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Environmental Quality of RSUD in Supporting Green Hospital Initiatives: A 2025 Case Study

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Abstract:

The green hospital concept emphasizes environmentally friendly hospital management that is safe for patients and health workers, and sustainable. This study aims to evaluate indoor air quality, particulate matter, noise, and water quality at RSUD Kabupaten Bekasi in 2025, referring to the Ministry of Health Regulation No. 2 of 2023 and related quality standards. The results show that several parameters exceed the quality standards, including CO_2 concentration, $PM_{2.5}$, environmental noise, BOD, COD, DO, mercury, lead, and total detergent. These findings form the basis for technical recommendations to support the transformation towards a green hospital.

Keywords: Environmental Quality, Green Hospital, Hospital, Ministry of Health Regulation No. 2/2023, Environmental Health.

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Introduction

Hospitals are healthcare facilities with significant environmental impacts due to their 24-hour operations, high energy consumption, medical waste generation, and substantial water use (WHO, 2020). Globally, the healthcare sector is estimated to contribute nearly 5% of total greenhouse gas emissions, making the transition toward sustainable healthcare systems an urgent priority (Health Care Without Harm, 2019). The *green hospital* concept has emerged as a strategic approach integrating energy efficiency, pollution control, waste management, water conservation, and environmental quality improvement within healthcare facilities (Karliner & Guenther, 2011). This approach is not only environmentally oriented but also aims to enhance patient and healthcare worker safety through the control of environmental risk factors.

Indoor air quality (IAQ) is one of the primary indicators in assessing hospital environmental performance because it is directly associated with nosocomial infection risks and respiratory health problems (ASHRAE, 2019). Elevated carbon dioxide (CO_2) concentrations indicate inadequate ventilation and may increase the transmission risk of airborne pathogens (Morawska et al., 2020). Furthermore, exposure to fine particulate matter such as $PM_{2.5}$ has been linked to increased hospital admissions and cardiopulmonary disorders, even at concentrations below national standards (WHO,

2021). Recent meta-analyses demonstrate that even small increases in $PM_{2.5}$ levels significantly elevate mortality and morbidity risks, particularly among vulnerable populations such as hospital patients (Yuan et al., 2019).

In addition to air quality, environmental noise levels in hospitals play a crucial role in patient comfort and recovery (Basner et al., 2014). The WHO recommends that nighttime noise levels in hospitals should not exceed 35 dBA to preserve sleep quality and promote healing (WHO, 2019). Excessive noise exposure has been shown to increase physiological stress responses, blood pressure, and delay recovery processes (Yang, Xie, Li, & Jin, 2023). Studies conducted in various hospitals indicate that corridors, waiting areas, and external building zones frequently exceed recommended noise thresholds (Busch-Vishniac et al., 2005).

Hospital wastewater quality is another major environmental concern, as it often contains high organic loads, pharmaceutical residues, heavy metals, and chemical detergents that may contaminate receiving water bodies (Oliveira, Al Aukidy, & Verlicchi, 2017). Parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO) reflect the effectiveness of biological treatment processes within wastewater treatment plants (Metcalf & Eddy, 2014). Toxic metals such as mercury (Hg) and lead (Pb) pose serious ecological and public health risks due to their persistence and bioaccumulative properties (WHO, 2017). Global reviews indicate that hospital wastewater treatment systems in developing countries frequently face operational challenges in effectively removing organic pollutants and heavy metals (Kümmerer, 2011).

The urgency of this study lies in the need for a comprehensive evaluation of hospital environmental quality as an integral component of green hospital transformation in alignment with national regulations and international standards (Kementerian Kesehatan RI, 2023). Monitoring environmental parameters that exceed quality standards serves as an early indicator of environmental health risks for patients, healthcare workers, and surrounding communities. Without evidence-based environmental assessments, green hospital implementation risks becoming merely administrative compliance rather than achieving substantive technical improvements (Karliner & Guenther, 2011).

Previous studies have examined hospital air quality and wastewater management in various countries and reported recurring issues related to ventilation inadequacy, particulate pollution, and high organic wastewater loads (Morawska et al., 2020; Oliveira et al., 2017). Research conducted in Indonesia has also identified challenges in controlling hospital noise levels and optimizing wastewater treatment plant performance (KLHK, 2021). However, most of these studies were conducted prior to the implementation of the latest regulatory framework, including the Indonesian Ministry of Health Regulation No. 2 of 2023 concerning Hospital Environmental Health Standards. Therefore, updated empirical assessments aligned with the newest regulatory standards are necessary to reflect current environmental conditions in 2025.

Based on this review, a research gap exists in the limited number of comprehensive studies integrating indoor air quality, particulate matter, environmental noise, and wastewater quality assessment within a unified green hospital framework based on the latest Indonesian regulations. The novelty of this study lies in its integrated evaluative approach to assessing environmental quality parameters at RSUD Kabupaten Bekasi in 2025 by directly comparing measurement

results with updated national standards while formulating technically grounded recommendations based on international guidelines. This study aims to analyze the environmental quality of RSUD Kabupaten Bekasi in 2025 and to develop technical recommendations to support sustainable green hospital implementation.

Methods

This study employed a descriptive observational approach based on field measurements conducted from March to June 2025 by the sanitation team of Bekasi Regency General Hospital (RSUD Kabupaten Bekasi). The parameters measured included indoor air quality, particulate matter, noise levels, and water quality. Measurements were carried out in accordance with standard methods, and the results were compared with the quality standards set by Minister of Health Regulation No. 2 of 2023 for air quality, Minister of Environment Decree No. 48/MENLH/11/1996 for noise levels, and Minister of Environment and Forestry Regulation No. 22 of 2021 for Class I water quality.

Results and Discussion

Table 1. Indoor Air Measurement Results

Parameter	Results	Quality standards	Status
CO_2	4.394,9 ppm	1.000 ppm	Not Meets
Temperature	27,5°C	22–23°C	Not Meets

Table 2. Particulate Measurement Results

Parameter	Results	Quality standards	Status
$PM_{2.5}$	32,3 µg/m³	25 µg/m³	Not Meet
PM_{10}	33,2 µg/m³	70 µg/m³	Meet

Table 3. Noise Measurement Results

Location	Results	Quality standards	Status
Front Yard of Building B	59,8 dBA	55 dBA	Not Meets
Back Yard of Building E2	59,4 dBA	55 dBA	Not Meets

Table 4. Water Quality Measurement Results

Parameter	Results	Quality standards	Status	Description
BOD	6,8 mg/L	2 mg/L	Not Meets	Organic pollution
COD	15,2 mg/L	10 mg/L	Not Meets	Chemical compounds

				that are difficult to decompose
DO	1,5 mg/L	≥6 mg/L	Not Meets	Lack of dissolved oxygen
Hg	0,0025 mg/L	0,001 mg/L	Not Meets	Toxic heavy metals
Pb	0,057 mg/L	0,03 mg/L	Not Meets	Toxic heavy metals
Total Detergent	0,62 mg/L	0,2 mg/L	Not Meets	Disturbs aesthetics and aquatic life

Discussion

The measurement results indicate that several environmental quality parameters at Bekasi Regency General Hospital (RSUD Kabupaten Bekasi) in 2025 exceeded the established regulatory standards.

Indoor Air Quality (CO_2, Temperature, $PM_{2.5}$)

The CO_2 concentration (≈4,395 ppm) significantly exceeded the threshold set by Minister of Health Regulation No. 2 of 2023 (1,000 ppm), indicating inadequate ventilation and insufficient fresh air supply. Recent international studies emphasize the importance of increasing air exchange rates and improving filtration systems in hospitals (Systematic Review on Hospital Ventilation, 2025).

Regarding particulate matter, the hospital's $PM_{2.5}$ level (32.3 µg/m³) exceeded the general daily threshold of 25 µg/m³. Recent meta-analyses report an increased risk of hospital admissions even at concentrations below national quality standards (Meta-analysis on Hospital Air Quality, 2024). These findings are consistent with reports from other hospitals in Indonesia that have documented similar indoor air quality issues.

Noise Levels

The hospital's noise levels (≈59–60 dBA) slightly exceeded the regulatory limit of 55 dBA. International ICU studies report noise levels ranging from 51–70 dBA, comparable to the findings at RSUD. In Indonesia, surveys in several hospitals have found corridor and waiting area noise levels between 56–65 dBA. Major noise sources include nearby road traffic, medical equipment alarms, and internal operational activities.

Wastewater Quality (BOD, COD, DO, Hg, Pb, Detergents)

The BOD, COD, and DO parameters indicate that wastewater treatment processes are not yet optimal. Mercury (Hg) and lead (Pb) concentrations exceeded regulatory limits, suggesting incomplete control of heavy metal medical waste disposal. Surfactant/detergent levels also exceeded standards, potentially disrupting aquatic ecosystems. These conditions align with global findings that hospitals are significant sources of organic pollutants, heavy metals, and emerging chemical compounds (Hospital Wastewater Treatment Review, 2025).

Recommended Technical Improvements

1. Ventilation & CO_2 Control
   a. Apply ASHRAE 170 ventilation standards: ≥6 ACH for general patient rooms (≥2 ACH outdoor air) and ≥12 ACH for isolation rooms.
   b. Target indoor CO_2 levels <800–1,000 ppm.
   c. Use MERV-13 or HEPA H13 filtration, and portable air cleaners with adequate CADR.
   d. Conduct routine inspections of dampers, AHUs, and ventilation set-points.
2. $PM_{2.5}$ Control
   a. Implement low-emission policies for cleaning chemicals and particle-generating activities.
   b. Optimize capture efficiency at return grilles.
   c. Use pre-filters to extend HEPA filter lifespan.
3. Noise Mitigation
   a. Install acoustic panels in noisy areas and vegetative barriers along road-facing boundaries.
   b. Implement alarm management (threshold adjustment, delay of non-critical alarms, alarm bundling).
   c. Enforce quiet hours during nighttime.
4. Wastewater Treatment Plant (WWTP) & Effluent Quality Improvement
   a. Apply coagulation-flocculation pre-treatment for heavy metals and surfactants.
   b. Optimize biological processes (aeration, F/M ratio, SRT) to reduce BOD/COD.
   c. Add polishing stages such as activated carbon or Advanced Oxidation Processes (AOP).
   d. Consider constructed wetlands as an environmentally friendly post-treatment option.

Overall, the findings show that several environmental quality parameters at RSUD Kabupaten Bekasi in 2025 exceeded regulatory standards. Elevated CO_2 concentrations indicate the need for ventilation improvements (ASHRAE, 2019). High $PM_{2.5}$ levels may pose respiratory health risks (WHO, 2021). Noise exceeding permissible limits can affect mental and physical health (Basner et al., 2014). Contaminated wastewater highlights the need for improvements in treatment systems to support Green Hospital implementation.

Conclusion

This study evaluated the environmental quality of RSUD Kabupaten Bekasi in 2025 in supporting the implementation of green hospital initiatives. The findings indicate that several key environmental parameters exceeded the established regulatory standards. Indoor air quality assessment revealed significantly elevated CO_2 concentrations and room temperatures beyond recommended thresholds, indicating inadequate ventilation and thermal control. $PM_{2.5}$ levels also exceeded permissible limits, suggesting potential health risks for patients and healthcare workers, particularly those with respiratory vulnerabilities.

Environmental noise levels measured in external hospital areas were found to surpass the allowable limit of 55 dBA, potentially affecting patient comfort and recovery. In addition, wastewater quality analysis demonstrated that BOD, COD, and DO values did not meet Class I water quality standards, reflecting suboptimal

performance of the wastewater treatment plant (WWTP). The presence of heavy metals such as mercury (Hg) and lead (Pb), as well as elevated detergent concentrations, further indicates insufficient pollutant removal processes.

Overall, the results demonstrate that although RSUD Kabupaten Bekasi has initiated environmental monitoring efforts, substantial technical improvements are required to achieve compliance with national standards and to effectively support sustainable green hospital transformation.

Practical Recommendations

Based on the findings, several targeted improvements are recommended. Ventilation systems should be optimized to increase air exchange rates and improve filtration in order to reduce elevated CO_2 and $PM_{2.5}$ levels. Regular inspection and maintenance of air handling systems are necessary to ensure consistent indoor air quality compliance.

Noise reduction measures should include basic acoustic treatment in high-exposure areas, improved alarm management, and the implementation of quiet-hour policies.

Wastewater treatment performance must be enhanced by optimizing biological processes and strengthening heavy metal removal mechanisms. Periodic technical evaluation of the WWTP should be integrated into routine environmental management to ensure sustained compliance with regulatory standards.

Limitations

This study was limited by its descriptive observational design and short monitoring period (March–June 2025), which may not represent long-term or seasonal variations. The assessment covered selected environmental parameters only and did not include microbiological, energy, or greenhouse gas indicators. Additionally, as the study was conducted in a single regional hospital, the findings may not be generalizable to other healthcare facilities.

Future Research Directions

Future research should employ longitudinal and multi-center designs to capture seasonal variations and improve generalizability. Broader environmental indicators—including microbial air quality, pharmaceutical residues, and energy efficiency metrics—should be incorporated to strengthen green hospital assessment frameworks. Economic evaluations of environmental interventions are also recommended to support sustainable policy implementation.

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