

WASTEWATER TREATMENT PLANT MANAGEMENT AS AN INDICATOR OF GREEN HOSPITAL IMPLEMENTATION: A SYSTEMATIC LITERATURE REVIEW

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Abstract:

Wastewater treatment plants (WWTPs) play a crucial role in controlling hospital pollution. Assessing green hospital implementation requires consideration of effluent quality, resource consumption, and operational governance. Objective: To review evidence on WWTP management and formulate assessment aspects relevant to green hospital implementation. Methods: A rapid systematic review with narrative synthesis was conducted through four web searches on October 3, 2026. Primary research articles published in Indonesian or English between 2020 and 2026 addressing hospital wastewater or relevant green hospital attributes were eligible. Results: Of 79 records, 17 duplicates were removed and 62 records were screened. Forty-two records were excluded; full texts were sought for 20 reports and obtained for nine. Nine studies were included, while 11 reports remained inaccessible. The evidence revealed variations in treatment performance, residual antibiotics and resistant bacteria, the need for improved maintenance, and the environmental implications of energy consumption. Numerical inconsistencies in several reports limited interpretation. Discussion: The presence of a WWTP and pollutant removal alone are insufficient to establish sustainability. Assessment should address effluent compliance, operational stability, energy consumption, reuse safety, and worker protection. Conclusion: WWTP management can serve as one environmental indicator of green hospital implementation. The available evidence neither validates WWTP management as a stand-alone indicator nor identifies a universally optimal technology for all hospitals.

Keywords: Wastewater Treatment Plant; Green Hospital; Hospital; Environmental Sustainability; Systematic Literature Review

INTRODUCTION

Hospitals use water for patient care, sanitation, laundry, and various support activities. The resulting wastewater must be treated before discharge into the environment. An evaluation of a hospital in Denpasar showed that biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) can be used to compare water quality before and after treatment (Sukadewi et al., 2020). However, wastewater characteristics extend beyond conventional parameters. Kanmalai et al. (2023) detected antibiotic residues in effluents from hospital wastewater treatment plants in Thailand.

A green hospital integrates environmental considerations into hospital operations. In developing assessment attributes for Indonesia, Sutanto et al. (2020) identified ecological, economic, social, technological, environmental health, and institutional dimensions. Wastewater treatment technology forms part of a broader framework incorporating leadership, human resources, and management support. Therefore, the evaluation of WWTPs should also consider institutional capacity to sustain treatment performance.



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Life cycle assessment (LCA) can account for the environmental implications of resources consumed during treatment. A study of a hospital WWTP in Pakistan highlighted the relevance of energy consumption to environmental assessment (Khan et al., 2024). This review aims to synthesize evidence on hospital WWTP performance and management, identify operational barriers, and propose indicators for assessing the wastewater component of green hospital implementation. The review question is: Which aspects of WWTP management are supported by primary research as components of green hospital assessment?

METHODS

Study Design and Review Framework

This study was conducted as a systematic literature review, using a simplified procedure involving limited web searches and a single AI-assisted assessment workflow. Reporting of the selection process was adapted from PRISMA 2020, which is a reporting guideline and does not, in itself, ensure search comprehensiveness or methodological quality (Page et al., 2021).

Component	Operational definition
Population or context	Hospitals and wastewater treatment systems receiving hospital wastewater.
Exposure or phenomenon	WWTP management, treatment technologies, monitoring, maintenance, and sustainability governance.
Comparator	Influent–effluent quality, differences among sites or periods, or performance benchmarks used by individual studies. A comparator was not mandatory for management studies.
Outcomes	Effluent quality, pollutant removal, antibiotics or resistant bacteria, environmental impacts, worker safety, and green hospital attributes.

Information Sources and Search Strategy

Four primary searches were conducted on September 3, 2026, using a web search engine and the terms listed in Table 1. Results included publisher websites, bibliographic indexes, and repositories. Searches were not performed directly within PubMed, GARUDA, Scopus, or Google Scholar. All records displayed in the four primary search responses were documented, including records subsequently deemed ineligible. The overall number of matching results and complete pagination were unavailable.

Exploratory searches conducted before the four primary searches, as well as subsequent title or DOI searches, were used to verify report identities and accessibility. These verification procedures did not add records to the selection flow.

Table 1. Primary search queries and numbers of records displayed

Code	Exact search query	Records
A	efektivitas instalasi pengolahan air limbah rumah sakit jurnal	15
B	hospital wastewater treatment removal antibiotics primary study	21
C	green hospital pengelolaan limbah cair	16
D	hospital wastewater treatment life cycle assessment	27
Total	Records before duplicate removal	79



Eligibility Criteria

The inclusion criteria were primary research articles published in peer-reviewed journals between January 1, 2020, and September 3, 2026; written in Indonesian or English; addressing hospitals or wastewater treatment systems receiving hospital wastewater; reporting outcomes relevant to WWTP performance, management, or sustainability; and having full text accessible during the search session.

Review articles, guidelines, regulations, news, commercial websites, forums, presentations, books, conference proceedings, preprints, and repository-based academic works were excluded. Studies of solid waste or nonhospital WWTPs without relevant data were also excluded.

Study Selection and Data Extraction

Duplicates were identified by matching titles and publication identities across publisher pages, PDFs, and indexes. Index entries and PDF versions of the same article were counted as one study. Unique records were screened by title and abstract, and full texts were sought for potentially eligible reports. Extracted information included authors, year, country or hospital, study design, observation unit, technology, primary outcomes, and limitations. Selection and extraction were not verified by a second independent human reviewer. Decisions for all 79 records are documented in a supplementary log.

RESULTS

Literature Selection Results

The primary searches returned 79 records. After removing 17 duplicates, 62 unique records were screened, of which 42 were excluded at the title-and-abstract stage. Full texts were sought for 20 reports. Eleven reports could not be retrieved because of failed or restricted access or because only abstracts were available during the session. Nine full-text reports were assessed, and all met the inclusion criteria. No reports were excluded after full-text assessment. The final synthesis comprised nine studies reported in nine publications.

Literature Selection Flow Diagram

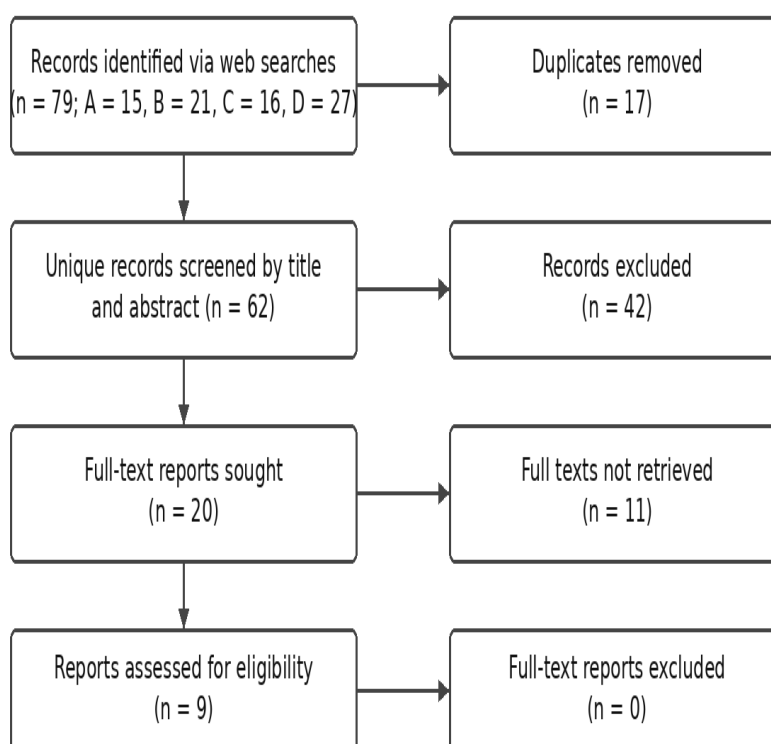


Figure 1. Adapted PRISMA 2020 selection flow for web searches.

Characteristics of Included Studies

Six studies were conducted in Indonesia, while Thailand, Egypt, and Pakistan each contributed one study. Two studies were published in 2020, three in 2023, two in 2024, one in 2025, and one in 2026. The main themes comprised three evaluations of conventional water quality, two studies on antibiotics or resistant bacteria, two studies examining green hospital attributes or strategies, and two studies concerning environmental impacts or worker protection.

Table 2. Summary of the nine studies included in the synthesis

Study ID and reference	Context and design	Extracted findings
S1 Sukadewi et al. (2020)	Cross-sectional observational study; three influent and three effluent samples; biofilter.	BOD decreased by 95.51%; COD by 90.32%; TSS by 89.69%.
S2 Arfani and Purnomo (2023)	Field-based influent–effluent evaluation; aerobic–anaerobic biofilter.	BOD: 30 to 7 mg/L; COD: 60 to 13 mg/L.
S3 Abduh et al. (2024)	Laboratory observations conducted in the morning and afternoon; anaerobic–aerobic biofilter.	Reported concentration tables and removal efficiencies were inconsistent.

Study ID and reference	Context and design	Extracted findings
S4 Kanmalai et al. (2023)	Three hospitals in Saraburi, Thailand; composite sampling; conventional activated sludge; LC-MS/MS.	Norfloxacin removal reached 94.78% at H1; ampicillin removal was 19.02% at H2.
S5 Mehanni et al. (2023)	Wastewater and effluent analysis, bacterial culture, and irrigation experiments.	Twenty-one bacterial isolates were obtained from effluent. Three selected isolates grew in the presence of tested antibiotics.
S6 Nasution et al. (2026)	Mixed-methods study; three interview informants and 14 questionnaire respondents; SWOT analysis.	Barriers included human resource preparedness, WWTP capacity or equipment, and suboptimal water reuse.
S7 Sutanto et al. (2020)	Four hospitals in and around Jakarta; attribute assessment, expert input, survey, and multidimensional scaling.	The framework comprised six dimensions, 42 attributes, and 151 subattributes. Wastewater treatment was part of a multidimensional assessment.
S8 Khan et al. (2024)	Life cycle assessment.	Reference flow rate: 300 m ³ /day; electricity consumption: 414 kWh/day.
S9 Nurdiyanto et al. (2025)	Descriptive evaluation and LCA; 33 wastewater management workers.	Health complaints and shortcomings in occupational protection were reported.

DISCUSSION

Pollutant Removal Efficiency and Effluent Compliance

Sukadewi et al. (2020) demonstrated that biological treatment can reduce pollutant concentrations under the observed operating conditions. However, the findings represent performance at a single site with a limited number of observations. Arfani and Purnomo (2023) found reductions in BOD and COD, while outlet temperature remained above the threshold applied in their study. Together, these studies suggest that treatment efficiency and regulatory compliance should be reported as distinct indicators (Sukadewi et al., 2020; Arfani & Purnomo, 2023).

A high percentage reduction may still leave elevated outlet concentrations when influent concentrations are very high. Conversely, a low removal percentage does not necessarily indicate noncompliance when the influent concentration is already low. Hospital assessments should therefore report outlet concentrations and the proportion of tests meeting each specified parameter.

Data integrity is also essential to accurate evaluation. In Abduh et al. (2024), the tables report an increase in COD from 51.5 to 61.5 mg/L in the morning and from 50.1 to 64.2 mg/L in the afternoon; however, the conclusion reports positive removal efficiencies of 4% and 96%. These figures are inconsistent with the concentration-reduction formula. This review does not select any figure as correct without clarification from the original authors (Abduh et al., 2024).

Antibiotic Residues and the Safety of Water Reuse

The Saraburi study demonstrated variability in removal rates across antibiotics despite the use of conventional activated-sludge treatment. This variation indicates that effective removal of conventional pollutants cannot automatically be extrapolated to the removal of pharmaceutical residues (Kanmalai et al., 2023).



Mehanni et al. (2023) isolated bacteria from treated effluent that were able to grow in the presence of the tested antibiotics. This finding supports the need to assess reuse safety but does not establish the magnitude of human infection risk or resistance-gene transfer under field conditions.

Within the green hospital framework, water reuse should be assessed through two components: the volume of reclaimed water that substitutes for freshwater demand and evidence that its quality is suitable for the intended use.

Energy Use and Environmental Impacts of Treatment

The data presented by Khan et al. (2024) yield an electricity intensity of approximately 1.38 kWh/m³, calculated in this review by dividing 414 kWh/day by 300 m³/day. This single-site estimate should not be regarded as a universal benchmark. Interpretation of LCA findings is also constrained by the scenarios included within the study system boundaries.

Accordingly, hospitals can monitor energy consumption per unit volume of treated wastewater alongside effluent quality. Comparisons among hospitals should account for pollutant loads and target treatment levels. Lower electricity consumption does not necessarily indicate a better system when the resulting effluent fails to meet applicable requirements.

Governance and Worker Protection

Nasution et al. (2026) linked wastewater management to operator preparedness, equipment maintenance, and internal policies. Research on green hospital attributes places wastewater treatment within a broader institutional and resource-management framework (Nasution et al., 2026; Sutanto et al., 2020). A synthesis of these two studies supports process indicators such as maintenance implementation, documentation of test results, and management involvement.

Worker protection should also form part of operational assessment. Nurdiyanto et al. (2025) reported health complaints and shortcomings in occupational protection practices. Inconsistencies in the reported number of complaints and limitations of the study design make it difficult to determine the magnitude of the risk (Nurdiyanto et al., 2025).

Proposed WWTP Management Indicators for Green Hospitals

Table 4 presents operational indicators proposed on the basis of the authors' synthesis.

Aspect	Proposed indicator	Interpretation
Effluent quality	Proportion of tests meeting each reference parameter; outlet concentration and flow rate.	Report results for each parameter and monitoring period.
Treatment performance	Change in influent-effluent concentration or load based on comparable sampling.	Distinguish concentration removal from load removal; evaluate pH within an acceptable range.
Operational reliability	System uptime, overload events, and corrective action following disruptions.	Assess against treatment requirements and designed capacity.
Maintenance and human resources	Implementation of maintenance schedules, operator training, and completeness of records.	Compare the existence of documents with verifiable implementation.
Energy and materials	kWh per m ³ treated; chemical consumption; documentation of sludge management.	Interpret relative to pollutant loads and effluent-quality targets.

Aspect	Proposed indicator	Interpretation
Water reuse	Reused water volume by intended purpose and water-quality test results.	Evaluate water savings alongside evidence of suitability for intended use.
Workers and governance	Compliance with occupational safety procedures, incident reporting, and audit follow-up.	Follow up complaints and exposure; do not treat these as direct proof of causation.

Review Limitations and Future Research Needs

Future reviews should search bibliographic databases directly using platform-specific strategies, export all retrieved records, and conduct screening with two reviewers. Primary studies should undertake repeated monitoring that links effluent quality with flow rate, energy use, maintenance, and pollutant characteristics. Evaluations of the proposed indicators should test whether changes in indicator scores are associated with measurable improvements in performance.

CONCLUSION

WWTP management can serve as one environmental indicator in green hospital implementation. A comprehensive assessment should cover effluent quality, treatment efficiency, operational reliability, energy and material consumption, water reuse safety, and governance and worker protection.

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