



HAZARD IDENTIFICATION AND EXPOSURE ASSESSMENT FOR WASTEWATER MANAGEMENT WORKERS

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ABSTRACT

Sanitation workers in hospitals are at high risk of developing health disorders due to direct exposure to wastewater during the operation and maintenance of wastewater treatment plants (WWTP). This study aims to identify the types of health problems experienced by 33 sanitation personnel at Sentra Medika Cibinong Hospital and to analyze the contribution of wastewater treatment processes to these health risks using the Life Cycle Assessment (LCA) approach. Methods: This study employed a qualitative descriptive method using a Life Cycle Assessment (LCA) approach. From a total population of 33 individuals, the researcher selected all 33 as the study sample. Data were analyzed using both quantitative and qualitative approaches. Additionally, the Life Cycle Assessment (LCA) methodology was employed to identify environmental impacts and potential health risks arising from the hospital's wastewater management system. Results: The results showed that 87.9% of the workers reported health complaints, including skin irritation, respiratory symptoms (shortness of breath, coughing), dizziness, nausea, vomiting, and gastrointestinal disorders. The highest exposure occurred during chemical dosing, sludge pit cleaning, and wastewater sampling. The LCA results indicated that the aeration and disinfection stages contributed significantly to hazardous emissions such as hydrogen sulfide (H₂S), chlorine, and fine particulates, which can pose serious health risks. Conclusion: This study highlights the urgent need to improve occupational health protection through proper use of personal protective equipment (PPE), routine training, and redesigning WWTP systems to be more worker-friendly. LCA proved to be an effective tool in identifying health-related risk hotspots throughout the wastewater management cycle.

Keywords: hospitalwwtp; life cycle assessment (lca)occupational health; sanitation workers; wastewater

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INTRODUCTION

Hospitals serve as essential facilities for delivering healthcare services to the community. Their design, operation, and maintenance must prioritize human and environmental health, covering aspects such as physical cleanliness, solid and liquid waste, clean water supply, and control of pests and vermin. Hospital waste contains a variety of microorganisms, depending on the type of waste, the level of treatment prior to disposal, and the healthcare facility's characteristics. Hospitals bear full responsibility for ensuring that the waste they generate does not pose health or environmental hazards. This includes the management of hospital wastewater (Sampurno, et.al., 2022) Hospital wastewater is a major source of environmental pollution, originating from various activities including domestic sources such as effluents from bathrooms, kitchens, washing facilities, and sinks, as well as clinical sources such as wound irrigation, blood washing, and laboratory waste. Given the significant potential impact of wastewater on both environmental sustainability and public health—including hospital staff—it is imperative that hospitals treat their wastewater to meet established quality standards. Hospital wastewater can be particularly hazardous to human health, as it may transmit numerous waterborne diseases. The characteristics of hospital wastewater include physical parameters (color, odor, temperature, solids, and solubility), chemical parameters (organic and inorganic substances, as well as gases), and biological characteristics (presence

of microorganisms such as bacteria, fungi, algae, protozoa, viruses, and helminths) (Said 2006; Hartini, et al., 2011; Khoiroh, 2020; Neshart, et al., 2021).

Sentra Medika Cibinong Hospital is a private Type B hospital, established in 2011, with a capacity of 255 beds and approximately 900 staff members. The hospital operates a Wastewater Treatment Plant (WWTP) with a daily capacity of 100 m³. However, with the expansion of hospital services, the existing WWTP is no longer sufficient to accommodate the increasing load. As a result, the effluent quality from the WWTP often fluctuates and becomes difficult to control. Wastewater quality standards represent the maximum allowable limits for pollutants that can be discharged into the environment. For hospitals, these standards are defined as the threshold levels of contaminants permitted in wastewater released into water bodies or soil from any operational activity. The applicable standard for hospital wastewater in Indonesia is regulated by the Ministry of Environment and Forestry Regulation No. 5 of 2014, which outlines permissible limits for parameters such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and concentrations of heavy metals (Neshart, et al., 2021).

Healthcare workers responsible for managing hospital wastewater systems, including WWTP operators, are at risk of adverse health outcomes. These include infections and communicable diseases from exposure to pathogenic viruses and bacteria, respiratory issues from inhaling toxic gases like hydrogen sulfide (H₂S) and methane (CH₄), skin irritations due to contact with wastewater or treatment chemicals, and potential toxic effects on vital organs such as the liver and kidneys. Additionally, occupational stress can arise due to job demands, organizational changes, work environment, and unclear roles. Efficient and environmentally friendly hospital wastewater management is therefore critical to prevent negative health outcomes and preserve ecosystem integrity. Accordingly, continuous evaluation and improvement of hospital wastewater systems are necessary from technical, economic, and environmental perspectives (World Health Organization (WHO), 2014; European Agency for Safety and Health at Work, 2018; . Public Health Ontario, 2019). Life Cycle Assessment (LCA) is a methodological framework used to evaluate the environmental impact of a product or system throughout its entire life cycle. In the context of hospital wastewater management, LCA can be applied to assess the environmental consequences of each stage—collection, treatment, and final disposal. This approach provides a comprehensive understanding of how each phase contributes to environmental impacts such as energy consumption, greenhouse gas emissions, and resource depletion. By identifying the most impactful stages, LCA helps prioritize interventions that minimize environmental burdens (Adi, 2023)

To investigate the potential health risks and environmental impacts associated with hospital wastewater management at Sentra Medika Cibinong Hospital, an initial survey and sampling were conducted involving 10 sanitation workers, including two environmental health staff, two technicians, two cleaning service workers, two gardeners, and two kitchen staff. The findings revealed that environmental health staff reported skin irritation during bacterial and chlorine application and sample collection. Gardeners and cleaning service workers experienced skin irritation, dizziness, and nausea while cleaning the control tanks and treatment basins. Technicians reported similar symptoms, in addition to hearing issues, during pump maintenance. Kitchen staff experienced dizziness and nausea while cleaning grease traps. Based on the aforementioned background, this study aims to assess the Hazard Identification and Exposure Assessment for Wastewater Management Workers at Sentra Medika Cibinong Hospital using a Life Cycle Assessment (LCA) approach.

METHOD

Study Design

This study employed a qualitative descriptive method using a Life Cycle Assessment (LCA) approach. This method was chosen to examine the current conditions of a specific object of study in real time, allowing for a comprehensive analysis of environmental and health-related impacts associated with hospital wastewater management.

Population and Sample

The population of this study included all sanitation and operational staff involved in the management of wastewater facilities and infrastructure, both directly in the Wastewater Treatment Plant (WWTP) area and in supporting areas such as the kitchen, garden, and cleaning zones. From a total population of 33 individuals, the researcher selected all 33 as the study sample. The selection was based on the relevance of their job roles and the intensity and frequency of their exposure to wastewater-related tasks. This full-population sampling ensured adequate representation and allowed for more efficient in-depth interviews and data collection.

Instruments

The research instruments included laboratory test results for key wastewater quality parameters, specifically: pH, Biochemical Oxygen Demand (BOD₅), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Oil and Grease, and Ammonia (NH₃-N). Sample collection and testing were conducted in accordance with standardized methods, including the Indonesian National Standard (SNI) and the *Standard Methods for the Examination of Water and Wastewater* by the American Public Health Association (APHA). Fieldwork was supported by various tools to facilitate surveys, direct field measurements, documentation, and environmental impact modeling using the LCA approach. These tools included observational and structured interview questionnaires, observation checklists, digital cameras, and mobile phones equipped with cameras.

Data Collection

Both primary and secondary data were used in this study. Primary data were obtained through direct measurements and observations at the research site. Secondary data were gathered through interviews with key informants selected using purposive sampling techniques, as well as field documentation. This multi-source data collection allowed for a thorough understanding of the subject matter. Data collection methods combined both qualitative and quantitative techniques to provide a comprehensive picture of the relationship between wastewater management and the potential health risks to sanitation workers. Techniques included structured observation, in-depth interviews, documentation review, field measurements, and collection of laboratory and technical data related to the WWTP.

Data Analysis

Data were analyzed using both quantitative and qualitative approaches. Additionally, the Life Cycle Assessment (LCA) methodology was employed to identify environmental impacts and potential health risks arising from the hospital's wastewater management system. The analysis was carried out using SimaPro software, which supported the Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and the identification of environmental and health impact hotspots related to hospital wastewater treatment processes.

RESULT

Human Resources for Wastewater Management at Sentra Medika Cibinong Hospital

Human resources (HR) play a critical role in the hospital wastewater management system. The success of the Wastewater Treatment Plant (WWTP) operations heavily depends on the

competence, number, distribution, and engagement of personnel involved in technical operations, monitoring, and maintenance activities. At Sentra Medika Cibinong Hospital, wastewater management personnel are not limited to technical operators at the WWTP but also include staff from various units directly connected to the discharge and handling of both domestic and non-infectious medical wastewater. Based on observations and interviews conducted during the study, a total of 33 personnel were identified as being involved in the management of wastewater facilities and infrastructure. The distribution of these human resources is presented in the table below:

Table 1.

Human Resources Involved in Wastewater Management at Sentra Medika Cibinong Hospital

No	Type of Personnel	Work Unit	Number of Personnel
1	Environmental Officers	Health Environmental Health Unit	3
2	Technical Staff	Infrastructure Maintenance Unit (WWTP Mechanics)	14
3	Cleaning Service Staff	General Areas and Building Control Networks	10
4	Gardeners	Garden Areas and External Control Networks	4
5	Kitchen Staff	Kitchen and Grease Trap	2
	Total		33

These findings highlight the multidisciplinary involvement required for effective hospital wastewater management. It underscores the need for coordinated efforts across multiple units to ensure that wastewater handling complies with operational, health, and environmental standards.

Health Disorders Experienced by Wastewater Treatment Personnel

In the hospital wastewater treatment process, particularly involving biological systems such as anaerobic and aerobic treatment within the Wastewater Treatment Plant (WWTP), the emission of odorous gases is inevitable. Therefore, it is crucial to measure odor-related parameters, such as ammonia (NH₃) and hydrogen sulfide (H₂S), as these serve as key indicators of environmental discomfort and potential health risks for personnel working in treatment areas.

Table 2.

Characteristics of Respondents Based on Field Observations at Sentra Medika Cibinong Hospital

Characteristic	Category	f	%
Age	20–30 years	16	49
	31–40 years	7	21
	>40 years	10	30
Education	High School	27	82
	Diploma (D3)	5	15
	Bachelor (S1)	1	3
Length of Work	<5 years	12	36
	5–10 years	14	43
	>10 years	7	21

This study involved 33 respondents who are responsible for operating and maintaining wastewater treatment facilities (WWTP) at Sentra Medika Cibinong Hospital. The demographic and professional characteristics of these respondents were analyzed to understand factors that may influence their vulnerability to health issues related to occupational exposure. The key characteristics assessed included age, level of education, and duration of employment. Observations and interviews regarding technical wastewater management activities at the hospital revealed several operational shortcomings, such as irregular maintenance schedules, inadequate use of personal protective equipment (PPE), and

insufficient knowledge of occupational safety protocols. The following findings were identified:

1. Several personnel involved in wastewater treatment operations did not consistently use PPE, particularly during routine tasks such as sampling or tank cleaning.
2. The working environment around the WWTP was exposed to foul odors and potentially toxic gases, including hydrogen sulfide (H₂S).
3. There was a lack of regular training on occupational safety and emergency procedures related to hospital wastewater management.
4. Personnel reported experiencing symptoms such as skin irritation, headaches, and gastrointestinal disturbances, and routine health checks were not conducted.

The findings above are based on a survey of 33 personnel directly engaged in WWTP operations. The survey aimed to identify potential health issues arising from direct exposure to technical processes and chemical substances used in wastewater treatment. The results revealed a variety of complaints, including: Respiratory problems (e.g., coughing, shortness of breath), Skin issues (e.g., itching, irritation), Headaches and nausea, Upper respiratory tract infections and Allergic reactions. These findings underscore the importance of comprehensive occupational health management, including the enforcement of PPE usage, regular health monitoring, and ongoing safety training for wastewater treatment personnel in hospital settings. The following table presents the frequency of reported health complaints by wastewater treatment personnel at Sentra Medika Cibinong Hospital:

Table 3.
Health Complaints Among Wastewater Treatment Personnel

Type of Complaint	f	%
Respiratory disorders	12	36
Skin problems	5	15
Dizziness/nausea	7	22
Upper respiratory tract infection	1	3
Allergies	3	9
No complaints	5	15

Source: Field Observation and Interview Data

As shown in the table above, the most frequently reported health complaint was respiratory disorders (36%), likely associated with exposure to gases or particles emitted during aeration processes and the handling of chemicals such as chlorine. This was followed by dizziness and nausea (22%), which may be linked to the inhalation of chemical vapors and strong odors originating from the primary and secondary treatment units. Based on the collected data, a relationship was identified between technical wastewater management practices and the occurrence of health complaints. Analysis using the Chi-square test indicated a statistically significant relationship between non-standardized wastewater management practices and an increased risk of health issues among workers.

Table 4.
Association Between Occupational Exposure and Health Complaints

Work Exposure (Frequency/Duration)	Experienced Complaints	No Complaints
High (≥5 days/week or >4 hours/day)	23	2
Low (<5 days/week or ≤4 hours/day)	5	3
Total	28	5

Source: Field Observation and Interview Data

As illustrated in Table 4, occupational exposure—defined in terms of frequency and duration of direct involvement in WWTP environments, such as control tanks, anaerobic-aerobic units, pipeline maintenance areas, and untreated liquid waste handling—emerged as a major risk factor contributing to various health complaints. Among the 33 respondents surveyed, most were exposed to the WWTP environment for more than five days a week and over four hours

per day. Observations indicated that increased exposure duration and frequency corresponded with a higher likelihood of experiencing health-related symptoms.

Table 5 .
Chi-Square Test Results

Statistical Test	Value	df	p-value	Interpretation
Pearson Chi-Square	4.881	1	0.027	Significant ($p < 0.05$)
Fisher's Exact Test	–	–	0.035	Significant (small sample)

Source: Field Data Analysis Results

Based on the Chi-square analysis, a statistically significant relationship ($p = 0.027$) was found between the level of occupational exposure and the occurrence of health complaints. Personnel with higher exposure—both in frequency and duration—were significantly more likely to report health symptoms compared to those with lower exposure.

Interpretation of Life Cycle Impact Assessment (LCIA) Data

The results of the Life Cycle Impact Assessment (LCIA) analysis and hotspot visualization reveal that the primary sources of environmental impact and potential health risks in the technical management of hospital wastewater stem from several key components and processes. These findings are summarized in the following table:

Table 6.
Key Impact Categories Requiring Mitigation Focus

Impact Category	Primary Source	Risks and Implications
Global Warming Potential (GWP)	Blowers, Pumps	Significant contribution to carbon emissions and climate change
Human Toxicity (Non-Cancer)	Chemicals, Sludge Management	Direct risks to worker health through toxic exposure
Human Toxicity (Cancer)	Blowers, Pumps, PPE	Dependence on fossil fuels and plastic-based materials
Particulate Matter Formation	Chemicals	Risk of contamination affecting terrestrial and aquatic ecosystems

Source: Field Data and LCIA Analysis Results

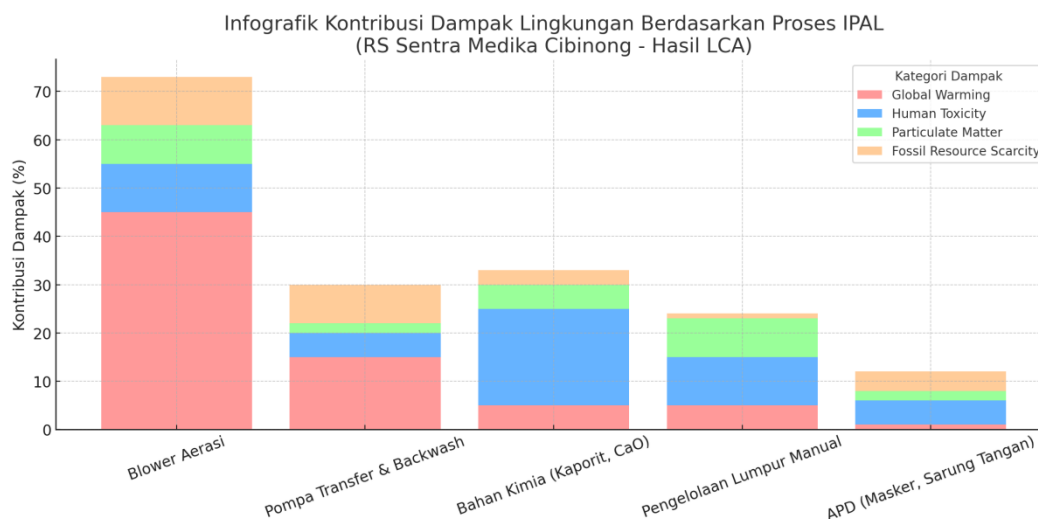


Figure 1. Environmental Impact Contributions by WWTP Processes at Sentra Medika Cibinong Hospital

Health Risks to Workers Based on LCA

The Life Cycle Assessment (LCA) applied to the hospital wastewater treatment system indicates that several technical processes contribute significantly to environmental impact categories that correlate with human health risks. These findings are reinforced by survey data documenting health complaints from wastewater treatment personnel (IPAL operators) at the hospital. The LCA identified several environmental impact categories directly associated with human health risks:

1. **Human Toxicity (Non-Cancer and Cancer):**
This category reflects the potential hazards of chemical substances or toxic agents that may cause systemic disorders, allergic reactions, or irritation upon exposure.
2. **Particulate Matter Formation:**
Exposure to fine particulate matter, typically originating from chemical use or mechanical processes, poses a respiratory hazard to workers and may contribute to long-term pulmonary conditions.
3. **Terrestrial and Freshwater Ecotoxicity:**
This category indicates the presence of contaminants in soil and water ecosystems that can indirectly affect human health through food chains or direct contact.

Overall, these findings underscore the need for targeted mitigation strategies in the hospital's wastewater management system, particularly in reducing chemical exposure, improving engineering controls, and enhancing occupational health and safety protocols for workers.

DISCUSSION

Characteristics and Volume of Hospital Wastewater

The wastewater generated at Sentra Medika Cibinong Hospital originates from various medical and non-medical activities, including inpatient wards, operating rooms, laboratories, emergency departments, kitchens, laundries, canteens, and toilets. Data collected during the study period revealed that the average volume of wastewater produced was approximately 2,688 m³ per month, or 89.6 m³ per day, with the highest daily volume recorded in December at 105.19 m³/day—exceeding the current installed capacity of the hospital's Wastewater Treatment Plant (WWTP), which is 100 m³/day.

This finding highlights a critical issue in the balance between wastewater generation and treatment capacity, aligning with findings by Yekti (2021), who reported that limited WWTP capacity is a key driver of increased hospital wastewater pollution and underperformance in treatment efficiency. Hospital wastewater is characteristically complex and poses a significant environmental pollution risk if not properly managed. According to the World Health Organization (2014) and the Indonesian Ministry of Health (Regulation No. 7/2019), hospital wastewater may contain organic and inorganic matter, pathogenic microorganisms (viruses, bacteria, protozoa), toxic chemicals (e.g., chlorine, heavy metals), and pharmaceutical residues *World Health Organization (WHO)*. This study assessed wastewater parameters including BOD, COD, TSS, pH, temperature, and pathogenic microorganisms, in accordance with environmental quality standards under Ministerial Regulation No. 5/2014 [7]. Peraturan Menteri Lingkungan Hidup Dan Kehutanan Republik Indonesia

Studies such as Kümmerer et al. (2018) in *Science of the Total Environment* have shown that hospitals produce wastewater with high organic and microbial loads—particularly from laboratories, isolation wards, and medical equipment cleaning—with BOD concentrations up

to 500 mg/L and COD up to 1,000 mg/L, substantially exceeding typical domestic wastewater levels. Similarly, Sarwono (2024) found that the mismatch between wastewater load and WWTP capacity at RS Pupuk Kaltim Bontang increased environmental pollution and direct occupational exposure risks.

Wastewater Management at Sentra Medika Cibinong Hospital

Wastewater management at Sentra Medika Cibinong Hospital plays a crucial role in environmental health, aiming to prevent pollution and protect both public and occupational health. The hospital operates a 100 m³/day anaerobic-aerobic biofilter WWTP, combining biological decomposition under both oxygen-free and oxygen-rich conditions. Despite this infrastructure, the system faces structural and operational challenges affecting treatment effectiveness. As observed, the average daily wastewater volume often approaches or exceeds plant capacity, especially during periods of high patient occupancy. For instance, in certain months, volumes reached up to 105.19 m³/day, causing system overload. This condition parallels findings from Yekti (2021) in the SIER Industrial Estate, where WWTP overloading led to decreased treatment efficiency and elevated pollutant levels (BOD, COD, TSS) in effluent. A major systemic issue is the lack of comprehensive integration. Several facilities—including the mortuary, crematorium, canteen, and radiotherapy building—are not connected to the central WWTP, increasing the risk of untreated discharge into the surrounding environment. This condition violates principles of integrated hospital wastewater management as mandated by MoH Regulation No. 7/2019, which requires holistic treatment coverage across all hospital units.

The WWTP's energy use also contributes to environmental burdens. Mechanical components such as aeration blowers consume the most energy at 2.238 kWh/m³, followed by transfer pumps (0.746 kWh/m³) and backwash pumps (1.119 kWh/m³). This energy consumption significantly contributes to greenhouse gas emissions. These results are consistent with findings by Sampurno (2023) at RSPAL Dr. Ramelan Hospital, identifying the aeration unit as the main contributor to global warming potential (GWP) in LCA assessments. Chemically, the hospital employs conventional disinfection using calcium hypochlorite (Ca(OCl)₂) and neutralization with quicklime (CaO) and sodium carbonate (NaHCO₃). While effective for microbial reduction, these chemicals contribute to human toxicity and freshwater ecotoxicity impacts, echoing concerns raised by Kümmerer et al. (2018) about the long-term accumulation of disinfectants in aquatic environments.

Sludge management is another concern. Sludge from sedimentation units is removed manually without mechanical dewatering technology or proper occupational health and safety (OHS) protections. This exposes staff to biological and chemical contaminants. Sarwono (2024) also emphasized sludge handling as a key hotspot in climate and health impact risk, especially when performed without adequate equipment or training. Another overlooked issue is the wide range of personnel involved in wastewater tasks, including technicians, gardeners, cleaning staff, and kitchen workers, most of whom lack health and safety training. Pratiwi (2023) found that IPAL operators in shipbuilding industries exhibited high vulnerability to respiratory and skin conditions due to gas exposure from anaerobic-aerobic processes and disinfectants.

Systemic Gaps in Wastewater Distribution

The hospital's wastewater distribution system is designed to channel effluent from service units to the WWTP. However, observations show that several buildings remain disconnected, with potential discharge into open drains or municipal sewer systems. This increases the likelihood of environmental contamination in nearby public spaces such as gardens, kitchens, or parking areas. Identified risks in the wastewater distribution system include: Lack of a detailed piping map, complicating leak detection and repairs, Absence of separation between

medical and non-medical wastewater streams, compromising WWTP effectiveness and increasing toxic exposure. Infrequent inspection and maintenance of pipelines and control chambers, resulting in blockages, backflow, and undetected leaks. These issues mirror findings by Yekti (2021) in SIER, where poor distribution network design was a major contributor to pollution accumulation in initial treatment units. Such systemic gaps are particularly alarming considering the hospital's proximity to residential neighborhoods. These findings point to non-compliance with environmental sanitation requirements under MoH Regulation No. 7/2019, which mandates integrated, compliant wastewater systems for hospitals.

Health Impacts and Occupational Risks

An incomplete and partially open distribution system presents direct health hazards to sanitation staff. Survey results revealed that workers frequently reported health issues during maintenance activities (e.g., control chamber cleaning or pipe repairs), including skin irritation, respiratory discomfort, headaches, nausea, and vomiting. These findings are consistent with WHO (2014), which notes that open or leaky sewage systems can emit toxic gases (e.g., H₂S, CH₄) and harbor disease vectors such as flies and cockroaches (WHO, 2014). As recommended by Sampurno (2023), optimizing wastewater infrastructure is essential to reduce emissions, occupational hazards, and improve treatment efficiency through targeted LCA-based strategies.

Wastewater Management at Sentra Medika Cibinong Hospital

Wastewater management at Sentra Medika Cibinong Hospital constitutes a critical component of environmental health management, aimed at preventing pollution and safeguarding the health of both the public and healthcare workers. The hospital is equipped with a Wastewater Treatment Plant (WWTP) with an installed capacity of 100 m³/day, utilizing an anaerobic-aerobic biofilter system—a combined method involving biological decomposition of organic substances under anaerobic (without oxygen) and aerobic (with oxygen) conditions. Nevertheless, the hospital continues to face several structural and operational issues that affect the effectiveness of its current WWTP. Research data indicate that the existing plant capacity is insufficient to accommodate the wastewater load from all hospital activities, especially during periods of high patient occupancy. The average wastewater volume reaches 89.6 m³/day, with occasional peaks exceeding the maximum WWTP capacity, such as 105.19 m³/day in certain months. This aligns with findings from Yekti (2021) in the SIER industrial zone of Surabaya, which demonstrated that WWTP overload significantly reduces treatment efficiency and increases pollution indicators such as BOD, COD, and TSS.

Moreover, the hospital's wastewater management system lacks full integration. Several facilities—including the mortuary, crematorium, canteen, and radiotherapy building—are not connected to the central WWTP system, raising concerns over potential untreated discharge into the environment. This situation contradicts the principles of integrated hospital waste management as mandated in the Indonesian Ministry of Health Regulation No. 7 of 2019, which emphasizes comprehensive and unified wastewater management across all hospital units. From an energy use perspective, the WWTP heavily relies on mechanical equipment, with aeration blowers accounting for the highest energy consumption (2.238 kWh/m³), followed by transfer pumps (0.746 kWh/m³) and backwash filter pumps (1.119 kWh/m³). This energy usage contributes significantly to greenhouse gas emissions. These findings are consistent with Sampurno's (2023) study at RSPAL Dr. Ramelan Hospital in Surabaya, which identified the aeration unit as the major contributor to global warming potential in hospital WWTPs using Life Cycle Assessment (LCA).

Regarding chemical usage, the final disinfection stage at the hospital still relies on conventional methods involving calcium hypochlorite, quicklime (CaO), and sodium carbonate (NaHCO₃). While effective in reducing microbiological contaminants, these substances pose toxicity risks in categories such as human health and freshwater ecotoxicity,

as highlighted by Kümmerer et al. (2018) in *Science of the Total Environment*, particularly due to the potential accumulation of disinfectants in aquatic ecosystems.³⁷ Another significant issue is the management of sludge, which lacks mechanical treatment or drying systems. Sludge from sedimentation units is manually removed by personnel without proper occupational safety measures, exposing them to biological and chemical hazards. This also increases the workload of non-sanitarian staff. Sarwono (2024), in his study at Pupuk Kaltim Hospital in Bontang, also emphasized sludge management as a hotspot contributing to both climate change and occupational health risks when conducted without protective equipment or further treatment.

Furthermore, wastewater handling at the hospital involves various staff members beyond sanitarians, including technical staff, gardeners, cleaning services, and kitchen workers. Limited training and inadequate protective measures increase their risk of direct exposure to hazardous substances. Pratiwi's (2023) study on shipyard industry workers found that WWTP personnel are highly vulnerable to respiratory and dermatological issues due to exposure to gases from anaerobic-aerobic processes and disinfectants. Based on a comprehensive evaluation, it can be concluded that wastewater management at Sentra Medika Cibinong Hospital is at a critical point and requires significant improvement. The following strategic measures are recommended based on analytical findings and comparisons with relevant literature: (1) Increase WWTP capacity to at least 300 m³/day based on estimated clean water demand (400–450 L/bed/day) and a wastewater conversion rate of 85–90% (MOH Regulation No. 7/2019). (2) Integrate all wastewater sources into a unified WWTP pipeline system. (3) Apply energy-efficient technologies in the aeration unit, such as fine bubble diffusers or inverter blowers. (4) Substitute conventional disinfectants with low-toxicity and environmentally friendly chemicals (e.g., liquid sodium hypochlorite). (5) Automate sludge dewatering using geobags or belt press systems to minimize direct exposure risks. (6) Enhance staff competencies and occupational safety through regular training and provision of standard PPE for WWTP operations.

By applying a comprehensive Life Cycle Assessment (LCA) approach, the hospital can identify the most impactful stages of wastewater treatment on environmental and occupational health, and design a more efficient, safe, and sustainable waste management system in line with the national framework for environmental health development. The WWTP at Sentra Medika Cibinong operates using an anaerobic-aerobic biofilter system with a capacity of 100 m³/day. Wastewater volume data indicate that during November and December, influent volumes exceeded the WWTP's design capacity, reaching 98.70–105.19 m³/day. This condition poses the following risks: (1) Biological treatment processes may be disrupted due to overload, resulting in reduced treatment efficiency. (2) Effluent parameters such as BOD, COD, TSS, and Ammonia show fluctuating values, occasionally exceeding regulatory limits.

The hospital's wastewater piping system is designed to channel effluent from various service units to the WWTP. However, field observations reveal that certain buildings—including the general canteen, mortuary, oncology services, and crematorium—are not yet fully connected to the WWTP system. Consequently, wastewater from these buildings may be discharged into open drains or municipal drainage, increasing the risk of environmental contamination near open service areas such as gardens, kitchens, or parking lots. Field assessments identified several hazards in the hospital's wastewater conveyance system, including: (1) Inadequate pipeline mapping, which hinders leak tracing and source identification; (2) Lack of segregation between medical and non-medical wastewater channels, reducing WWTP efficiency and increasing hazardous exposure risk; (3) Absence of routine monitoring for pipelines and control chambers, leading to frequent blockages, backflows, or undetected leaks.

These problems mirror those found in Yekti's (2021) study of the SIER industrial WWTP, where poor conveyance system organization was the main cause of pollutant buildup in the initial distribution unit. Such system fragmentation poses serious environmental health threats, especially given the hospital's proximity to residential areas. This reveals a discrepancy between the existing conveyance system and the principles of area sanitation as stipulated in MOH Regulation No. 7 of 2019, which mandates that hospital sanitation systems meet the standards of integration and treatment of all wastewater types (Kemenkes RI, 2019). Additionally, the incomplete and insecure wastewater conveyance system exposes sanitation workers to direct hazards. Surveys conducted during this study reported various health symptoms experienced by staff while cleaning control chambers or repairing pipes, including skin irritation, respiratory problems, dizziness, and nausea. These findings align with WHO (2014), which stated that open or leaking wastewater channels may release toxic gases such as H₂S and CH₄, and provide breeding grounds for disease vectors like flies and cockroaches (*European Agency for Safety and Health at Work, 2018*). Sampurno (2023) also emphasized in his LCA study at RSPAL Dr. Ramelan Hospital that improvements in wastewater conveyance systems are crucial for reducing emissions, minimizing occupational accidents, and enhancing overall treatment efficiency.

Health Disorders among Wastewater Treatment Facility Workers

The Wastewater Treatment Plant (WWTP) is a critical component of the hospital's sanitation infrastructure. At Sentra Medika Cibinong Hospital, WWTP operations involve personnel from various backgrounds, including environmental health staff, technicians, cleaning service workers, gardeners, and kitchen staff. These individuals are engaged in high-risk tasks such as cleaning control tanks, collecting samples, administering chemicals (e.g., chlorine and quicklime), and manually handling sludge.

1. Types of Health Disorders Identified

A survey of 33 WWTP personnel revealed that 85% reported experiencing health complaints. The most frequently reported issues were respiratory disorders, predominantly associated with the aeration process involving blowers, which emit gases such as hydrogen sulfide (H₂S) and ammonia. Dizziness and nausea were commonly experienced near chemical processing units, while skin problems and allergies were prevalent among workers involved in manual sludge handling and cleaning tasks.

2. Sources of Exposure Risk

Three primary processes were identified as sources of occupational health risks: (1) Aeration using blowers → Emission of gases and fine particulates (contributing to particulate matter formation in LCA). (2) Chemical use → Acute and chronic toxicity potential (contributing to human toxicity in LCA). (3) Manual sludge handling → Direct contact with hazardous waste and pathogenic microorganisms. These risks are exacerbated by inconsistent use of personal protective equipment (PPE), inadequate occupational safety and health (OSH) training, and poor ventilation in WWTP areas.

3. Relation to Life Cycle Assessment (LCA) Findings

LCA analysis indicated that the impact categories "Human Toxicity" and "Particulate Matter Formation" had the highest contribution to worker health risks. Emissions from aeration and chemical treatment significantly contributed to respiratory and neurological disorders, while manual sludge handling was linked to dermatological and infectious conditions. Based on the activity mapping and LCA results, the following WWTP processes pose the greatest health risks:

a. **Aeration:** Generates bioaerosols and toxic gases (e.g., ammonia, H₂S), and particulates that irritate the respiratory tract and may affect the central nervous system. Moya et al. (2011) in the *International Journal of Hygiene and Environmental Health* found that hospital WWTP

operators are at risk of H₂S and airborne endotoxin exposure, potentially leading to chronic bronchitis, persistent coughing, and shortness of breath.

b. Chemical handling: Disinfectants such as calcium hypochlorite (chlorine) release strong oxidizing agents that can irritate the skin and respiratory tract. WHO (2014) reports chronic exposure to chlorine can cause corrosive effects on the respiratory system and skin, particularly in poorly ventilated workspaces. Kümmerer et al. (2018) in *Science of the Total Environment* further warn that hospital disinfectants contribute to human toxicity and hypersensitivity reactions.

c. Manual sludge management: Performed without enclosed systems, resulting in direct contact with pathogens (e.g., *E. coli*, *Salmonella*, viruses) and hazardous chemicals absorbed in the sludge. Workers without PPE face higher risks of gastrointestinal and skin infections due to prolonged biological exposure.

Despite the high-risk nature of these processes, occupational protection systems for WWTP workers at Sentra Medika Cibinong Hospital remain inadequate. Observations revealed inconsistent PPE usage; some workers handled liquid waste and sludge without gloves or masks. There was no routine, WWTP-specific OSH training, and the chemical and aeration rooms lacked proper ventilation systems. Muhammad Abdul Rofiq (2019) emphasized that PPE compliance is influenced by risk perception and training. Without regular training, workers' understanding of occupational hazards remains low. Sampurno (2023), in an LCA study of RSPAL Surabaya, concluded that health risks can be significantly reduced through automated sludge handling systems, the use of low-toxicity chemicals, and proper ventilation engineering. Repeated exposure to WWTP contaminants can cause both acute and chronic conditions. Mild neurological symptoms (e.g., dizziness, fatigue, difficulty concentrating) reported by some respondents may indicate chronic exposure to volatile organic compounds (VOCs) or hydrogen sulfide (H₂S). Moreover, the existence of non-medical units (e.g., crematorium, mortuary) not yet integrated with the WWTP has increased the workload without corresponding enhancements in worker protection or manpower.

Strategic technical and behavioral interventions are needed to reduce health risks among WWTP personnel, including: (1) Periodic occupational risk audits using LCA and Hazard Identification and Risk Assessment (HIRA). (2) Implementation of OSH-based Standard Operating Procedures (SOPs), especially for sludge handling and disinfection stages. (3) Regular provision and monitoring of full PPE use. (4) Periodic training for all workers, including non-healthcare staff, on waste handling and occupational disease prevention. (5) Routine health monitoring (e.g., lung, skin, and liver function checks) for early detection of WWTP-related health issues.

Results of the Life Cycle Assessment (LCA)

This study employed a cradle-to-gate Life Cycle Assessment (LCA) approach, encompassing all wastewater treatment processes—from collection and biological/chemical treatment to the discharge of treated effluent into the environment. The analysis was conducted using SimaPro 9.0 software and applied the ReCiPe 2016 Midpoint characterization method, allowing for detailed evaluation of impact categories such as Global Warming Potential (GWP), Human Toxicity, Ecotoxicity, and Particulate Matter Formation. The environmental impact contributions by WWTP processes at Sentra Medika Cibinong Hospital are illustrated in the following figure:

LCA simulation results indicate that the largest environmental impacts are derived from electricity consumption, chemical usage, and sludge management processes. Key findings include: (1) Aeration blowers contribute up to 45% of total GWP due to electricity consumption of 2.238 kWh/m³. (2) Transfer and backwash pumps contribute approximately

15% of GWP and 8% of fossil resource depletion, reflecting Indonesia's coal-dependent energy mix. (3) Chemicals such as calcium hypochlorite and quicklime are major contributors to the Human Toxicity category (up to 20%) due to their acute and cumulative toxic effects on both workers and the environment. (4) Manual sludge handling without closed systems contributes to Particulate Matter Formation (8%) and increases biological exposure risk. (5) Routine PPE use (e.g., masks, nitrile gloves), although minimal in volume, still contributes to plastic waste and fossil resource depletion.

These results align with several studies on LCA in hospital and industrial WWTPs. Sampurno (2023) found that blowers and sludge handling units accounted for over 60% of total environmental impacts, particularly in GWP and Human Toxicity. Chlorine use and manual processes exacerbated health and environmental impacts. Sarwono (2024) reported that the biological treatment unit at a fertilizer hospital contributed 252,000 kg CO₂ eq/year, with Respiratory Inorganics (PM Formation) being the largest contributor to health-related impacts (DALYs). Kümmerer et al. (2018) highlighted that chlorine-based disinfectants in hospital WWTPs produce hazardous by-products (e.g., AOX) with carcinogenic and mutagenic effects, raising freshwater ecotoxicity levels. Pratiwi (2023) found that in shipyard industries using aerobic-anaerobic biofilters, sludge handling was the largest contributor to particulate matter and long-term respiratory issues.

Strategic recommendations based on the LCA findings include: (1) Energy efficiency: Replace conventional blowers with energy-saving technologies like inverter blowers or fine bubble diffusers. Consider solar panels for partial electricity supply. (2) Chemical alternatives: Reduce dependence on calcium hypochlorite by switching to liquid sodium hypochlorite or UV disinfection to reduce human toxicity and exposure risks. (3) Sludge management: Adopt enclosed sludge drying beds or automated belt presses to minimize manual labor and pathogen exposure. (4) Automated monitoring systems (SCADA): Enable real-time control of chemical dosing, flow rates, temperature, and pH to prevent overdosing and operational issues. (5) LCA integration in hospital management: Use LCA findings as a basis for environmental and occupational health evaluations and for long-term planning of sustainable WWTP technology.

CONCLUSION

The evaluation of wastewater management at Sentra Medika Cibinong Hospital revealed significant technical, environmental, and occupational health challenges in the operation of its Wastewater Treatment Plant (WWTP). Key findings indicate that the aeration and sludge management processes consume large amounts of energy, utilize hazardous chemicals, and expose workers to high occupational health risks, including respiratory, dermatological, and neurological disorders. Life Cycle Assessment (LCA) using the ReCiPe 2016 Midpoint method identified the aeration system, chemical disinfection, and manual sludge handling as the main contributors to environmental impacts—particularly in the categories of Global Warming Potential (GWP), Human Toxicity, and Particulate Matter Formation. These processes not only generate significant emissions and toxic by-products but also lack adequate engineering controls and occupational health safeguards. The health risk assessment further confirmed that 85% of WWTP personnel experienced symptoms associated with chronic exposure to gases, chemicals, and biological agents, with inadequate use of personal protective equipment (PPE) and poor ventilation exacerbating these risks. To improve sustainability and safety, a multi-dimensional approach is essential. This includes upgrading to energy-efficient and automated treatment technologies, substituting high-toxicity disinfectants with safer alternatives, adopting enclosed sludge handling systems, enhancing occupational safety training, and conducting routine health surveillance of WWTP workers. Integrating LCA into hospital wastewater management enables evidence-based

decisions that align environmental sustainability with occupational health protection. Such integration is critical for achieving long-term improvements in hospital environmental performance, safeguarding worker health, and complying with national environmental and occupational regulations.

REFERENCES

- Adi, B. K. (2023). Pengelolaan limbah B3 (bahan berbahaya beracun) di RSUD Dr. Soehadi Prijonegoro Sragen: Pendekatan life cycle assessment (LCA).
- European Agency for Safety and Health at Work. (2018). Management of occupational health and safety in European workplaces — Evidence from the Second European Survey of Enterprises on New and Emerging Risks (ESENER-2).
- Julianto, A. (2023). Perbedaan penurunan kandungan bakteri *Escherichia coli* dengan pemberian klorin pada limbah cair RSUD Dr. H. Koesnadi Bondowoso.
- Kementerian Kesehatan Republik Indonesia. (2019). Peraturan Menteri Kesehatan Republik Indonesia Nomor 7 Tahun 2019 tentang Kesehatan Lingkungan Rumah Sakit.
- Kementerian Kesehatan Republik Indonesia. (2020). Peraturan Menteri Kesehatan Republik Indonesia Nomor 3 Tahun 2020 tentang Klasifikasi dan Perizinan Rumah Sakit.
- Kümmerer, K., et al. (2018). [Article on environmental impact]. *Science of The Total Environment*.
- Khoiroh, U. (2020). Pengolahan limbah cair di UPT Rumah Sakit Mata Masyarakat Jawa Timur.
- Neshart, R., Wibowo, D., & Sukri, A. S. (2021). Perencanaan desain instalasi pengolahan air limbah dengan metode biofilter anaerob-aerob.
- Pratiwi, S. W., Zakiyayasin, S. Q., & Nisa, Z. (2023). Life cycle assessment (LCA) proses pengolahan air limbah domestik di perusahaan galangan kapal.
- Public Health Ontario. (2019). Recommendations for the prevention, detection and management of occupational contact dermatitis in health care settings.
- Rofiq, M. A., Siregar, S. D., & Wau, H. (2019). Hubungan penggunaan alat pelindung diri (APD) dan perilaku kerja dengan keselamatan kerja pada petugas kebersihan di Kelurahan Petisah Tengah.
- Sampurno, A. P., Adi, E. A., & Hidayah, E. N. (2022). Penerapan life cycle assessment pada sistem manajemen pengolahan limbah rumah sakit (Studi kasus di RSPAL Dr. Ramelan Surabaya).
- Said, N. I. (2006). Paket teknologi pengolahan air limbah rumah sakit yang murah dan efisien. BPPT, Kelompok Teknologi Pengelolaan Air Bersih dan Limbah Cair.
- Sarwono, E., Rahayu, D. E., Huda, H., Ibrahim, & Buraka, M. I. (2024). Analisis life cycle assessment (LCA) pada instalasi pengolahan air limbah (IPAL) Rumah Sakit Pupuk Kaltim Bontang.
- World Health Organization. (2014). Safe management of wastes from health-care activities (2nd ed.).

Yekti, H. S., & Mirwan, M. (2021). Analisis dampak pencemaran lingkungan dengan metode Life Cycle Assessment (LCA) pada instalasi pengolahan air limbah (IPAL) PT. Surabaya Indu