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Optimizing Hospital Waste Management Systems through Statistical Approaches: Evidence from a Central Java Hospital

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ABSTRACT

Hospital wastewater contains various contaminants that can endanger both environmental and public health if not managed properly. This study investigates the optimization of a hospital wastewater treatment system in Purwokerto using descriptive statistical analysis. Data were collected for the year 2023 from one hospital and included parameters such as Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia, oils and grease, pH, total coliform, and several heavy metals including cadmium. Results indicate that most parameters met environmental quality standards set by the Ministry of Environment Regulation No. 68/2016, except for total coliform and cadmium, which occasionally exceeded the thresholds. The study suggests several optimization strategies including improved disinfection methods, regular monitoring, technological upgrades, and better staff training to enhance the treatment system's efficiency and ensure compliance with environmental regulations.

1. Introduction

The rapid increase in the number of hospitals in Indonesia has led to a proportional rise in the generation of medical waste, including hazardous and toxic materials that pose significant risks to human health and the environment. Medical waste can be categorized into infectious, pathological, chemical, pharmaceutical, and radioactive waste, all of which require specific handling and treatment processes [1]. Improper management of these wastes, especially liquid waste, can lead to serious environmental contamination and public health hazards.

Hospitals contribute significantly to the generation of wastewater that contains organic matter, pathogens, pharmaceutical residues, and heavy metals. According to the World Health Organization (WHO), hospital wastewater is a potential source of nosocomial infections and can significantly affect the health of surrounding communities if not properly treated [2]. In Indonesia, the Ministry of Environment and Forestry has issued regulations, such as PermenLH No. 68/2016, to set quality standards for hospital effluents to minimize environmental impact [3].

Despite existing regulations, many healthcare facilities still struggle with implementing effective wastewater treatment systems due to constraints such as limited budgets, lack of technical expertise, and insufficient monitoring [4]. A study by Kotika et al. (2023) revealed that only a fraction of hospitals in Indonesia meet the required wastewater discharge standards [5]. Furthermore, frequent exceedances of permissible levels of biological and chemical contaminants highlight the need for systematic evaluation and optimization of existing wastewater treatment practices.

Statistical analysis provides an effective approach for assessing the performance of wastewater treatment systems. Descriptive statistics allow for the summarization of complex data sets and help identify trends, anomalies, and areas requiring intervention. Moreover, inferential statistical techniques such as t-tests, ANOVA, and regression analyses enable researchers to evaluate the impact of optimization strategies and ensure data-driven decision-making [6].

This study aims to evaluate and optimize the performance of a hospital wastewater treatment plant (IPAL) in Purwokerto using statistical methods. By analyzing annual data across multiple quality parameters, the study seeks to identify deviations from the standards and propose targeted strategies for improving treatment efficiency. The findings are expected to contribute to the enhancement of hospital environmental management systems and promote sustainable healthcare practices in Indonesia.

2. Research Methodology

2.1. Materials

The data used in this study are secondary data obtained from the Working Partner of the Ahmad Dahlan University (UAD) Chemical Engineering Master Study Program in Semarang. The data is in the form of hospital wastewater quality monitoring results for one year at one of the hospitals in Purwokerto, Central Java. In the calculation, some values in the data showed inaccurate number formats, such as the symbols “<” or “>”. To maintain the consistency of statistical processing, the values were determined based on the closest value approach that is below or above the limit indicated by the symbol. The IPAL RS Purwokerto parameters based on descriptive analysis can be seen in table 1.

Table 1. General Parameters on IPAL RS Purwokerto Data

No	Parameter	Unit	Month												Quality Standard
			January	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	
1	Total Suspended Solids (TSS)	mg/L	< 10	< 10	< 10	< 10	< 13	< 13	< 9	< 9	15	17	30	13	30
2	Ammonia (NH_3)	mg/L	3.5	4.91	3.21	0.49	0.48	< 0.08	1.18	6.81	5.96	6.11	4.94	4.21	10
3	BOD	mg/L	10	10	10	11	24	21	20	21	20	21	10	< 6	30
4	COD	mg/L	34.9	32.1	64.2	30.4	36.1	74.5	80.7	64.3	77.5	33.5	66.0	12.6	100
5	Oil and Grease	mg/L	2.37	2.53	2.56	2.47	2.56	3.25	2.37	3.17	1.67	2.50	2.18	5	5
6	pH	mg/L	7.2	6.65	7.3	6.5	7.3	7.2	7.5	6.5	7.3	7.1	7.3	7.2	6.0 - 9.0
7	Total Coliform	CFU/100 ml	< 2	< 2	> 16000	< 2	< 2	< 2	< 2	> 16000	< 2	< 2	< 2	< 2	3000

In addition to the general parameters shown in Table 1, the IPAL RS Purwokerto wastewater quality data also includes heavy metal and other chemical parameters as shown in Table 2. These parameters provide a more comprehensive picture of the potential pollution and effluent treatment effectiveness at the facility.

Table 2. Heavy Metal Parameters and Specific Pollutants in IPAL RS Purwokerto Data

No	Parameter	Unit	Month												Quality Standard
			January	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*Desember*	
			Chemical												
1	Mercury (Hg) Total	mg/L	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.002
2	Free Ammonia	mg/L	0.021	0.04	0.004	0.017	< 0.004	0.42	0.012	0.52	0.71	0.069	0.038	1	1
3	Arsenic (As) Total	mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.1
4	Barium (Ba) Total	mg/L	< 0.73	1.24	< 0.73	0.73	1.39	< 0.73	0.85	1.54	< 0.85	1.01	< 0.85	< 0.85	2
5	Iron (Fe) Dissolved	mg/L	< 0.44	< 0.44	< 0.44	< 0.44	< 0.44	< 0.68	< 0.68	< 0.68	< 0.68	< 0.68	< 0.68	< 0.68	5
6	Detergent (MBAS)	mg/L	0.83	0.09	0.41	< 0.07	< 0.07	0.08	0.09	0.09	< 0.09	< 0.09	< 0.09	< 0.09	5
7	Phenol	mg/L	0.1	0.11	0.15	< 0.15	< 0.15	< 0.15	< 0.15	0.15	< 0.15	< 0.15	< 0.15	< 0.15	0.5
8	Fluoride (F)	mg/L	0.46	0.11	0.97	0.15	0.98	0.11	< 0.1	0.44	0.53	0.1	0.25	0.22	2
9	Cadmium (Cd) Total	mg/L	< 0.03	0.03	0.03	< 0.03	< 0.03	< 0.03	< 0.02	0.23	< 0.02	< 0.02	< 0.02	< 0.02	0.05
10	Free Chlorine	mg/L	0.53	0.32	0.98	0.34	0.20	0.46	0.14	0.25	0.46	< 0.14	< 0.14	< 0.14	1
11	Cobalt (Co) Total	mg/L	< 0.16	< 0.16	< 0.16	< 0.16	< 0.16	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	0.4
12	Chromium Total (Cr)	mg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.12	< 0.12	< 0.12	< 0.12	0.5
13	Chromium Val. 6 (Cr 6+)	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.1
14	Manganese (Mn) Dissolved	mg/L	< 0.61	0.61	0.61	0.61	< 0.61	< 0.61	< 0.59	< 0.59	< 0.59	< 0.59	< 0.59	< 0.59	2
15	Nickel (Ni) Total	mg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	0.2
16	Nitrate (NO3-N)	mg/L	< 1	< 1	< 1	5.4	< 1	1.1	2.1	1.2	1.2	< 0.9	1.2	< 0.9	20
17	Nitrite as N (NO2-N)	mg/L	< 0.03	0.04	0.03	0.03	0.03	0.03	0.1	0.1	0.1	0.1	0.1	0.1	1
18	pH	-	6.5	7.3	7.3	7.1	7.3	7.3	7.3	7.2	7.3	7.2	7.2	7.2	6.0 - 9.0
19	Selenium (Se) Total	mg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.05
20	Zinc (Zn) Total	mg/L	< 0.14	0.14	0.14	0.14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
21	Cyanide (Cn-)	mg/L	0.013	0.009	0.012	0.02	0.019	0.019	0.020	0.012	0.012	0.015	0.015	0.015	0.05
22	Sulfide	mg/L	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.03	< 0.03	0.06	0.03	0.03	0.03	0.03	0.3
23	Copper (Cu) Total	mg/L	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	0.2
24	Tin (Sn) Total	mg/L	< 1.36	< 1.36	< 1.36	< 1.36	< 1.36	< 1.22	< 1.22	1.61	< 1.22	1.95	< 1.22	< 1.22	2
25	Lead (Pb) Total	mg/L	< 0.08	0.10	0.08	0.08	< 0.08	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	0.1

2.2. Procedures

This research was conducted with a descriptive statistical analysis approach to hospital wastewater quality parameters. The first step was to collect parameter data from the hospital's WWTP monitoring documents throughout 2023. The data was then classified and processed using statistical methods such as average, standard deviation, median, and compared with the quality standards set by PermenLH No. 68 of 2016. The results of this comparison are used to evaluate whether the sewage treatment system is running optimally.

Furthermore, parameters that do not meet the standards, such as total coliform and cadmium (Cd), were identified. Optimization of the treatment system was carried out with proposed technological improvements such as advanced filtration, biological methods, and heavy metal removal using adsorption and ion exchange technology. Advanced statistical approaches such as ANOVA and linear regression tests were also used to assess the effectiveness of the optimization. The treatment results are presented in the form of tables and graphs that illustrate the fluctuation of parameter values throughout the year as well as the effectiveness of effluent treatment before and after optimization.

3. Results and Discussion

This research used descriptive statistical analysis to evaluate the effectiveness of wastewater treatment at a hospital in Purwokerto, Central Java. The data, collected over one year, included key parameters such as Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, oil and grease, ammonia, total coliforms, and various heavy metals. The results were then compared to environmental quality standards regulated by Indonesian government standards PermenLH No. 68 Year 2016.

3.1. General Wastewater Parameters

The descriptive analysis results for primary wastewater parameters are presented in Table 3.

Table 3. Statistical Analysis of Hospital Wastewater Parameters Compared to Quality Standards

Parameter	Statistical measurement (Mean ± standard deviation)	Quality standard	Results
Total Suspended Solids (TSS)	12.42±6.29	30	Meets the criteria
Biochemical Oxygen Demand (BOD)	15.17±6.35	30	Meets the criteria
Ammonia	3.49±2.41	10	Meets the criteria
Chemical Oxygen Demand (COD)	50.57±22.87	100	Meets the criteria
Oil and Grease	2.5±0.45	5	Meets the criteria
pH	7.17±0.33	6-9	Meets the criteria
Total coliform	2834±6616	3000	Does not meet the criteria

Data analysis indicates that the average and median levels of TSS, ammonia, BOD, COD, oil and grease, and pH generally fall below or within the quality standards set by Regulation of the Minister of Environment No. 68 of 2016 namely 30 mg/L for TSS and BOD, 10 mg/L for ammonia, 100 mg/L for COD, 5 mg/L for oil and grease, and a pH range of 6–9 demonstrating that the hospital wastewater treatment system is functioning effectively overall. However, several fluctuations require attention: TSS levels reached the threshold in November, ammonia levels varied moderately from month to month, BOD spiked to 24 mg/L in June possibly due to increased hospital activity or reduced treatment efficiency, and COD showed significant fluctuation, peaking in July and rising sharply from May to June. In contrast, oil and grease levels, as well as pH values, remained relatively stable throughout the year. Regarding biological parameters, the average concentration of Total Coliform was also below the standard limit of 3000 mg/L, with a very low median value of 1 mg/L, indicating low microbial contamination in most months. However, the high standard deviation suggests notable variation in some months. To maintain and enhance treatment performance, optimization efforts are necessary, including the adoption of advanced filtration, oxidation, and pH control technologies, more effective biological treatment and oil/grease removal methods, improved disinfection to control Total Coliform fluctuations, stricter control of pollution sources, enhanced staff training, and more rigorous and frequent monitoring of wastewater parameters to ensure compliance with environmental standards.

3.2. Heavy Metals and Specific Pollutants in Wastewater

The table below presents the statistical measurement results of a number of effluent parameters generated by hospitals in Purwokerto for the year 2023. Each parameter is evaluated based on its mean value and standard deviation, and compared with the quality standard set by the Minister of Environment Regulation No. 68 Year 2016. The parameters include heavy metal elements, organic and inorganic compounds, and biological indicators that have the potential to pollute the environment if not handled properly.

Table 4. Statistical Results Between Parameters and Quality Standards

Parameter	Statistical measurement (Mean ± standard deviation)	Quality standard	Results
Mercury (Hg)	$0.001 \pm 2.83 \times 10^{-20}$	0.002	Meets the criteria
Free Ammonia	0.15±0.235	1	Meets the criteria
Total Arsenic (As)	$0.009 \pm 1.81 \times 10^{-18}$	0.1	Meets the criteria
Total Barium (Ba)	0.95±0.28	2	Meets the criteria
Dissolved Iron (Fe)	0.55±0.13	5	Meets the criteria
Detergents (MBAS)	0.16±0.23	5	Meets the criteria
Phenol	0.13±0.04	0.5	Meets the criteria
Fluoride (F)	0.35±0.33	2	Meets the criteria
Total Cadmium (Cd)	0.003±0.06	0.05	Does not meet the criteria
Free Chlorine	0.36±0.28	1	Meets the criteria
Total Cobalt (Co)	0.14±0.016	0.4	Meets the criteria
Total Chromium (Cr)	0.1±0.01	0.5	Meets the criteria
Hexavalent Chromium (Cr^{6+})	0.03±0.005	0.1	Meets the criteria
Dissolved Manganese (Mn)	0.59±0.01	2	Meets the criteria
Total Nickel (Ni)	0.08±0.01	0.2	Meets the criteria
Nitrate (NO_3-N)	1.55±1.28	20	Meets the criteria
Nitrite (NO_2-N)	0.08±0.07	1	Meets the criteria
Total Selenium (Se)	$0.004 \pm 9.05 \times 10^{-19}$	0.05	Meets the criteria
Total Zinc (Zn)	0.11±0.02	5	Meets the criteria
Cyanide (CN^-)	0.01±0.004	0.05	Meets the criteria
Sulfide	0.18±0.3	2	Meets the criteria
Total Copper (Cu)	0.18±0.3	2	Meets the criteria
Total Tin (Sn)	1.37±0.21	2	Meets the criteria
Total Lead (Pb)	0.07±0.01	0.1	Meets the criteria

The results showed that most of the parameters analyzed, such as mercury (Hg), arsenic (As), barium (Ba), iron (Fe), detergent (MBAS), phenol, fluoride, free chlorine, as well as chromium in total and valence six (Cr and Cr6+) forms, were within the permissible limits and met the quality standards. This indicates that the hospital's effluent treatment system generally works effectively in reducing pollutant concentrations.

However, there was one parameter that did not meet the criteria, the total cadmium (Cd) level, which exceeded the threshold with a measurement mean of 0.003 mg/L and standard deviation of 0.06 mg/L, exceeding the quality standard of 0.05 mg/L. This non-conformity indicates heavy metal contamination that could originate from pharmaceutical waste, metal medical devices, or chemical laboratory activities. This requires serious handling considering that cadmium is toxic and bioaccumulative.

To overcome these problems, the application of advanced treatment technologies such as filtration systems with ion exchange resins or the use of adsorbents such as activated carbon is recommended. In addition, increased periodic monitoring and internal environmental audits are also needed to ensure that the discharged wastewater meets applicable environmental standards and does not endanger public health or the surrounding ecosystem.

4. Conclusion

The study concludes that while the existing treatment system generally meets environmental standards, specific attention is needed for controlling biological and heavy metal pollutants. Statistical evaluations confirm the necessity and effectiveness of targeted optimization interventions. Continued improvements in technology, staff training, and regulatory compliance are essential for sustainable hospital waste management.

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