Hospital Wastewater Treatment Efficiency and Pharmaceutical Residues Risk Mitigation: An Analysis of Environmental Regulatory Compliance

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Abstract.
Research Objective: The objective of the study is to investigate the management practices of hospital waste water, identify the associated risks and evaluate the applied treatment technologies to enable compliance with environmental regulatory criteria. Hospital wastewater is characterized by complex properties, including organic materials, microorganisms, medicinal chemicals and pharmaceutical residues that may cause significant detrimental effects on human health and the environment if not properly treated.
Research Method: The study was carried out with a descriptive-analytical approach by direct observation and document evaluation of the hospital wastewater treatment plant (WWTP) management.
Research Results: The study found that wastewater management still has challenges in operational consistency, equipment maintenance, and effluent quality monitoring. The main risks mentioned are failure of treatment procedure, biological exposure for operators and probable contamination of receiving water bodies. The treatment technologies used are mainly based on physical, biological and chemical processes and the operational success is strongly impacted by budget availability, installation capacity, operator competence and maintenance quality.
Conclusion: The effective management of hospital wastewater demands an integrated approach encompassing technical, administrative and risk control issues for operational sustainability and the protection of environmental health.
Research Contribution: This study is a guide for environmental health practitioners in hospital settings to evaluate and regulatory reference for policy makers.

Keywords: First Keyword, Second Keyword, Third Keyword. Hospital wastewater, risk assessment, treatment processes, environmental compliance

1 Introduction

Hospitals are important health care institutions that create liquid effluents with highly complicated matrices. In addition to the typical domestic pollutant parameters of high organic load hospital wastewater contains pathogenic microorganisms, dangerous

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medical chemicals and emerging pharmaceutical residues, especially Active Pharmaceutical Ingredients (APIs) like antibiotics and residual medicines. The direct disposal of these effluents into the environment without proper control considerably raises the potential for detrimental impacts on human health and serious ecological deterioration in the receiving aquatic ecosystems [1].

The main problem in the treatment of hospital wastewater is the presence of pharmaceutical residues, bacteria, isotopes and other dangerous compounds which can cause environmental contamination and represent a considerable health concern [2][3]). Most of these pharmaceuticals are derived from patient excretions (urine and feces) in the form of incompletely metabolized medications, which then enter the sewage system and pose a contamination risk to receiving water bodies [4][5].

Current research on hospital wastewater predominantly focuses on a limited spectrum of pharmaceutical compounds primarily antibiotics and anti-inflammatory drugs as well as their behavior and transformation mechanisms within wastewater management systems and the broader environment [5][6][7][8]. Consequently, strict adherence to environmental regulations is imperative for all healthcare facilities.

In the Indonesian setting, the Ministry of Environment and Forestry Regulation No. rigorously regulates the effluent quality criteria for domestic wastewater and healthcare facilities. 2016. P.68 [9]. This regulatory framework sets maximum allowable limits for essential parameters as pH, BOD, COD, Ammonia, TSS and Total Coliform. Moreover, the government has passed the Ministry of Environment Regulation No. 11 of 2025 [10] to enable a more responsive environmental monitoring framework. This revision of the directive emphasizes risk-based management, continued reliable operation of treatment works, and robust protection of receiving waters.

These legislative frameworks exist, but their practical execution still faces technical and managerial obstacles. Traditional wastewater treatment plants (WWTPs) generally ignore such problems as operational inconsistency, limited installation capacity and the cumulative effects of pharmaceutical residues, therefore seriously threatening systemic failures in medical waste treatment. Given this urgency, the aim of this study is to assess the effluent quality of four hospitals in the Greater Jakarta (Jakarta, Bogor, Tangerang) area, to identify the emerging operational risks and biological contamination, and to analyze their compliance with the regulatory framework set by the Ministry of Environment and Forestry (MoEF) Regulation P.68/2016 and the Ministry of Environment (MoE) Regulation 11/2025.

Materials and Methods

In this study, a descriptive-analytical approach was used to examine hospital wastewater management practices, treatment performance, operational hazards, and regulatory compliance. The study was performed in four hospitals in the Greater Jakarta Metropolitan Area (Jakarta, Bogor, and Tangerang), Indonesia in 2024. The selected hospitals were of diverse classes and geographical locations to ensure a wider representation of hospital wastewater management practices in urban healthcare institutions.

Participating hospitals were: (i) Hospital PR (Type B, Jakarta) observed during January-

June and October 2024; (ii) Hospital BN (Type C, Bogor) was tracked in January-October 2024; (iii) Hospital CI (Type B, Bogor) was monitored in September 2024; and (iv) Hospital XY (Type B, Tangerang) was monitored in July-September 2024.

Data were acquired by direct field observations of the operation of wastewater treatment plants (WWTPs) and detailed analysis of documents on environmental management. Secondary data included routine self-monitoring reports and laboratory analytical findings from external accredited laboratories with ISO/IEC 17025 certification and accredited by the Indonesian National Accreditation Committee (KAN). The document review covered wastewater treatment system performance, operational records, maintenance operations, monitoring frequency and compliance paperwork.

The wastewater quality data comprised important physicochemical and microbiological parameters, which are most often utilized for the evaluation of hospital effluents notably pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia (NH 3-N) and total coliform. These parameters were chosen because they are the main regulatory indicators for assessing hospital wastewater quality and treatment efficiency.

The data were tallied and analyzed using descriptive and comparative methods. The quality parameters of wastewater that were measured were compared to the effluent quality criteria regulated by Indonesian Ministry of Environment and Forestry Regulation No. P.68/2016 to evaluate the degree of compliance with the regulations.

Moreover, a qualitative environmental risk assessment was carried out based on the criteria set forth in the Ministry of Environment Regulation No. 11/2025. The assessment considered probable operational failures, risks of biological exposure to WWTP workers and possibilities for environmental pollution from improperly treated wastewater discharges. Further support to risk identification was provided by field observations of treatment processes, operational management practices, equipment maintenance and monitoring systems. The analytical results were then used to evaluate the effectiveness of existing wastewater treatment technologies and to identify key parameters affecting treatment performance and environmental compliance.

2. Results and Discussion

In this phase, wastewater quality parameters are evaluated and a qualitative environmental risk assessment is conducted utilizing descriptive and comparative analytical methodologies. The measured wastewater quality parameters were compared with the effluent criteria of Indonesian Ministry of Environment and Forestry Regulation No. P.68/2016 to establish regulatory compliance. Additionally, potential operational hazards, biological exposure risks to WWTP operators and environmental pollution from wastewater discharges were evaluated in accordance with the Ministry of Environment Regulation No. 11/2025, supplemented by field observations. This integration enabled a comprehensive assessment of the performance of existing wastewater treatment systems and the key factors determining treatment performance and regulatory compliance.

Results

The quality of final effluent before discharge into the receiving water bodies based on the secondary monitoring datasets and empirical field data obtained from the four designated hospitals are provided in Table 1:

Table 1. Field Data Results of Hospital Wastewater Effluent Quality

Hospital	*Type*	*Location*	*River (Class)*	*COD*	*BOD*	*Ammonia*	*pH*	*Total Coliform*	*Period*
Hospital PR	B	Jakarta	Ciliwung (2)	29.5	9.5	4.6	7.4	66.7	January–June, and October 2024
Hospital BN	C	Bogor	Cibuluh (2)	38.1	12.2	1.5	6.9	340	January–October 2024
Hospital CI	B	Bogor	Ciliwung (2)	21.2	4.5	6.7	8.5	2100	September 2024
Hospital XY	B	Tangerang	Pesanggrahan (2)	48.9	13.1	0.1	6.4	1000	July–September 2024

Source: Processed by researchers, 2024
Note: Concentration comparison is based on the MoEF Regulation No. P.68 of 2016.

Table 2 Reference of Effluent Quality Standards

Monitoring Parameter	Water Quality Standard P68/2016
COD	100 mg/l
BOD	30 mg/l
Amonia	10 mg/l
pH	6 ~ 9
Total Coliform	3000 jml/100ml

Source: MoEF Regulation No. P.68 of 2016

Table 1 shows the characteristics of treated hospital wastewater from the four hospitals studied. The parameters examined were chemical oxygen demand (COD), bio-chemical oxygen demand (BOD), ammonia (NH3-N), pH and total coliform as the main indicators used to determine the quality of hospital wastewater under the regulation of the Ministry of Environment and Forestry of Indonesia No. P.68/2016. All treated effluents were discharged into Class II receiving water bodies, Ciliwung, Cibuluh and Pesanggrahan Rivers.

Table 1 Characteristics of hospital waste water discharge of hospitals studied. The monitoring results of the four hospitals showed large disparities in wastewater quality, which reflected differences in the treatment performance and operational conditions of the WWTPs. The

variations were notably noticeable for organic pollution markers (COD and BOD), for ammonia concentrations and for the microbiological quality. The pH values were quite consistent for all the sampling locations.

The concentrations of organic contaminants varied widely between the surveyed hospitals. Hospital XY had the highest organic loading with COD and BOD readings of 48.9 mg/L and 13.1 mg/L, respectively. Hospital BN showed the second highest organic pollutant concentrations, with COD and BOD values of 38.1 mg/L and 12.2 mg/L, respectively. The PR hospital had intermediate amounts (COD = 29.5 mg/L; BOD = 9.5 mg/L) whereas the CI hospital exhibited the lowest concentrations of organic pollutants (COD = 21.2 mg/L; BOD = 4.5 mg/L).

Ammonia exhibited a different trend. Hospital CI had the highest ammonia concentration (6.7 mg/L), followed by Hospital PR (4.6 mg/L). Hospital BN had lower ammonia concentrations (1.5 mg/L) whereas lowest value was found at Hospital XY (0.1 mg/L). These results suggest that ammonia removal efficacy was independent from organic pollutant removal in the examined WWTPs.

The pH values were reasonably consistent and ranged from 6.4 and 8.5 in all hospitals. Hospital XY showed the lowest pH value (6.4) and Hospital CI the highest pH value (8.5). Although pH values varied, all measured pH values were within the permitted operational range required by applicable environmental rules. In addition, there were significant disparities in terms of microbiological quality. The greatest total coliform content was found in Hospital CI (2,100 CFU/100 mL) followed by Hospital XY (1,000 CFU/100 mL) and Hospital BN (340 MPN/100 mL). On the other hand, the minimum microbiological contamination was recorded in Hospital PR with just 66.7 CFU/100 mL of total coliforms .

The treatment performance varied throughout the hospitals and across various water quality metrics when compared with the national effluent quality criteria. The highest shown were organic contaminants, ammonia and microbiological indications.

variability and were the major elements that required constant operational monitoring and process improvement to maintain consistent compliance with environmental requirements.

The examination of wastewater quality indicated that all the investigated hospitals were in compliance with the effluent quality criteria set by the Indonesian Ministry of Environment and Forestry Regulation No. P.68/2016 . None of the values analyzed exceeded the regulation limits for COD, BOD, ammonia, pH or total coliform. However, the observed variation amongst hospitals reflects variances in the performance of wastewater treatment and operational consistency. However, compliance with regulations at the time of monitoring does not imply necessarily a consistent long-term treatment efficiency, particularly when important physicochemical and microbiological parameters vary significantly.

All hospitals had fulfilled the relevant discharge regulations, although Hospital XY had the greatest concentration of organic pollutants (COD and BOD) whereas Hospital CI had the

highest concentration of ammonia and total coliform. The results show that the treatment performance depended on the operational parameters and process efficiency of each wastewater treatment plant (WWTP). Generally, greater COD and BOD concentrations are indicative of higher organic input to the treatment system. greater ammonia concentrations may also be indicative of inadequate nitrification due to poor biological treatment performance.

It is interesting to note that a difference exists between removal of organic debris and removal of ammonia in the hospitals surveyed. The hospital CI had the lowest COD and BOD concentrations but the greatest ammonia content. This result shows that efficient removal of organic matter does not mean efficient removal of nitrogen. Biological nitrification is a process that depends on the activity of autotrophic microorganisms, especially Nitrosomonas and Nitrobacter, which are very sensitive to operational disruptions and harmful substances. The presence of pharmaceutical residues, disinfectants and antimicrobial compounds can hinder the nitrifying bacteria leading to a reduction in ammonia oxidation efficiency and cause ammonia build-up in the treated effluent [11].

The relatively low BOD/COD ratios found in some hospitals, especially in Hospital XY and Hospital BN, further indicate the presence of weakly biodegradable organic chemicals in these hospitals [16][17][18]. Hospital wastewater has been reported to contain pharmaceutical residues, disinfectants and other complex organic pollutants that are hard to breakdown by standard biological treatment procedures. Previous studies have shown that antibiotic residues can inhibit microbial metabolism, limit the efficacy of biological treatment, and change the composition of microbial communities in activated sludge systems [4][11][12]. Similar observations have been observed by Verlicchi et al. (2010a) and Nugraha et al. (2025) [5][13], who concluded that pharmaceutical pollutants may impact long-term stability and therapeutic efficiency of hospital WWTPs.

The microbiological results are also worth a special mention. Total coliform concentrations were below the national regulatory limit but microbial counts in Hospital CI and Hospital XY were considerably higher than in the other studied hospitals. From an environmental perspective, the treated hospital effluents may still constitute a potential route for the dissemination of pathogenic microorganisms and antimicrobial resistance (AMR), particularly upon discharge into receiving water bodies used for recreation, fisheries or other public purposes.

Previous research have shown that wastewater treatment plants can be reservoirs for the survival of antibiotic-resistant bacteria and antibiotic resistance genes and their release into aquatic habitats when the treatment and disinfection are not complete [14][15].

These findings are in accordance with the concepts of the Indonesian Ministry of Environment Regulation No. 11/2025 that focuses on risk-based environmental management and the continuously operational reliability of wastewater treatment facilities. Differences in wastewater quality between hospitals suggest that compliance should be based not only on periodic effluent monitoring but also on operational performance, preventive maintenance,

process stability and systematic environmental risk assessment. The treatment performance is anticipated to vary over time as a function of equipment reliability, operator competency, monitoring frequency and quality of maintenance.

Overall, the results show that sustainable hospital waste-water management is achieved by an integrated approach of effective treatment technologies, operational control, constant performance monitoring and proactive environmental risk management. Enhancement of these aspects would improve the long-term reliability of hospital WWTPs and improve regulatory compliance and reduce the potential environmental impacts associated with hospital wastewater discharges including the release of pharmaceutical residues and the spread of antimicrobial resistance.

3. Conclusion

This study assessed the performance of hospital wastewater treatment plants (WWTPs) at four hospitals located in the Greater Jakarta Metropolitan Area (Jakarta, Bogor, and Tangerang), Indonesia, through the integration of wastewater quality assessment, operational risk evaluation, and regulatory compliance analysis. The results showed that all evaluated hospitals met the effluent quality standards set by the Indonesian Ministry of Environment and Forestry Regulation No. P.68/2016 for measured metrics such as COD, BOD, ammonia, pH and total coliform. Even after regulatory compliance, there were significant differences in treatment performance among the institutions, especially for organic pollutants, ammonia and microbiological markers. These results indicated that the compliance with dis-charge criteria would not reflect the long-term operational stability of hospital wastewater treatment systems. The high ammonia concentration found at Hospital CI and the comparatively high total coliform counts in several hospitals indicate probable difficulties in the efficacy of biological treatment and disinfection. Furthermore, pharmaceutical residues, albeit not specifically assessed in this work, may lead to lower biological treatment efficacy and increased environmental concerns related to antimicrobial resistance (AMR).

Within the risk-based management framework, sustainable hospital wastewater management should go beyond regulatory compliance and focus on operational reliability, preventive maintenance, continuous environmental monitoring, and systematic risk assessment in line with the principles of the Indonesian Ministry of Environment Regulation No. 11/2025. Strengthening these features will enhance the long-term performance of hospital WWTPs, limit potential impacts on receiving water bodies, and contribute to the protection of environmental and public health.

Recommendations

The study findings suggest that hospitals could improve sustainable wastewater management by employing source control, i.e. by segregating wastewater containing high concentrations of pharmaceuticals and hazardous medical residues before the usual treatment. Targeted pretreatment of wastewater generated from critical units such as clinical laboratories, oncology

and chemotherapy wards and hospital pharmacies using appropriate advanced technologies (e.g., activated carbon adsorption or advanced oxidation processes) may further improve removal of recalcitrant contaminants. Also, operational management needs to be enhanced by preventative maintenance, ongoing operator training, systematic performance evaluation and real-time effluent monitoring, so that treatment performance and regulatory compliance are maintained constant. Future research should focus on direct quantification of pharmaceutical residues, antibiotic resistance genes and antimicrobial resistant microorganisms and on the evaluation of advanced treatment technologies under full-scale operational conditions to support evidence-based improvements in hospital wastewater management and environmental protection.

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Disclosure of Interests.

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