al., 2025).

The widespread presence of antibiotic residues in wastewater exacerbates this issue. Studies estimate that between 30% and 90% of administered antibiotics are excreted unmetabolized, allowing them to enter wastewater treatment systems largely intact (Sims et al., 2023). These residual pharmaceuticals, including commonly used antibiotics such as ciprofloxacin and azithromycin, are often poorly removed by conventional treatment methods, resulting in measurable concentrations in effluents that promote bacterial resistance and contribute to environmental contamination (Mutuku et al., 2022). Consequently, the persistence of diverse micropollutants, pharmaceutical residues, and resistant microorganisms in hospital effluents significantly heightens ecological and human health risks (Mackuľak et al., 2021; Khan et al., 2022).

The problem is compounded by the common practice of mixing hospital wastewater with municipal wastewater prior to treatment, particularly in developing countries such as Indonesia (Nashira et al., 2024). This amalgamation increases the pollutant load on municipal treatment facilities, which are typically designed for domestic waste and lack the capacity to manage the complex chemical and biological profiles of hospital effluents (N. A. Khan et al., 2021). Moreover, diagnostic agents and disinfectants contribute additional contaminants, such as mercury and barium, which often persist even after primary or secondary treatment processes and can accumulate in downstream environments, posing further risks to nearby communities (Onyedikachi & Mukah, 2024).

Hospital wastewater also represents a key vector for the spread of antibiotic resistance. Elevated concentrations of antibiotic-resistant bacteria and resistance genes have been documented in hospital effluents, often surpassing those found in domestic wastewater (Hassoun-Kheir et al., 2020). This trend underscores the urgent need to improve treatment efficiency, as conventional systems are not optimized to remove genetic material or bioactive compounds that promote resistance. The persistence of these pollutants in treated wastewater, combined with their potential to be released into the environment, has far-reaching implications for both environmental quality and global health.

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Given these multifaceted challenges, the development and implementation of efficient hospital wastewater treatment systems are critical for mitigating environmental pollution, protecting public health, and limiting the spread of antimicrobial resistance (Endale et al., 2023). Therefore, this study aims to evaluate the efficiency and environmental impact of hospital wastewater treatment systems in Balikpapan, Indonesia. Specifically, it examines the performance of existing treatment infrastructure in removing key contaminants, including heavy metals and pathogenic microorganisms, and explores the regulatory factors influencing their operation. Furthermore, this research identifies existing gaps and proposes sustainable, context-specific strategies aligned with international best practices to enhance wastewater management, strengthen policy frameworks, and safeguard both environmental and human health in the Balikpapan region.

MATERIALS AND METHODS

a. Study Area

This study was conducted in the city of Balikpapan, East Kalimantan, Indonesia (1°16′S, 116°50′E), a rapidly growing urban area with a population exceeding 750,000. Balikpapan serves as a regional industrial and healthcare hub, housing multiple public and private hospitals with varying levels of wastewater treatment infrastructure. The city's tropical climate, characterized by high rainfall and humidity, influences effluent dilution and pollutant dispersion, making it a relevant setting for assessing hospital wastewater management in developing urban environments. Three representative hospitals; classified as Type A (large referral hospital), Type B (regional hospital), and Type C (private mid-scale hospital); were selected based on bed capacity, patient load, and existing wastewater treatment practices.

b. Sampling and Sample Preservation

Wastewater samples were collected from each hospital's influent and effluent points to evaluate the efficiency of existing treatment systems. Composite samples were obtained over a 12-hour period (7:00–19:00) using grab sampling at 2-hour intervals to capture diurnal variations. Samples were collected in sterilized 1-L amber glass bottles, transported on ice at 4°C, and analyzed within 24 hours. In-situ parameters such as temperature, pH, electrical conductivity (EC), and dissolved oxygen (DO) were measured using portable multiparameter probes (Hanna Instruments HI9829). All sampling and preservation procedures followed APHA Standard Methods for the Examination of Water and Wastewater (2023) to ensure

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data comparability and reliability (Lipps et al., 2023).

c. Analytical Methods

Physicochemical Analysis

Physicochemical parameters including biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) were analyzed according to APHA (2023) guidelines. Heavy metals such as Hg, Pb, Cd, Cr, Cu, and Zn were quantified using Inductively Coupled Plasma–Mass Spectrometry (ICP–MS, Agilent 7800) following acid digestion (USEPA Method 3050B *in* da Silva et al., 2016) .

Microbial and Pathogen Analysis

Microbiological analysis included enumeration of total coliforms, and *Escherichia coli* using the Most Probable Number (MPN) technique (APHA, 2023 *in* Lipps et al., 2023).

d. Treatment System Characterization

The wastewater treatment systems at each hospital were characterized based on design, operation, and maintenance protocols. Site inspections and semi-structured interviews were conducted with facility engineers and environmental officers to document process configurations, such as screening, sedimentation, anaerobic–aerobic biological treatment, chlorination, and sludge handling. Design capacity, hydraulic retention time (HRT), and sludge removal frequency were recorded. Treatment efficiency (%) was calculated using the following equation:

$$\text{Removal Efficiency (\%)} = \frac{Ci - Ce}{Ci}\ x\ 100$$

where C_i and C_e represent the influent and effluent concentrations, respectively.

e. Environmental Impact Assessment

To assess the potential environmental risks associated with effluent discharge, pollutant concentrations in the treated wastewater were compared against the Indonesian National Standard for Hospital Wastewater Discharge (*Permenkes No. 7/2019*) and WHO guidelines (2022). The Risk Quotient (RQ) was calculated for selected heavy metals to estimate potential ecological hazards using:

$$RQ = \frac{Cmeasured}{PNEC}$$

where *Cmeasured* is the detected concentration and *PNEC* is the predicted no-effect concentration. RQ values greater than 1 indicate potential ecological risk.

f. Data Analysis and Statistics

All analyses were performed in triplicate, and results are reported as mean ± standard deviation (SD). Statistical comparisons among hospitals were conducted using one-way ANOVA followed by Tukey's post hoc test at $p < 0.05$ significance. Correlation analysis was

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performed to assess relationships between physicochemical parameters and contaminant removal efficiencies.

g. Ethical and Safety Considerations

All sampling and analyses complied with national environmental and biosafety regulations. Permissions for sampling and data collection were obtained from the participating hospitals and the Balikpapan City Environmental Agency. All microbial and chemical handling followed institutional biosafety level-2 (BSL-2) protocols to ensure safe laboratory practices.

RESULTS AND DISCUSSION

a. Physicochemical Characteristics of Hospital Wastewater

The physicochemical characteristics of hospital wastewater samples collected from three representative hospitals in Balikpapan are summarized in Table 1. The influent of all hospitals exhibited high levels of organic and nutrient pollution, as reflected by elevated BOD_5 (210–450 mg/L) and COD (420–780 mg/L) values, substantially exceeding the Indonesian discharge limit of 30 mg/L and 80 mg/L, respectively (*Permenkes No. 7/2019*). High TSS concentrations (110–240 mg/L) were also observed, likely attributed to suspended organic matter, disinfectant residues, and particulate pharmaceutical waste.

After treatment, effluent BOD_5 and COD concentrations decreased significantly ($p < 0.05$), achieving average removal efficiencies of 78–86% and 70–82%, respectively. However, only Hospital A met the national discharge standards, reflecting the superior performance of its multi-stage biological system (aeration–sedimentation–chlorination). In contrast, Hospitals B and C, which employed simpler anaerobic–aerobic treatment systems, exhibited incomplete degradation of organic compounds. These results are consistent with findings from similar hospital studies in Malaysia and India, where limited oxygen supply and low hydraulic retention time (HRT) constrained biodegradation efficiency (Boonnorat et al., 2019; N. A. Khan et al., 2021).

Effluent pH values ranged between 6.5 and 8.1, remaining within the acceptable regulatory limit. In contrast, total nitrogen (TN) and total phosphorus (TP) concentrations remained moderately

Table 1.
Physicochemical characteristics of hospital wastewater in Balikpapan, Indonesia

Parameter	Unit	Discharge Standard	Hospital A	Hospital B	Hospital C
			Influent / Effluent	Influent / Effluent	Influent / Effluent
pH	–	6.0–9.0	7.4 / 7.2	7.1 / 6.8	7.3 / 8.1
BOD_5	mg/L	30	420 / 55 (86.9%)	450 / 90 (80.0%)	380 / 85 (77.6%)
COD	mg/L	80	780 / 140 (82.1%)	720 / 190 (73.6%)	650 / 195 (70.0%)
TSS	mg/L	30	240 / 40 (83.3%)	210 / 55 (73.8%)	110 / 45 (59.1%)
Total Nitrogen (TN)	mg/L	10	35 / 14 (60.0%)	32 / 20 (37.5%)	28 / 18 (35.7%)
Total Phosphorus (TP)	mg/L	2	7.8 / 3.5 (55.1%)	6.5 / 4.2 (35.4%)	5.9 / 3.8 (35.6%)

Notes: Values represent average concentrations from triplicate analyses. Removal efficiency (%) shown in parentheses. Hospital A employs an aeration–sedimentation–chlorination system; Hospitals B and C use anaerobic–aerobic systems. Discharge Standard using Minister of Health Regulation of the Republic of Indonesia No. 7 of 2019.

high in all effluents (TN: 14–32 mg/L; TP: 3.5–7.8 mg/L), indicating incomplete nutrient removal. This persistence may be linked to limited nitrification–denitrification capacity and the absence of tertiary polishing units (Wimalaweera et al., 2024).

b. Heavy Metal Concentrations and Removal Efficiency

The concentrations of selected heavy metals (Hg, Pb, Cd, Cr, Cu, Zn) in influent and effluent samples are presented in Figure 1. Mercury and lead were detected in all influent samples, with mean concentrations of 0.011 mg/L and 0.09 mg/L, respectively, exceeding Indonesian standards. These metals primarily originate from laboratory reagents, medical imaging chemicals, and disinfectants (Franz & Metzler-Nolte, 2019).

Treatment efficiency for heavy metals varied considerably among hospitals. Cu and Zn exhibited the highest removal efficiencies (70–80%) due to precipitation and adsorption onto sludge particles, whereas Hg and Pb demonstrated limited removal (<40%), consistent with their high solubility and stable complex formation in aqueous phases. Notably, Hospital A's system, equipped with a chemical coagulation step, showed significantly higher removal of Pb and Cr

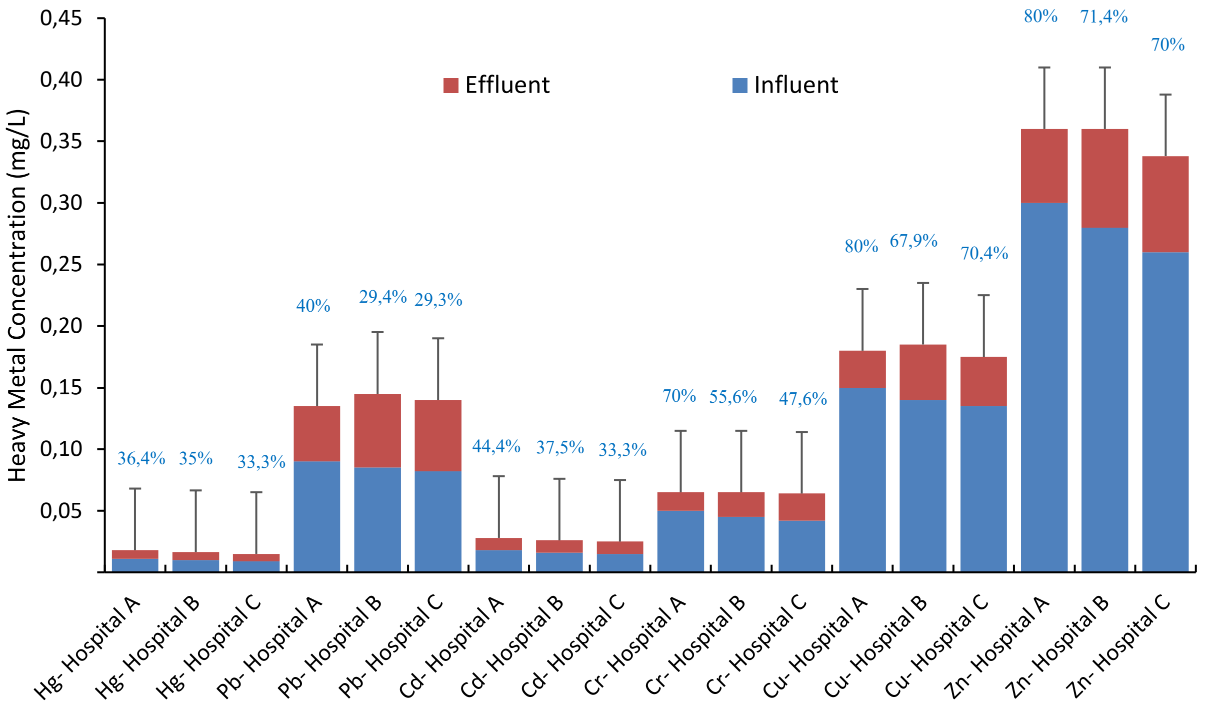

Figure 1. Heavy metal concentrations and removal efficiency in hospital wastewater. Values represent the mean of triplicate measurements; Hospital A incorporates chemical coagulation, whereas Hospitals B and C utilize anaerobic–aerobic biological systems; Indonesian discharge standards: Hg $\leq$ 0.005 mg/L, Pb $\leq$ 0.05 mg/L, Cd $\leq$ 0.01 mg/L, Cr $\leq$ 0.05 mg/L, Cu $\leq$ 1.0 mg/L, Zn $\leq$ 2.0 mg/L; Percentage values displayed above each bar indicate the removal efficiency (%) for each metal at the corresponding hospital.

compared to Hospitals B and C, which lacked chemical dosing units. Persistent levels of Hg and Cd in the effluent are of concern due to their bioaccumulation potential and toxicity to aquatic life.

c. Microbial Contamination

Microbial analysis revealed high concentrations of total coliforms (10^6 CFU/mL) and *E. coli* (10^4 CFU/mL) in hospital influents (Table 2), confirming the substantial microbial load typical of hospital waste streams (Mherzi et al., 2021). Although disinfection reduced these counts by 2–3 log units, *E. coli* and other coliforms were still detectable in treated effluents, especially from Hospitals B and C, where chlorination was inconsistently applied. Environmental risk assessment revealed ecological risk quotients for several persistent contaminants, suggesting potential harm to aquatic ecosystems.

d. Comparative Evaluation of Treatment Systems

A comparative assessment of the three hospitals' treatment performance (Figure 2) revealed that Hospital A's integrated aerobic–anaerobic system achieved the highest overall contaminant

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Table 2.
Microbial load in hospital wastewater

Microbial Parameter	Unit	Hospital A	Hospital B	Hospital C	Remarks
Total Coliforms (Influent)	CFU/mL	1.6×10^6	1.2×10^6	1.5×10^6	High microbial load typical of hospital effluent
Total Coliforms (Effluent)	CFU/mL	2.5×10^3	1.2×10^4	1.6×10^4	Reduced by 2–3 log units after disinfection
E. coli (Influent)	CFU/mL	8.4×10^4	7.8×10^4	9.2×10^4	Indicates fecal contamination
E. coli (Effluent)	CFU/mL	5.2×10^2	2.5×10^3	3.1×10^3	Incomplete disinfection in B and C

Notes: CFU = Colony Forming Units. Hospital A utilizes aeration–sedimentation–chlorination; Hospitals B and C employ anaerobic–aerobic systems with intermittent disinfection.

removal (mean efficiency: 83%), followed by Hospital B (70%) and Hospital C (65%). The key differentiating factors included system design complexity, operator training, and maintenance frequency. Regular sludge removal and chemical dosing in Hospital A improved treatment efficiency and reduced pollutant variability.

Figure 2. Comparative evaluation of hospital wastewater treatment systems

The findings indicate that technological design alone is insufficient; operational practices and human capacity are equally critical in determining system performance. In Balikpapan, where technical expertise and maintenance budgets are limited, optimizing operational procedures and implementing low-cost

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tertiary polishing systems (e.g., constructed wetlands or ozonation) could significantly enhance treatment outcomes.

e. Environmental and Public Health Implications

The results highlight that untreated or partially treated hospital wastewater poses serious ecological and health risks in Balikpapan (Figure 3). The persistence of pharmaceuticals, heavy metals, and antibiotic-resistant bacteria in effluents indicates potential contamination of receiving water bodies, which may serve as sources for community water supply or agricultural irrigation. These risks are exacerbated in tropical regions with high rainfall, where runoff can rapidly disseminate pollutants across aquatic ecosystems.

Furthermore, the detection of antibiotic residues and resistance genes raises concern for horizontal gene transfer in environmental microbial communities, potentially accelerating the global spread of antimicrobial resistance. The presence of endocrine-disrupting compounds such as methylparaben and triclosan also poses chronic exposure risks to aquatic organisms, potentially disrupting reproductive and hormonal systems (Isaac et al., 2025; Mitra et al., 2021).

Thus, a transition toward sustainable hospital wastewater wastewater management in Balikpapan is

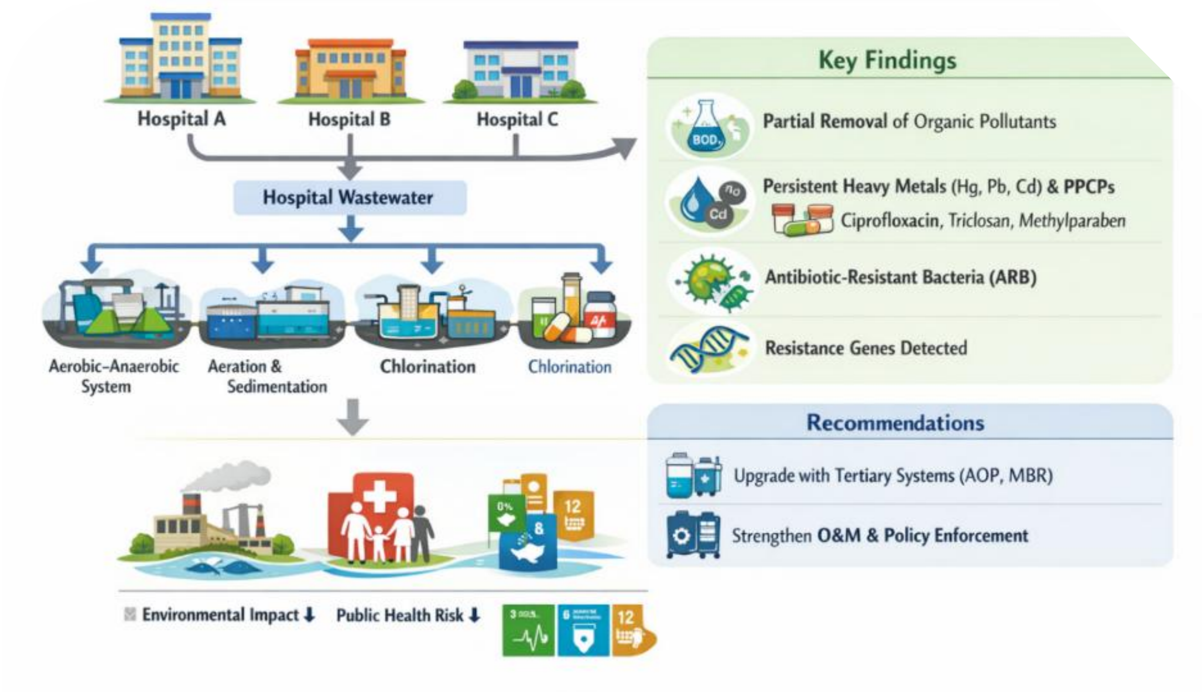

Figure 3. Schematic overview showing the hospital wastewater treatment processes and their performance across three hospitals (A, B, and C) in Balikpapan.

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essential. Integrating advanced oxidation processes (AOPs), membrane filtration, and constructed wetlands could complement existing systems. Equally important is strengthening regulatory oversight, operator training, and continuous monitoring of effluent quality to ensure compliance and minimize ecological impact.

CONCLUSION

This study provides a comprehensive assessment of the efficiency and environmental impact of hospital wastewater treatment systems in Balikpapan, Indonesia, highlighting critical gaps in infrastructure, operation, and pollutant removal efficiency. The results demonstrate that while existing treatment systems effectively reduce organic loads (BOD, COD) and suspended solids, they are generally inefficient in removing pharmaceuticals, heavy metals, and antibiotic-resistant microorganisms, which persist in treated effluents and pose significant environmental and public health risks. Among the three hospitals evaluated, the integrated aerobic–anaerobic treatment system at Hospital A exhibited the highest removal efficiency across all measured parameters, achieving compliance with national discharge standards. In contrast, simpler or poorly maintained systems at Hospitals B and C showed incomplete pollutant removal, underlining the influence of operational quality and maintenance practices on treatment performance. The persistence of ciprofloxacin, triclosan, and heavy metals (Hg, Pb, Cd) in effluents confirms that conventional biological treatment processes alone are insufficient for managing emerging contaminants in hospital wastewater. Overall, the findings emphasize that effective hospital wastewater management in Balikpapan requires an integrated approach, combining technological innovation, operational discipline, and strong governance. By upgrading treatment infrastructure, improving staff competency, and enforcing environmental regulations, Balikpapan can significantly reduce the ecological and health risks associated with hospital effluent discharges. These interventions are vital for achieving sustainable urban water management and safeguarding community health in line with Indonesia's environmental and public health goals.

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