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Effectiveness of the Domestic Wastewater Quality Monitoring System at a General Hospital's Wastewater Treatment Plant

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Abstract

Hospital domestic wastewater carries organic and microbiological pollution loads requiring both adequate treatment and reliable monitoring; however, effectiveness is often judged solely from laboratory pass/fail results rather than the monitoring system itself. This study examines the effectiveness of the wastewater quality monitoring system at a general hospital's wastewater treatment plant in Buleleng Regency, Bali, Indonesia, using five years of outlet monitoring data (2021–2025). A sequential explanatory mixed-methods design was applied: a quantitative phase analyzed 16 laboratory test records for trend and compliance, followed by a qualitative phase comprising a document checklist, a gap analysis against national wastewater regulation, a SWOT analysis, and limited staff clarification. Results show 93.75% of test results met the applicable standard, with one pH exceedance in December 2022 never followed by documented corrective action. Monitoring frequency reached the minimum target in only three of four fully recorded years, and no single test covered the complete mandatory parameter set. Gap analysis across nine monitoring-system aspects found none fully compliant with ideal provisions. Treatment performance is generally sound, but the monitoring system remains structurally weak in governance. Priority strategies identified are a formal corrective-action procedure, a standardized operation-and-maintenance logbook, and completion of the mandatory testing parameter package.

Keywords

Compliance, Corrective Action, Hospital Wastewater Treatment, Wastewater Quality Monitoring.

1. Introduction

Hospitals generate domestic wastewater containing substantial organic and microbiological pollutants that require treatment through Wastewater Treatment Plants (WWTPs) and continuous quality monitoring. In Indonesia, this obligation is currently regulated by Regulation of the Minister of Environment/Environmental Control Agency Number 11 of 2025 concerning Wastewater Quality Standards and Wastewater Treatment Technology Standards for Domestic Wastewater, which replaced Regulation of the Minister of Environment and Forestry Number 68 of 2016 with stricter parameters and expanded microbiological requirements (Ministry of Environment/Environmental Control Agency of the Republic of Indonesia, 2025). However, hospital wastewater remains a global environmental challenge, as studies have reported the persistence of organic pollutants, antibiotic residues, and antimicrobial-resistant microorganisms in hospital effluents despite conventional treatment processes (Tulashie et al., 2018; Fatimazahra et al., 2023; Khan et al., 2024). This indicates that wastewater management effectiveness depends not only on treatment technology but also on the reliability of monitoring systems that ensure compliance and continuous improvement.

Previous studies have mainly evaluated hospital WWTP performance through influent–effluent comparisons at specific observation periods. Baeti et al. (2022) assessed WWTP performance at Roemani Muhammadiyah Hospital, while Rahmat and Mallongi (2018) examined Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) characteristics at Lanto Dg. Pasewang Regional Hospital. An evaluation of wastewater treatment effectiveness and liquid-waste quality at Dr. Soetomo General Hospital, Surabaya (Dewi et al., 2022). Khan et al. (2024) evaluated the environmental impact of hospital wastewater treatment in Pakistan. In contrast, Rhomadhoni and Ayu (2019) identified increasing BOD, COD, and phosphate exceedances in a private hospital in Surabaya. Although these studies provide important information on treatment effectiveness, most remain descriptive and cross-sectional, with limited evaluation of monitoring governance, including monitoring frequency, parameter completeness, documentation traceability, reporting mechanisms, and corrective actions.

The phenomenon gap is reflected in the inconsistent performance of hospital WWTPs across different facilities. Several studies reported effective treatment performance, such as the aerobic biological system at Dr. H. A. Rotinsulu Lung Hospital, which reduced COD, BOD, and Most Probable Number (MPN) coliform levels, and the WWTP evaluation at GMIM Pancaran Kasih General Hospital, Manado, which demonstrated effective control of BOD, COD, and pH parameters (Maddusa, 2019; Wibowo & Yogisutanti, 2023). Conversely, studies at Indramayu Regional Hospital and a private hospital in Cirebon found variations in WWTP performance related to treatment technology and operational conditions (Fahira & Slamet, 2022; Arifin & Nabil, 2025). Similar issues were reported in a COVID-19-designated hospital in Bangladesh, where BOD, COD, and fecal coliform exceeded acceptable limits (Mondal & Fakhruddin, 2025). Studies at W. Z. Yohanes Regional Hospital, Kupang, and "X" Hospital in Jambi further demonstrate differences in WWTP management practices among healthcare facilities (Waang et al., 2016; Ulfah et al., 2024).

These variations suggest that the interaction between WWTP performance and monitoring system effectiveness influences wastewater quality compliance. However, existing studies rarely examine whether monitoring practices themselves are compliant, consistent, and capable of supporting corrective actions when deviations occur. Most compliance evaluations focus only on wastewater quality results, while neglecting monitoring implementation aspects such as sampling regularity, parameter completeness, documentation, and follow-up mechanisms.

This study addresses three research gaps. First, limited studies integrate multi-year wastewater quality trend analysis with evaluation of monitoring governance in a single research design. Second, previous studies generally assess compliance based only on parameter results without evaluating the quality of the monitoring process. Third, no study has evaluated wastewater monitoring-system readiness in a non-metropolitan Indonesian hospital under the newly implemented 2025 regulation. Therefore, this study contributes novelty by applying a sequential explanatory mixed-methods approach, combining five-year quantitative trend analysis with qualitative evaluation through document review, gap analysis, and SWOT analysis to identify both performance patterns and underlying management factors (Ivankova et al., 2006; Creswell & Plano Clark, 2018; Gunn et al., 2024).

The research problem addressed in this study concerns the extent to which hospital wastewater monitoring systems perform effectively during 2021–2025 and the strategic improvements required to enhance compliance and continual improvement. The study proposes that WWTP outlet quality will generally comply with standards, monitoring-conduct compliance will be lower than result compliance, and corrective-action mechanisms will represent the weakest monitoring dimension, consistent with previous evidence and ISO 14001:2015 principles (Wibowo & Yogisutanti, 2023; Khan et al., 2024; Birhan et al., 2024; Gunn et al., 2024).

Accordingly, this study aims to, analyze the characteristics, trend, and compliance level of domestic wastewater quality at the WWTP outlet for 2021–2025 against applicable regulations, evaluate the condition of WWTP Infrastructure and Preperation and Maintenance (O&M), together with the effectiveness of the monitoring system across sampling regularity, parameter adequacy, documentation traceability, reporting mechanisms, and corrective follow-up; and formulate priority, realistic strategies for strengthening the effectiveness of that monitoring system.

2. Literature Review

2.1. Hospital Wastewater Monitoring and Environmental Governance

Domestic wastewater from health-care facilities is characterized by physical (temperature, TSS, TDS), chemical (pH, BOD, COD, ammonia, oil and grease, MBAS, residual chlorine), and microbiological (total/fecal coliform) parameters, all of which require treatment prior to discharge (Ministry of Health of the Republic of Indonesia, 2019). International evidence reinforces this concern: assessments of hospital WWTPs in Nigeria, Ghana, and Pakistan report that even where organic parameters are substantially reduced, several facilities still exceed national discharge limits and continue to release antimicrobial-resistant bacteria (Khan et al., 2024; Nashira et al., 2024). While broader sustainability assessments emphasize that treatment technology choice in developing countries must be paired with adequate operational capacity to be effective (Starkl et al., 2022; Awad et al., 2024).

Within the Plan-Do-Check-Act framework adopted by ISO 14001:2015 (International Organization for Standardization, 2015), monitoring ("check") is not merely a laboratory-testing activity but a system comprising five dimensions: (a) regularity of sampling frequency and method, (b) adequacy of parameter coverage, (c) documentation traceability, (d) internal and external reporting mechanisms, and (e) Corrective and Preventive Action (CAPA) for non-conformances. Effective environmental monitoring is further supported by organizational commitment: managerial commitment and technical capability have been shown to mediate the relationship between environmental management practices and organizational efficiency more broadly, suggesting that monitoring-system effectiveness cannot be separated from institutional support and resourcing (Ali, 2021). Monitoring effectiveness should therefore be assessed not only by outcome (whether effluent meets the standard) but also by process (whether monitoring is conducted and documented to standard), because a good result at one point in time does not guarantee system reliability when a future anomaly occurs a concern consistent with broader sustainability-economics literature emphasizing that short-term performance indicators alone are insufficient evidence of long-term system resilience (Arumdani et al., 2024).

2.2. Hospital Wastewater Treatment Performance and Quality Compliance

The effectiveness of WWTP technology, operational management, and maintenance practices strongly influences hospital wastewater treatment performance. Hospital effluents contain complex pollutants, including organic matter, nutrients, pathogens, pharmaceutical residues, and antimicrobial-resistant microorganisms, which require appropriate treatment before discharge into the environment. Treatment performance is commonly evaluated through physicochemical and microbiological parameters, such as BOD, COD, Total Suspended Solids (TSS), ammonia, pH, and coliform levels (Rachman et al., 2025). Recent evidence indicates that although many hospital WWTPs are capable of reducing pollutant loads, treatment outcomes remain inconsistent due to differences in technology selection, operational capacity, and facility management. A systematic review by Amin et al. (2024) reported that several hospital wastewater treatment systems in low- and middle-income countries still failed to achieve adequate microbial removal, highlighting the importance of improving treatment reliability and long-term monitoring systems.

Quality compliance in hospital wastewater management should therefore be understood not only as the achievement of discharge standards but also as the ability of WWTP systems to maintain stable performance over time. Variations in influent characteristics, hydraulic loading, treatment processes, and operational practices may affect the consistency of effluent quality. Recent studies emphasize that conventional treatment technologies may require optimization or additional processes to address emerging contaminants and microbiological risks in hospital effluents (Sharma et al., 2024). Consequently, evaluating WWTP performance requires an integrated assessment of wastewater quality trends, infrastructure conditions, and operational practices. This approach enables identification of whether compliance reflects a consistently effective treatment system or only temporary achievement of regulatory limits.

3. Methods

This study employed a sequential explanatory mixed-methods design, consisting of a quantitative phase to identify wastewater quality patterns and compliance trends, followed by a qualitative phase to explain the factors underlying those findings (Ivankova et al., 2006; Creswell & Plano Clark, 2018). The study was conducted at a general hospital located in Sulanyah Village, Seririt District, Buleleng Regency, Bali Province, Indonesia. The unit of analysis was the WWTP outlet monitoring system, including wastewater quality records and supporting monitoring documents. The quantitative dataset consisted of 16 accredited laboratory test reports collected from March 2021 to January 2025, obtained from two accredited regional public-health laboratories. These reports represented routine wastewater quality monitoring activities conducted by the hospital during the five-year observation period.

Quantitative data were collected through structured extraction of all laboratory reports into a standardized data-extraction sheet containing sampling date, wastewater discharge volume, measured parameters, applicable quality standards, testing laboratory, and compliance status. Each parameter result was compared with the applicable wastewater quality standards to determine whether it complied with regulatory requirements. Qualitative data were collected through three approaches: (1) a checklist assessing the availability and completeness of 20 monitoring-related documents; (2) a gap analysis comparing existing monitoring practices with regulatory requirements, environmental permit provisions, and internal Standard Operating Procedures (SOPs) across nine monitoring-system aspects; and (3) clarification with five key personnel, including sanitation staff, WWTP operators, and general affairs staff. These clarifications were documented as part of the research audit trail to support interpretations of quantitative findings rather than being treated as formal interviews.

Credibility of the qualitative findings was supported through source triangulation across the document checklist, the gap-analysis matrix, and informant clarification, with each clarification record cross-checked against the corresponding written document before being accepted as corroborating evidence. Informants were selected purposively based on their direct operational responsibility for wastewater monitoring (the WWTP operator, the sanitation officer, and general affairs staff); clarification sessions were conducted individually, lasted approximately 20–30 minutes, and followed a semi-structured format focused on discrepancies identified during document review.

Quantitative data were analyzed descriptively using spreadsheet-based processing to calculate annual means, ranges, standard deviations, and trends for each wastewater parameter from 2021–2025. Compliance was assessed through (1) the percentage of laboratory results meeting wastewater quality standards and (2) the percentage of years meeting required monitoring frequency and parameter requirements. Qualitative data were analyzed through document content analysis and synthesized into a gap-analysis matrix using three categories: compliant, partially compliant, and non-compliant. The identified gaps were further evaluated using SWOT analysis to develop strategic improvement alternatives. Integration of quantitative and qualitative findings occurred during the interpretation stage, where qualitative evidence was used to explain quantitative patterns, particularly the pH exceedance observed in December 2022. Strategy prioritization was subsequently conducted using an urgency–feasibility matrix to determine improvement priorities based on the severity of identified gaps and the estimated resources and time required for implementation.

4. Results

4.1. Wastewater Quality Characteristics, Trends, and Compliance Status

Recorded wastewater discharge at the hospital was relatively low, averaging approximately 3.98 m^3/day (equivalent to around 1,453 m^3/year). Based on the applicable wastewater discharge classification, this volume places the facility within the $3 < x \leq 50$ m^3/day category for domestic wastewater quality standard determination. This classification is important because the applicable regulatory requirements, including monitoring obligations and discharge quality limits, are determined according to wastewater volume categories. The annual mean values of the monitored wastewater parameters, including physicochemical and microbiological indicators, are summarized in Table 1, while the temporal trends of the three main organic pollution indicators (BOD, COD, and TSS) during the 2021–2025 observation period are presented in Figure 1. These results provide an overview of wastewater treatment performance and the consistency of WWTP outlet quality over the five-year monitoring period.

Table 1. Annual Mean Wastewater Quality Parameters at the WWTP Outlet, 2021-2025

Year	Mean pH	Mean BOD (mg/L)	Mean COD (mg/L)	Mean TSS (mg/L)	Mean NH3-N (mg/L)	Mean Coliform (MPN/100mL)
2021	7.47	15.70	41.68	12.45	0.68	252.50
2022*	8.36	0.81	16.33	3.00	0.26	<2
2023	7.81	14.33	39.50	10.68	0.62	234.00
2024	7.48	12.58	35.50	9.50	0.53	218.25
2025**	7.45	12.20	34.50	9.20	0.44	215.00

Note: n = 4 tests in 2021, 2023, and 2024; n = 3 tests in 2022 (mean calculated from incomplete parameter coverage, as TSS/NH_3-N/coliform were reported in only 1 of 3 tests); n = 1 test in 2025 (January only). Source: processed from hospital laboratory test records, 2021-2025

As presented in Table 1, the annual mean wastewater quality parameters at the WWTP outlet showed relatively stable performance during the 2021–2025 observation period. The pH values remained within a neutral range, ranging from 7.45 to 8.36, although 2022 recorded a slightly higher average value compared with other years. The organic pollutant indicators, including BOD, COD, and TSS, generally showed a decreasing pattern after 2021, with the lowest mean concentrations observed in 2022 (BOD 0.81 mg/L, COD 16.33 mg/L, and TSS 3.00 mg/L), followed by a slight increase in 2023 and gradual reduction until 2025. Ammonia concentrations remained consistently low throughout the monitoring period (0.26–0.68 mg/L), while coliform levels showed an overall declining trend from 252.50 MPN/100 mL in 2021 to 215.00 MPN/100 mL in 2025. These findings indicate that the WWTP maintained relatively consistent treatment performance; however, fluctuations in several parameters highlight the need for continuous monitoring to ensure sustained compliance and identify potential operational variations.

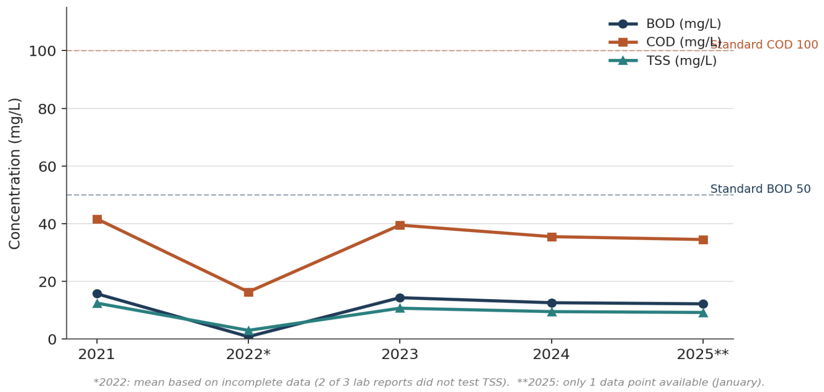

Figure 1. Annual Mean BOD, COD, and TSS at the WWTP Outlet, 2021-2025

Figure 1 shows that BOD and COD show a declining and comparatively stable pattern from 2023 through 2025, remaining well below the applicable standards (BOD 50 mg/L; COD 100 mg/L), consistent with proposition P1 and with international findings that biological treatment stages can substantially reduce organic load even where facilities operate under resource constraints (Awad et al., 2024; Khan et al., 2024). The unusually low 2022 mean (BOD 0.81 mg/L) should be read cautiously: it derives from only three reports that did not test identical parameter sets, so the 2022 trend partly reflects differing laboratory testing packages rather than a genuine improvement in treatment performance.

Of the 16 wastewater quality test results recorded between 2021 and 2025, 15 results (93.75%) were reported as compliant with the applicable wastewater quality standards, while one result (6.25%) was identified as non-compliant. The only recorded non-compliance occurred in December 2022, when the pH value reached 9.2, exceeding the permitted range of 6–9. Other monitored parameters during the observation period remained within the required limits, indicating that the WWTP generally maintained effective treatment performance and regulatory compliance. The isolated pH exceedance suggests a temporary deviation rather than a persistent treatment failure, which variations may have influenced in influent characteristics, operational conditions, or treatment processes. Therefore, continuous monitoring remains essential to detect similar deviations early and ensure that corrective actions can be implemented promptly.

The annual compliance distribution and detailed results are summarized in Table 2 and Figure 2. Notably, none of the 16 tests covered the complete mandatory parameter set: fecal coliform and residual chlorine were never tested throughout the study period, and monitoring frequency reached the minimum required target of four tests per year in only three of the four fully recorded years (2021, 2023, 2024).

Table 2. Sampling Frequency and Test-Result Compliance Rate (2021-2025)

Year	**Tests**	**Frequency target met (≥4/yr)**	**Months compliant**	**Months non-compliant**	**Notes**
2021	4	Yes	4 (100%)	0	All parameters within standard
2022	3	No	2 (66.7%)	1 (pH 9.2)	Incomplete parameters; no documented CAPA
2023	4	Yes	4 (100%)	0	Improving trend post-2022
2024	4	Yes	4 (100%)	0	Most stable performance
2025	1	Baseline	1 (100%)	0	Only one data point (January)

As shown in Table 2, the wastewater quality monitoring implementation demonstrated generally good compliance in terms of monitoring frequency and parameter performance during the 2021–2025 period, although some limitations were identified. The required monitoring frequency (≥4 tests/year) was achieved in 2021, 2023, and 2024, with all recorded months showing compliance with applicable standards. In contrast, 2022 did not meet the required monitoring frequency, with only three tests conducted, and one monitoring period recorded non-compliance due to a pH value of 9.2 exceeding the allowable limit. This year also showed incomplete parameter documentation and the absence of documented CAPA, indicating a weakness in the monitoring governance system despite generally acceptable wastewater quality results. In 2023 and 2024, monitoring performance improved, with complete annual frequency achievement and stable compliance across monitored parameters, suggesting better operational consistency after the 2022 deviation. Meanwhile, the 2025 data should be interpreted cautiously because only one monitoring result was available in January, which was insufficient to represent annual performance but provided an initial indication of continued compliance. The findings indicate that while test-result compliance was high, monitoring-conduct compliance and corrective-action documentation remain important areas for system improvement.

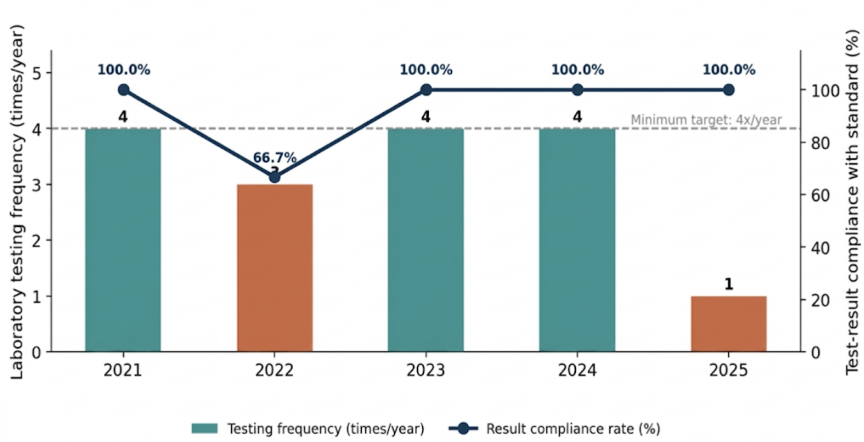

Figure 2. Sampling Frequency and Test-Result Compliance Rate, 2021-2025

Figure 2 shows that laboratory testing frequency generally achieved the minimum monitoring target of four tests per year in 2021, 2023, and 2024, resulting in 100% compliance with the required monitoring frequency. However, monitoring performance declined in 2022, when only three tests were conducted, representing 66.7% compliance with the annual target. This reduction was accompanied by incomplete parameter monitoring and the occurrence of one non-compliant pH result, indicating a temporary weakness in monitoring implementation. In 2025, only one laboratory test was recorded, which represents a substantial shortfall compared with the required frequency. Therefore, the compliance rate for 2025 was not calculated as an annual performance indicator because the available data only represented one observation point in January. These findings highlight that although wastewater quality results were generally compliant, maintaining consistent monitoring frequency remains essential to ensure reliable evaluation of WWTP performance and timely identification of potential operational problems.

4.2. WWTP Infrastructure and Operation-and-Maintenance Conditions

A review of 20 monitoring-related documents revealed that the wastewater monitoring system had been partially implemented; however, several documentation weaknesses limited its effectiveness. Fourteen documents were available, including monitoring records, operational documents, and supporting administrative files, but most were incomplete, inconsistently maintained, or lacked standardized formats. These conditions reduced the reliability and traceability of monitoring activities because important information, such as monitoring schedules, operational conditions, and evaluation results, was not always recorded systematically. The absence of standardized documentation practices also made it difficult in assess whether monitoring activities were conducted consistently according to regulatory requirements and internal procedures.

Six required documents were identified as completely unavailable, representing important gaps in the monitoring governance system. These missing documents included a formal Corrective and Preventive Action (CAPA) procedure, sampling minutes for two of the three monitoring reports in 2022, follow-up documentation related to the pH exceedance, a formal annual wastewater monitoring calendar, and calibration records for the field pH meter. The absence of a CAPA procedure and follow-up records was particularly significant because it indicated that deviations from wastewater quality standards were not supported by a structured mechanism for investigation, corrective response, and prevention of recurrence. Similarly, the lack of calibration records may affect confidence in field measurement accuracy and the reliability of monitoring results.

Although a daily Operation and Maintenance (O&M) logbook was available, its implementation was inconsistent and did not follow a standardized recording format. As a result, the logbook could not adequately support retrospective evaluation of operational conditions, particularly during critical periods such as the December 2022 pH exceedance. Limited operational records made it difficult to determine whether the deviation was associated with changes in influent characteristics, treatment process conditions, equipment performance, or operational practices. These findings demonstrate that while the hospital had basic monitoring practices in place, strengthening documentation systems, corrective-action mechanisms, and operational record management is necessary to improve the overall effectiveness and reliability of the wastewater monitoring system.

4.3. Monitoring System Strategies and SWOT Analysis

Before evaluating the overall compliance level of the wastewater monitoring system, a gap analysis was conducted to identify differences between existing practices and the ideal requirements established by regulations, environmental permits, and internal operational procedures. This analysis focused on nine key aspects of monitoring governance, including monitoring procedures, parameter completeness, documentation, reporting mechanisms, and corrective-action implementation. The purpose of this assessment was to determine whether the hospital's monitoring system was sufficiently structured to support consistent wastewater quality control and continuous improvement beyond the achievement of laboratory compliance alone.

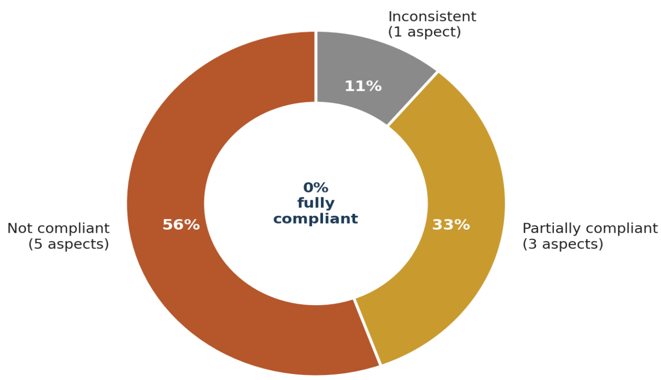

Figure 3. Distribution of Compliance Status Across 9 Monitoring-System Aspects

The gap analysis across nine monitoring-system aspects revealed that none of the evaluated aspects fully met the ideal provisions required by applicable regulations, environmental permits, and internal procedures. As presented in Figure 3, five aspects (55.6%) were categorized as "not compliant," three aspects (33.3%) were classified as "partially compliant," and one aspect (11.1%) was identified as "inconsistent." The identified gaps primarily involved weaknesses in documentation completeness, monitoring standardization, corrective-action procedures, and follow-up mechanisms after non-conformities occurred. This pattern indicates that although wastewater quality results were generally within acceptable limits, the supporting monitoring governance system had not yet reached an optimal level of maturity. The findings support proposition P3, which states that the corrective-action mechanism represents the most critical weakness within the monitoring system, emphasizing the need to strengthen systematic CAPA implementation as part of continuous environmental performance improvement.

Table 3. Summary of SWOT Factors for the Wastewater Quality Monitoring System

Category	**Key Factors Identified**
Strengths (S)	Accredited laboratory testing; consistent sampling point (100%); generally compliant effluent (93.75%); sustained testing budget; certified sanitation officer.
Weaknesses (W)	Undocumented CAPA for the pH exceedance; incomplete parameter coverage; unstandardized O&M logbook; absence of a written CAPA procedure; inconsistent testing frequency; incomplete sampling minutes.
Opportunities (O)	New national wastewater regulation (2025); hospital accreditation requirements; increasingly affordable IoT monitoring sensors; regional agency training programs; accessible accredited laboratory.
Threats (T)	Rising wastewater load from service expansion; stricter future regulation; regulatory inspection risk; limited locally trained WWTP personnel.

Table 3 indicates that the wastewater monitoring system has strong laboratory support, consistent sampling practices, and generally high compliance. However, weaknesses remain in CAPA documentation, parameter coverage, monitoring frequency, and operational record standardization. Opportunities from updated regulations, accreditation requirements, IoT technology, and training programs can strengthen the system, while increasing wastewater loads, stricter regulations, inspection risks, and limited skilled personnel remain key threats.

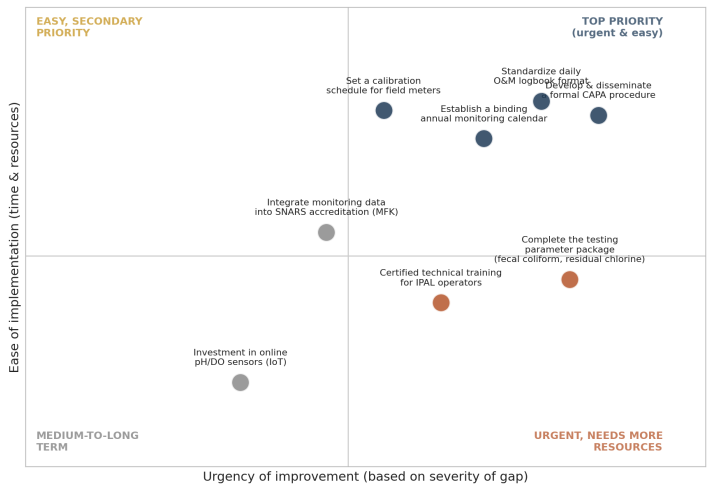

Figure 4. Strategy Prioritization Matrix for Strengthening the Monitoring System

Eight strategy options generated through SWOT analysis were mapped on an urgency–feasibility matrix in Figure 4 to determine realistic priorities. Three strategies fall in the top-priority quadrant: developing and disseminating a formal CAPA procedure with a maximum seven-working-day response target, standardizing the daily O&M logbook format, and establishing a binding annual monitoring calendar. None of these requires major investment, and each directly closes the most critical vulnerabilities identified above.

Completing the testing parameter package and providing certified technical training for operators are urgent but require greater resources and time. Investment in online (IoT) pH/DO monitoring sensors is realistically positioned as a follow-on agenda once basic governance foundations are strengthened first, consistent with the continual-improvement principle of ISO 14001:2015, which holds that strengthening an environmental management system is more effective when begun with incremental procedural improvements rather than large technology investments made without an adequate governance foundation (International Organization for Standardization, 2015).

5. Discussion

This study found that the hospital WWTP maintained generally satisfactory wastewater treatment performance during the 2021–2025 observation period, with an overall result-compliance rate of 93.75%. However, the evaluation also identified weaknesses in monitoring governance, particularly regarding monitoring frequency, parameter completeness, documentation, and corrective-action implementation. These findings indicate that compliance with wastewater quality standards does not necessarily reflect a well-functioning monitoring system capable of ensuring continuous environmental compliance (Maninna et al., 2022).

A key finding of this study is the distinction between result compliance and monitoring-conduct compliance. In terms of wastewater quality, the hospital demonstrated consistently good performance, with only one non-compliant laboratory result during the five-year observation period. This finding is consistent with studies at Dr. H. A. Rotinsulu Lung Hospital and GMIM Pancaran Kasih General Hospital, which likewise reported that hospital WWTPs were generally able to produce effluent meeting regulatory standards (Maddusa, 2019; Wibowo & Yogisutanti, 2023). These results support proposition P1, indicating that the existing treatment system was capable of maintaining acceptable wastewater quality under normal operating conditions. Thus, the expected overall compliance of WWTP effluent results was supported by the observed data, although isolated deviations remained possible.

In contrast, monitoring implementation showed lower compliance than laboratory results alone would suggest. Only three of the four complete observation years achieved the minimum required monitoring frequency, while none of the laboratory reports included the complete mandatory parameter set because fecal coliform and residual chlorine were not analyzed throughout the study period. Furthermore, the pH exceedance recorded in December 2022 was addressed operationally through chemical dosing adjustment and equipment inspection, but no documented CAPA or formal verification of the corrective measures was available.Similar challenges have been reported in hospital wastewater monitoring, where microbiological monitoring and governance practices often remain less developed than routine physicochemical testing (Fatimazahra et al., 2023; Mondal & Fakhruddin, 2025).

The absence of documented CAPA is also inconsistent with the ISO 14001:2015 Plan–Do–Check–Act framework, which emphasizes systematic corrective action as an essential component of continual environmental improvement (International Organization for Standardization, 2015). Likewise, Ali (2021) and Starkl et al. (2022) argue that effective environmental performance depends not only on treatment technology but also on institutional capacity and managerial commitment.

The documentary review further supports these findings. Although the hospital consistently conducted laboratory testing through accredited laboratories, several essential governance components, including standardized operating procedures, calibration records, monitoring schedules, and corrective-action documentation, were incomplete or unavailable. Similar observations have been reported by Fahira and Slamet (2022) and Awad et al. (2024), who emphasized that sustainable WWTP performance is influenced not only by treatment technology but also by operational management, documentation quality, and institutional support. Therefore, maintaining compliant effluent quality alone is insufficient to ensure long-term environmental performance if monitoring governance remains weak.

The SWOT analysis shows that the monitoring system has strong foundations through accredited laboratory testing, consistent sampling, high effluent compliance (93.75%), and certified personnel, but weaknesses remain in CAPA, parameter completeness, monitoring frequency, and documentation (Mannina et al., 2022). Regulatory developments, accreditation, IoT technology, and training provide improvement opportunities, while rising wastewater loads, stricter regulations, inspection risks, and limited skilled personnel pose threats (Starkl et al., 2022). Therefore, priorities should focus on formal CAPA, standardized O&M records, and annual monitoring schedules before adopting advanced technologies, consistent with the continual-improvement principle of ISO 14001:2015 (International Organization for Standardization, 2015).

The findings of this study contribute practical evidence that evaluating hospital wastewater management should extend beyond laboratory compliance to include the effectiveness of monitoring implementation. Distinguishing outcome compliance from process compliance provides a more comprehensive assessment of WWTP performance and helps identify governance weaknesses that may not be apparent from laboratory results alone. Strengthening monitoring frequency, parameter completeness, documentation systems, and CAPA implementation will improve monitoring reliability, support continuous environmental improvement, and enhance regulatory compliance under Indonesia's wastewater management framework.

6. Conclusion

This study draws five main conclusions. First, the characteristics and trend of WWTP outlet wastewater quality for 2021–2025 indicate generally sound and increasingly stable treatment performance for BOD and COD since 2023. Second, compliance results are high (93.75%), but monitoring-conduct compliance frequency and parameter completeness are not yet fully consistent. Third, WWTP infrastructure and O&M conditions show good budget commitment to external testing but weak internal record-keeping systems, instrument calibration, and standard procedures. Fourth, overall monitoring-system effectiveness is low on the governance dimension; none of the nine aspects evaluated was fully compliant, with the CAPA mechanism as the most critical gap. Fifth, the most priority and realistic improvement strategies are developing a formal CAPA procedure, standardizing the O&M logbook, and establishing a binding annual monitoring calendar, implementable in the short term with internal resources.

This study contributes by making explicit the need to distinguish result compliance from monitoring-governance compliance in hospital WWTP evaluation, situating this distinction within both Indonesian and international literature, and by applying a mixed-methods design that integrates multi-year quantitative trends with a qualitative review of governance documents and practices. Limitations include the relatively small number of annual data points, reliance on available documents and limited clarification, and the single-case design itself: as an in-depth case study of one hospital, the findings offer analytical rather than statistical generalizability, and caution is warranted in extending the specific findings to hospitals with different capacities, technologies, or regulatory contexts. Future research should incorporate direct field observation, expanded parameter testing, and comparison across multiple facilities to strengthen generalizability.

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