

Technical Management Impact Assessment Wastewater Against Health Problems in Sanitarian Workers at Hospital X With *A Life Cycle Analysis (LCA) Approach*

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ABSTRACT

Hospital wastewater, laden with organic, microbial, and chemical contaminants, poses significant environmental and occupational health risks. Despite regulations, gaps persist in integrated assessment and mitigation strategies. This study evaluates the environmental and health impacts of wastewater management at Hospital X using LCA, identifying hotspots in energy use, chemical toxicity, and worker exposure. A mixed-methods approach combined LCA (SimaPro 9.0, *ReCiPe 2016 Midpoint*) with surveys of 33 sanitarian workers. Data included WWTP performance metrics, effluent quality, and health complaints. The WWTP (100 m³/day) exceeded capacity (105 m³/day), with aeration (45% of GHG emissions) and chlorine use (20% human toxicity) as key hotspots. Health surveys revealed 85% of workers suffered respiratory/skin issues, correlating with LCA-identified exposure risks. The study underscores the need for capacity expansion (≥ 300 m³/day), automation (sludge handling), and renewable energy integration, offering a model for sustainable hospital wastewater management in Indonesia.

Keywords: *Life Cycle Assessment, hospital wastewater, occupational health, environmental impact, Indonesia*

INTRODUCTION

Efforts to improve health services in Indonesia, particularly in urban areas, have led to rapid hospital development. While hospitals enhance healthcare access, they also generate waste that can pollute the environment and harm nearby communities. Hospitals must operate with attention to environmental and public health, managing solid and liquid waste, clean water, and pest control. However, hospital activities produce hazardous clinical and non-clinical waste, including wastewater containing harmful microorganisms, which poses risks if not properly managed (Commission, 2022; Indonesia, 2010; Rahman et al., 2018; Susanti, 2021).

Hospital wastewater originates from domestic sources (bathrooms, kitchens, cleaning activities) and clinical activities (wound washing, laboratory waste, etc.). This wastewater can transmit diseases and contains physical, chemical, and biological pollutants, including pathogens, organic/inorganic substances, and heavy metals (Arnawilis et al., 2019; Fitriani, 2019; Hidayatullah, 2019; Hussin et al., 2018; Said, 2006; Tonis et al., 2019). Without proper treatment, it can contaminate water sources, harm aquatic life, and spread infections such as cholera, hepatitis, and schistosomiasis. Compliance with wastewater quality standards (e.g., pH, BOD, COD) is crucial to minimize environmental damage.

Sanitarian workers handling hospital wastewater face significant health risks, including infections from pathogens like *Salmonella* and *Vibrio cholera*. Exposure to toxic gases (e.g., hydrogen sulfide) can cause respiratory issues, while contact with wastewater may lead to skin irritation and dermatitis. Long-term exposure to chemicals can damage organs like the liver and kidneys. Stress and occupational hazards further endanger workers, emphasizing the need for protective measures and proper waste management protocols.

Indonesian regulations, such as the Minister of Environment Regulation No. 5 of 2014, mandate hospitals to treat wastewater before disposal. Parameters like BOD and COD must be

controlled to prevent oxygen depletion in water bodies, which can kill aquatic life. Efficient wastewater treatment is essential to meet legal standards and protect ecosystems, requiring hospitals to adopt advanced treatment technologies and sustainable practices.

LCA is a valuable tool for evaluating the environmental impact of hospital wastewater management from collection to disposal. It helps identify energy consumption, greenhouse gas emissions, and resource use at each stage, enabling improvements to reduce ecological footprints. Indonesia's Ministry of Environment encourages LCA adoption in industries, including healthcare, to promote sustainable development, cost savings, and better environmental compliance.

Hospital X, a Type B facility with 255 beds, faces capacity issues in its wastewater treatment plant (WWTP). Due to service expansion, its current 100 m³/day WWTP is insufficient, leading to fluctuating effluent quality. Additional facilities (e.g., crematoriums, canteens) discharge untreated wastewater, exacerbating pollution risks. With an 85% bed occupancy rate, proper wastewater management is critical, especially since the hospital is near residential areas.

A preliminary survey of Hospital X's sanitation staff (including environmental health workers, technicians, and cleaners) revealed health issues from wastewater exposure. Workers reported skin irritation, dizziness, nausea, and respiratory problems during tasks like chemical dosing, pump maintenance, and grease trap cleaning. These findings highlight the urgent need for improved safety measures, better WWTP capacity, and comprehensive risk assessments to protect both workers and the environment.

Therefore, based on the description above, this research is important to be carried out to help the hospital to design a strategy by conducting a Study on the Impact of Technical Wastewater Management on Health Problems in Sanitarian Officers at Hospital X with a *Life Cycle Assessment* (LCA) approach. The purpose of this study is to assess the environmental and health impacts on sanitation workers from wastewater management at Hospital X using the Life Cycle Assessment (LCA) approach, which involves identifying and analyzing the sources, characteristics, and quantity of wastewater generated, evaluating the hospital's wastewater management process, and determining the effects on both workers and the environment through LCA.

This study contributes to existing research by using a Life Cycle Assessment (LCA) approach to comprehensively assess both environmental and occupational health impacts of wastewater management at Hospital X—an area previously underexplored. Unlike earlier studies such as Sampurno et al. (2022) and Sarwono et al. (2024) that applied LCA to industrial or hospital wastewater treatment plants (WWTPs), this research uniquely incorporates worker health risk assessments—finding that 85% of sanitation officers reported respiratory or skin issues—and links these to exposure hotspots like aeration blowers and manual sludge handling. It also addresses region-specific challenges, such as unmanaged discharges from crematoriums and canteens, which are overlooked in previous works (Pratiwi & Nisa, 2023; Yekti & Mirwan, 2021). Furthermore, it quantifies inefficiencies in energy (2,238 kWh/m³ for aeration) and chemical use (chlorine toxicity) through LCA, offering targeted mitigation strategies such as solar-powered blowers and UV disinfection, moving beyond generic solutions.

RESEARCH METHODS

The research methodology adopted in this study utilizes a qualitative descriptive approach combined with the Life Cycle Assessment (LCA) framework. This methodological combination allows for a systematic examination of current conditions related to wastewater management at Hospital X. Data collection incorporates both primary sources, including direct measurements and field observations, and secondary sources consisting of structured interviews with purposively selected informants and relevant documentation.

For data gathering, several research instruments were employed. Laboratory examinations were conducted to assess wastewater quality at both the inlet and outlet points of the Hospital's Wastewater Treatment Plant (WWTP). The research team utilized specialized tools including SimaPro 9.0 software for conducting the LCA analysis and digital cameras for comprehensive documentation of field activities. The study materials primarily comprised existing wastewater management records maintained by Hospital X. Structured interviews were conducted with key informants to obtain qualitative insights, while standard stationery and laptop computers facilitated data recording and processing tasks.

The study population encompassed all 33 sanitation workers actively involved in wastewater management operations at Hospital X. This included environmental health professionals, cleaning staff, maintenance technicians, gardening personnel, and kitchen workers. Notably, the research sample consisted of the entire population, ensuring complete representation of all personnel engaged in wastewater treatment activities.

The research process was organized into three distinct phases. The preparatory phase involved an extensive literature review, selection of the research site, preliminary field observations, and completion of necessary administrative procedures including research permit acquisition. During the implementation phase, researchers coordinated with hospital management, conducted thorough inspections of the WWTP facilities, and carried out in-depth interviews with plant operators. The final completion phase focused on comprehensive data analysis using the LCA methodology, detailed assessment of environmental and health impacts, preparation of research reports, and consultation with academic supervisors to validate findings and conclusions. This rigorous methodological approach was designed to ensure the collection of accurate, reliable data for evaluating the full spectrum of wastewater management impacts at the study site.

RESEARCH RESULTS

Wastewater Distribution System In Hospital X

1. Wastewater Network System in Hospital X Building

The wastewater distribution system and network in the hospital building are essential infrastructure that serves to drain wastewater from various sources to the treatment unit before it is disposed of safely. These systems must be designed according to health and environmental standards to prevent the spread of infection and environmental pollution.

The wastewater distribution system and network from the building at Hospital X is divided into several components including:

a. Wastewater Pipes

Drain wastewater from toilets, urinals, floor drains, sinks, bathtubs, wastewater from laboratories and medical equipment washing

b. Floor drain

Installed on bathroom floors and corridors to drain water from room cleaning or spills

c. Control Tub

Access points to monitor, control, and facilitate the maintenance of pipelines and wastewater flows within pipelines

d. Greasetrap

To accommodate kitchen waste so that fat does not enter the main wastewater pipe system.

The workflow of the distribution system and wastewater network at Hospital X is as follows:

a) Wastewater from the source

Wastewater from its source (toilets, laboratories, kitchens, etc.) is drained through a closed pipeline network and separated by the type of liquid waste (wastewater and dirty water)

- b) Transportation by pipeline
Wastewater is gravitationally drained to the control basin as a temporary shelter
- c) Pre-screening through the control tank
Wastewater is collected for the purpose of filtering large particles in pre-treatment to avoid blockages in the pipeline
- d) Processing at WWTP
The wastewater treatment process is carried out at the Wastewater Treatment Plant (WWTP) using physical, biological and chemical methods
- e) Final disposal
After the wastewater is treated at the WWTP, the wastewater is flowed to the receiving water body, namely the Cikeas River

2. Maintenance Mechanism of Dirty Water and Wastewater Drainage System in Hospital X

Maintenance of the dirty water and wastewater network systems in hospital buildings is an important part of facility management. These systems must be properly maintained to prevent operational disruptions, prevent the spread of disease, and ensure wastewater is managed in accordance with health and environmental standards.

The maintenance mechanism of the dirty water network system and wastewater channels at Hospital X is carried out through:

a. Periodic Inspections and Inspections

- Periodic inspections

Periodic inspections of the wastewater network system and wastewater channels at Hospital X are carried out by officers of the Hospital Facilities and Infrastructure Maintenance Installation Unit (IPSRS) with weekly and monthly frequency. For weekly inspections, visual inspections are carried out for early detection of leaks or unpleasant odors, for monthly inspections, water flow checks are carried out for the main pipe, final disposal and also control tanks.

- Periodic checks

Periodic inspections of the dirty water network system and wastewater channels at Hospital X are carried out by several related work units, not only the IPSRS Unit but also the wastewater production unit such as nutrition installations and household units. Periodic inspection activities carried out include the detection of leaks and blockages in wastewater channels, physical checks of control tanks, filters and greasetraps.

b. Duct Cleaning and Maintenance

Cleaning and maintenance of wastewater channels at Hospital X includes:

- Regular Cleaning

Routine cleaning of wastewater channels is carried out by officers from the Household Unit or cleaning service officers and also by officers from the IPSRS Unit. Routine cleaning carried out includes manual cleaning of the control basin to remove sludge or dirt that settles, cleaning floor drains in the kitchen area and hospital corridor areas.

- Trap Cleaning

Cleaning traps or grease filters in the kitchen is carried out by kitchen staff every 3 days.



Figure 1. Image Cleaning and treatment of wastewater lines at Hospital X

c. Repair and Replacement of Components

Repair and replacement of components in the dirty water network system and wastewater channels at Hospital X are carried out by IPSRS unit officers including repairing pipes that have leaks or damage and replacing pipe components that are worn or damaged due to corrosion.

d. Sludge and sediment management

Sludge and wastewater sediment management at Hospital X is carried out through draining sludge in the control basin periodically, which is once every 3 months or as needed. The draining and lifting of mud in the control basin was carried out by cleaning service officers and technicians from the IPSRS unit. The sludge that is lifted is dried and disposed of according to B3 waste management standards.

The routine maintenance schedule of the dirty water network system and wastewater channels at Hospital X is as follows:

Table 1. Routine maintenance schedule Dirty water network system and wastewater lines at Hospital X

Activities	Frequency	Action	Responsible
Visual inspection	Weekly and Monthly	Check for leaks, bad odors and water flow	IPSRS Unit and Household Unit
Control Tank Checking	Downloads	Check for deposits, leaks and the physical condition of the tub	IPSRS Unit and Household Unit
Floor Drain Cleaning	Downloads	Cleaning drains of dirt and blockages	IPSRS Unit and Household Unit
Drain Control Tub	3 monthly	Mud and sediment cleaning	IPSRS Unit and Household Unit
Grease trap cleaning	Once every 3 days	Eliminates fat buildup in the kitchen area	Nutrition Installation (Kitchen)
Pipe treatment with jetting	6 monthly	Cleaning pipes with high pressure to prevent clogging	Unit IPSRS

Source : RS X Secondary Data

A. Existing Conditions of Wastewater Treatment Plants at Hospital X

The wastewater treatment plant (WWTP) of Hospital X has been established since 2012. The wastewater treatment plant system (WWTP) at Hospital X uses a biological system, namely Aerobic and Anaerobic Biofilters, in this system all wastewater produced by hospital activities, namely those derived from domestic waste and wastewater derived from hospital clinical activities. Hospital X has a Wastewater Treatment Plant (WWTP) with a capacity of 100 M3/day, but as time goes by and the development of hospital services, the current WWTP of Hospital X is no longer in accordance with the required capacity. This has an impact on the effluent results of WWTP, where the results of the effluent quality swapantau inspection often fluctuate and are difficult to control. In addition to the rapid development of services at Hospital X, there is also a need for region-based wastewater management, because within the area of Hospital X there are also funeral home activities, crematoriums and public canteens which currently have not been managed for the wastewater produced.

The Wastewater Treatment Plant (WWTP) owned by Hospital X is a biological treatment system with an anaerobic-aerobic biofilter method. This system is designed to treat liquid waste from hospital activities to meet quality standards before it is discharged into the environment. WWTP consists of several main components, as follows:

1. Control Tub

Wastewater from various activities in hospitals, including from the kitchen after passing through closed channels or wastewater pipes enters the control tub. At Hospital X, there are 4 units of control tanks, all of which function as initial reservoirs before being distributed to WWTP. Wastewater control tanks themselves are structures or containers used to monitor, direct, and control the flow of wastewater in the sewer system. The control basin functions to precipitate sludge and solid particles before the wastewater flows into the WWTP with the aim of preventing blockages in the WWTP channel.

This control basin is an initial wastewater collection tank from the building with a capacity of 3.6 M3 each with dimensions of 60 cm x 60 cm. From the various activities of work units in hospitals that produce liquid waste, there are pipes or channels that are connected to the control tank. All liquid waste from these activities will enter the control basin before finally being flowed to the WWTP by gravity. The sources of liquid waste that enter each control basin are described as follows:

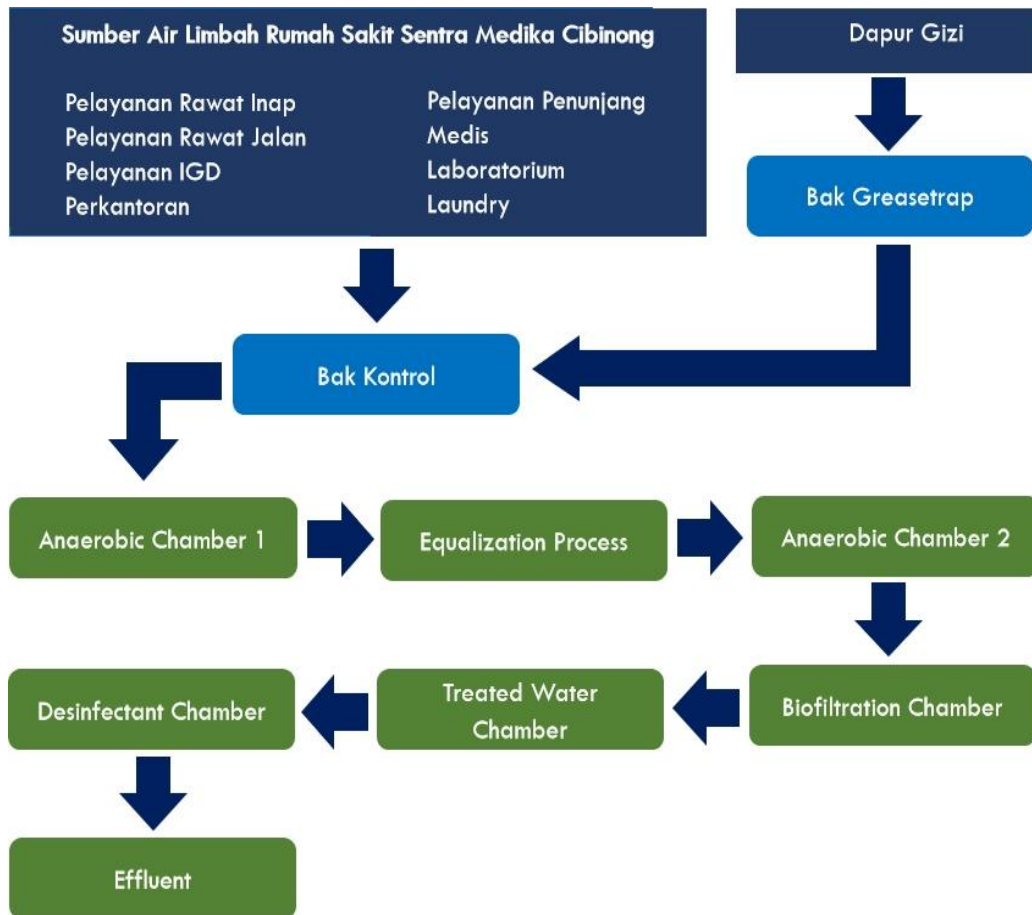


Figure 2. Liquid Waste Flow Diagram Drawing at WWTP Hospital X

Based on the chart, it can be seen that each control basin accommodates wastewater from all activities at Hospital X. Control tanks are maintained or cleaned by officers on a regular basis.





Figure 3. Picture of Officers Performing Control Tank Maintenance

2. Grease Trap

Hospitals are health facilities that not only provide medical services, but also produce various types of waste, including liquid waste containing fats and oils. One of the important components in the liquid waste management system in hospitals is *the grease trap*. *Grease traps* serve as a grease trap and oil from the hospital's kitchen activities before liquid waste is discharged into public sewers.

At Hospital X, there is a grease trap that is placed in the hospital kitchen area. *Grease traps* play an important role in preventing environmental pollution due to the accumulation of grease and oil in the sewers. If not handled properly, grease can harden and clog waterways, causing an unpleasant odor, and increasing the risk of groundwater and environmental pollution. Therefore, the installation and maintenance of greasetraps is a crucial step in maintaining cleanliness and meeting health and environmental standards. At Hospital X, *grease trap* maintenance is carried out every 3 days by the hospital kitchen staff, this activity is carried out to avoid blockage of the drain, besides that to avoid fat buildup, the officer inserts fat diluting drugs into *the grease trap*. The water flow from *the grease trap* will then enter the control tank before going to the WWTP. The *grease trap capacity* owned by Hospital X with a capacity of 2 M3 with dimensions of 2 x 1 x 1



Figure 4. Grease trap *Pictures* & Grease trap Maintenance Process Pictures at RS X

3. Wastewater Treatment Plant (WWTP) *Aerobic Anaerobic Biofilter system*

The wastewater treatment system at Hospital X uses an aerobic anaerobic biofilter system in the form of a manufacturer's tank with the following specifications:

Fire : Beaten

Type Tank : BMM - 100

Material Tank : FRP (Fiberglass Reinforced Plastic)

Machinery :

- Equalization blower, Yasunaga LP-120, 120 l/min, 1 phase 220 V, 118 W (1 unit)
- Aeration blower, Medo LAM-200, 200 l/min, 1 phase 220 V, 215 W (1 unit)
- Backwash Blower, Yasunaga LW-200, 200 l/min, 1 phase 220 V, 230 W (1 unit)
- Control Panel (1 unit)

The process diagram of Hospital X is as follows:

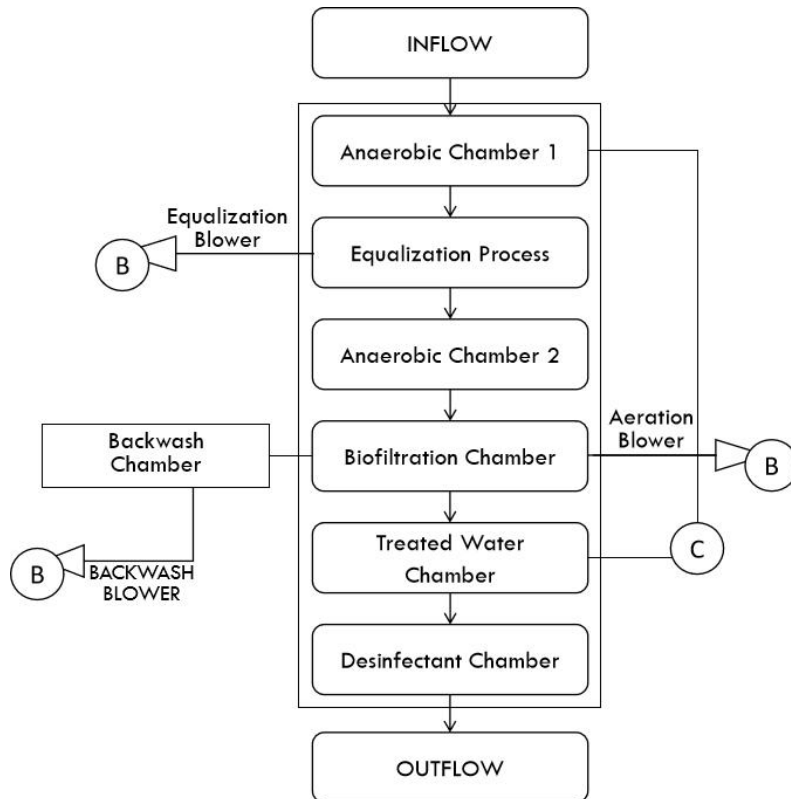


Figure 5. Process Diagram of the RS X WWTP System

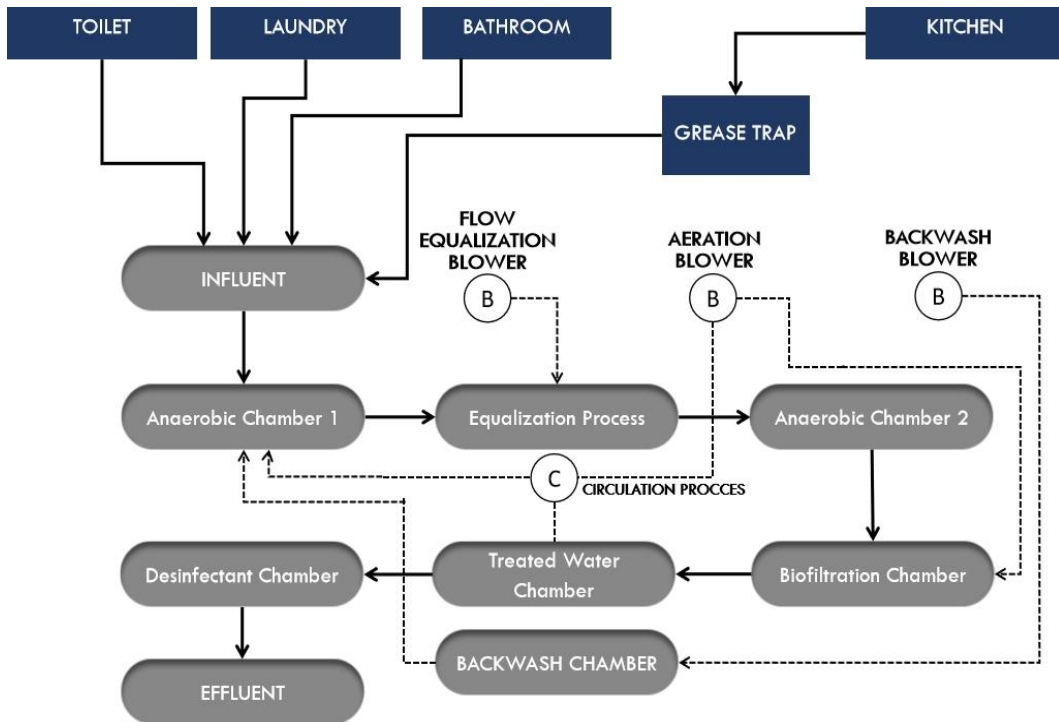


Figure 6. Flow Chart System IPAL RS X

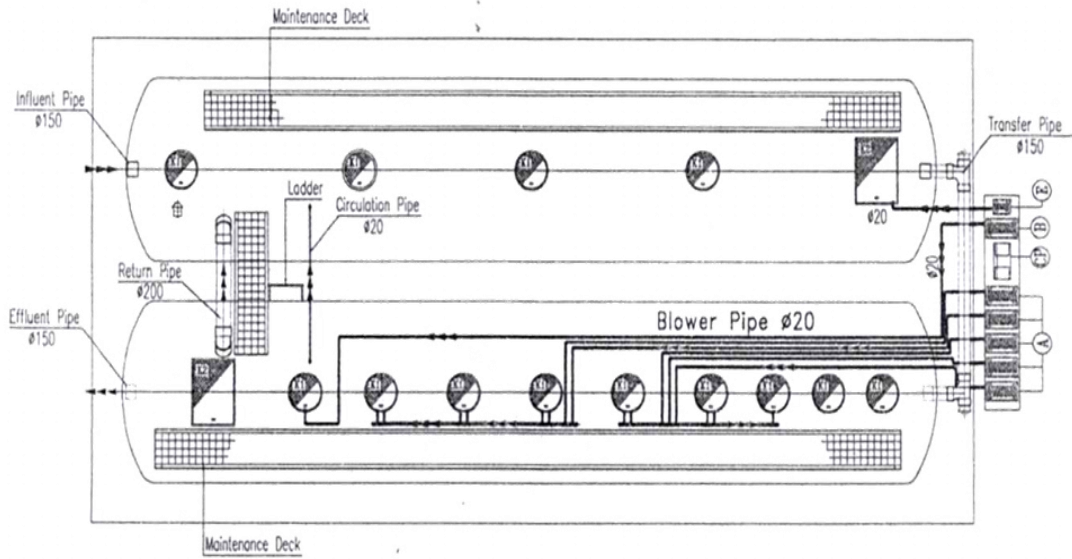


Figure 7. Drawing of the wastewater flow pipeline of the RS X WWTP System

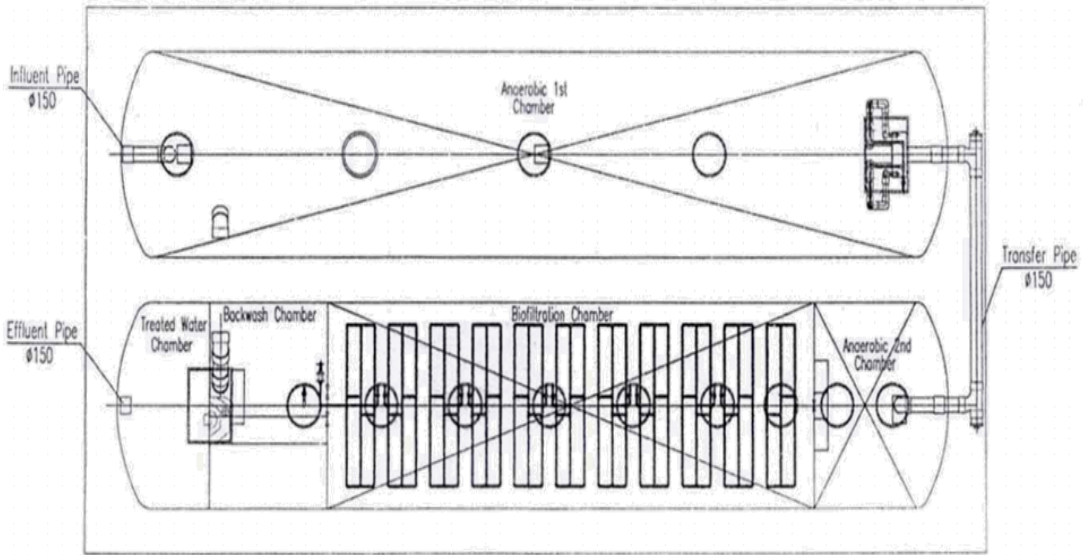
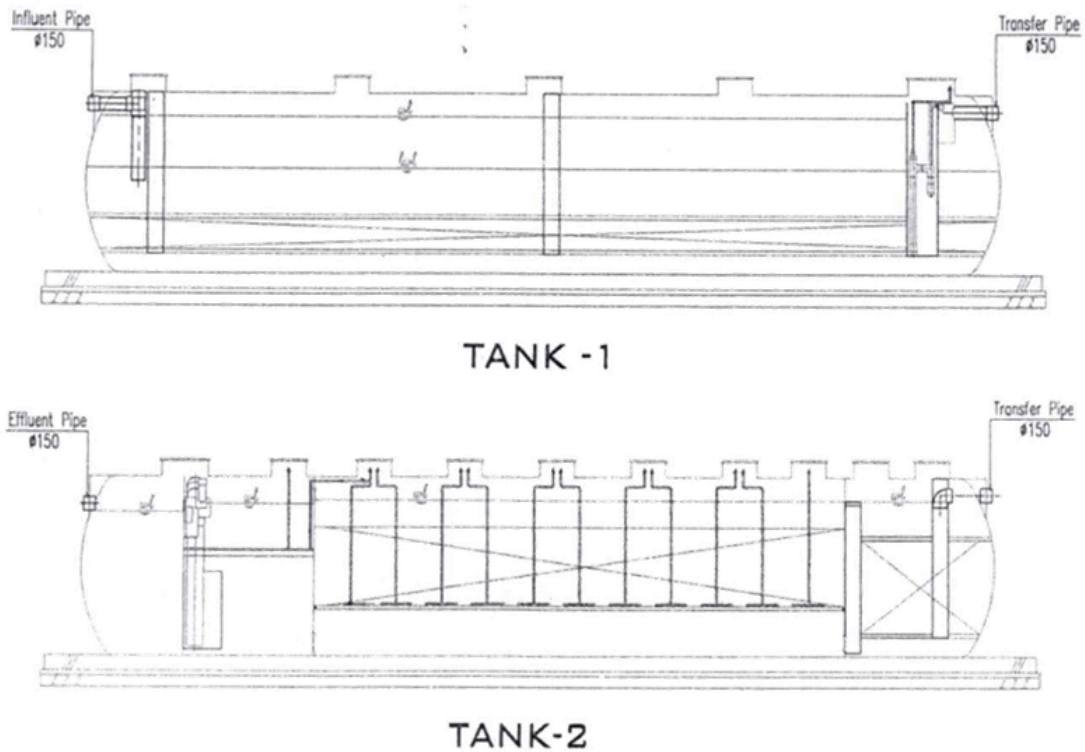


Figure 8. Top View of IPAL RS X



[Pic. 1-5] Drawing Section Tanki 1 & 2

Figure 9. Side View of WWTP RS X

Source : RS X Secondary Data

a. Anaerobic Chamber 1 & 2

An anaerobic chamber is a part of the treatment system that functions to decompose organic matter in wastewater in the absence of oxygen. This process is carried out by anaerobic bacteria that convert organic matter into methane (CH_4), carbon dioxide (CO_2), and biomass.

b. Equalization Process

Equalization tank is a unit in the wastewater treatment system that functions as a temporary reservoir to stabilize the discharge and characteristics of liquid waste, so that the next treatment process can run efficiently and consistently.

c. Biofiltration Chamber

A biofiltration chamber is a waste treatment unit that uses biological media and the activity of microorganisms to filter and decompose pollutants from wastewater naturally or with the help of an aeration system.

d. Treated Water Chamber

Treated Water Chamber is the final unit in the WWTP system that functions to accommodate wastewater that has been treated, before being discharged into the receiving water body.

e. Disinfectant Chamber

The Disinfectant Chamber is a unit in the WWTP system that functions to carry out the disinfection process of treated wastewater, to ensure the elimination of pathogenic microorganisms before the water is discharged into the receiving water body.

Although technically the wastewater treatment system of RS X is adequate for medium scale, the observation results show that the current WWTP capacity has exceeded the capacity. WWTP is designed to treat 100 m³/day, while the incoming waste load can reach 150–200 m³/day.

In the X Hospital complex, there are several buildings or other activities outside the main hospital building, including the funeral home building, crematorium building, new building for special cancer services, and public canteen. Although all activities in these buildings generate liquid waste, the results of field tracing show that not all buildings have been integrated into RS X's main WWTP sewage system.

Discussion

A. Work Environment Conditions at the Research Site

Hospital X is located on Jl. Raya Mayor Oking Jaya Atmadja No. 9, Cibinong Village, Cibinong District, Bogor Regency, West Java Province. This location is a strategic area in the center of Cibinong city that is easily accessible to people from various directions, both by private vehicles and public transportation. The location in the middle of residential, trade, and light industrial areas provides strategic advantages for RS X as a community referral health service provider.

B. Characteristics and Amount of RS X Liquid Waste

The liquid waste produced by Hospital X comes from various medical and non-medical activities, including from inpatient rooms, operating rooms, laboratories, emergency installations, kitchens, laundry, to canteens and toilets. Based on data collected during the study period, it is known that the average amount of liquid waste generated reached 2,688 m³ per month or around 89.6 m³ per day, with the highest volume recorded in December of 105.19 m³ per day, which exceeded the current maximum capacity of the hospital's WWTP which is 100 m³/day.

These findings show that the available wastewater treatment capacity is no longer proportional to the waste load generated. This is in line with the results of research by Yekti & Mirwan (2021) which states that limited WWTP capacity can be one of the main factors in the increasing burden of hospital waste pollution and the risk of *underperformance* in the treatment system.

In general, the characteristics of hospital liquid waste are very complex and have a high potential to cause environmental pollution if not managed properly. According to the *World Health Organization (2014)* and the Ministry of Health of the Republic of Indonesia (Permenkes No. 7 of 2019), hospital liquid waste can contain various contaminants such as organic, inorganic, pathogenic (viruses, bacteria, protozoa), toxic chemicals (chlorine, heavy metals), and pharmaceutical residues (Organization, 2014). In this study, the observed waste characteristic parameters include BOD, COD, TSS, pH, temperature, and pathogenic microorganism content, as stated in the liquid waste quality standards based on PermenLHK No. 5 of 2014.

In the context of Hospital X, preliminary measurements showed that several parameters of *effluent* results such as BOD and COD experienced fluctuations indicating inconsistencies in WWTP performance. This is possible due to the high variability of pollutant volume and load, as well as the presence of discharges from supporting buildings in hospital areas (such as funeral homes, canteens, crematoriums, and the construction of radiotherapy buildings) that have not been fully integrated into the WWTP system.

According to *Kümmerer (2018)* in the journal *Science of The Total Environment*, hospitals produce waste with a high variation in organic and microbiological loads, especially from laboratory activities, isolation rooms, and cleaning of medical devices, which can produce BOD concentrations of up to 500 mg/L and COD of up to 1000 mg/L, higher than ordinary

domestic waste (Kümmerer, 2018). In addition, a study by Edhi Sarwono (2024) at Pupuk Kaltim Bontang Hospital also found that the imbalance between waste load and WWTP capacity causes an increased risk of pollution to the environment and increases the potential for direct exposure to waste treatment officers (Sarwono et al., 2024).

This condition shows that it is important for hospitals, especially Hospital X, to recalculate WWTP capacity planning based on actual waste loads, including taking into account the contribution of non-medical support units that also produce liquid waste. The increase in the number of beds (*average bed occupancy rate* of 85%) and the growth of services that continue to grow are factors that strengthen this urgency.

Furthermore, the calculation of clean water needs based on the Minister of Health Regulation No. 7 of 2019 shows that for class B hospitals, the water demand for hygiene and sanitation purposes reaches 400-450 liters/TT/day.²² If the assumption of conversion of 85–90% of clean water into wastewater is used, then a hospital with 255 beds can produce about 86,700–103,275 liters/day, which significantly exceeds the existing WWTP capacity of 100 m³/day.

Thus, the characteristics and amount of liquid waste produced by these hospitals demand not only greater WWTP capacity, but also an adaptive, integrated, and actual data-based treatment system, as well as region-based management that includes all sources of waste from the hospital area and its supporting facilities. In addition, there is a need for a strict monitoring system on wastewater quality parameters and the reliability of the WWTP process to prevent wider environmental and occupational health impacts.

C. Wastewater Management at RS X

Wastewater management at Hospital X is one of the important components of environmental health management that aims to prevent pollution and protect public and worker health. The hospital has been equipped with a Wastewater Treatment Plant (WWTP) with an installed capacity of 100 m³/day and adopts an anaerobic-aerobic biofilter system, which is a combination method between the process of biological decomposition of organic substances in conditions without oxygen (anaerobic) and with oxygen (aerobic).

This system generally goes through several stages, namely: (1) initial screening and *grease trap*, (2) equalization of the tank to equalize the load and discharge of waste, (3) anaerobic reactor, (4) aerobic reactor using biofilter media, (5) sedimentation, and (6) disinfection using chemicals such as chlorine (Ca(ClO)₂) before being released into the environment.

However, wastewater management at RS X still faces a number of structural and operational problems that affect the effectiveness of the existing WWTP system. Based on the data from the research results, the current WWTP capacity is insufficient to accommodate the waste load from all hospital activities, especially at a time when patient occupancy is high. The average liquid waste reached 89.6 m³/day, even exceeding the maximum capacity of WWTP to 105.19 m³/day in a given month. This is in line with research by Yekti & Mirwan (2021) in the SIER Surabaya industrial area which shows that overload in the WWTP unit causes a decrease in processing efficiency and an increase in pollution in the BOD, COD, and TSS parameters.

In addition, wastewater management at RS X is still not fully integrated. Some facilities such as funeral homes, crematoriums, canteens, and radiotherapy buildings are not directly connected to the WWTP system, so there is the potential for direct discharge into the environment without treatment. This is contrary to the principle of integration of hospital waste management systems as mandated in the Minister of Health Regulation No. 7 of 2019, which emphasizes the importance of comprehensive and integrated wastewater management in all hospital units.

In terms of energy use, the WWTP system relies on a number of mechanical devices such as aeration blowers which have the highest energy consumption reaching 2,238 kWh/m³, followed by transfer pumps (0.746 kWh/m³) and *filter backwash* pumps (1,119 kWh/m³). This condition contributes significantly to greenhouse gas emissions. This finding is consistent with a study by Sampurno (2023) at RSPAL Dr. Ramelan Surabaya which shows that aeration units are the main source of environmental impacts in the *global warming potential* category in the *Life Cycle Assessment* (LCA) analysis of hospital WWTP.

In terms of chemical use, the final disinfection process at RS X still uses conventional methods with chlorine, as well as neutralizing materials such as lime (CaO) and sodium carbonate (NaHCO₃). Although effective in lowering microbiological contaminants, the use of these chemicals has an impact on the categories of *human toxicity* and *freshwater ecotoxicity* as emphasized by Kümmerer (2018) in *Science of the Total Environment*, which highlights the risk of the accumulation of disinfectant chemicals in the environment and surface water.

Another problem found is *sludge management* that does not use mechanical technology or a drying system. Sludge from the sedimentation unit is drained manually by officers without adequate K3 protection. This poses a risk of direct exposure to biological and chemical contaminants, as well as increases the workload of officers, the majority of whom do not have a sanitary background. Sarwono (2024) in his study at Pupuk Kaltim Bontang Hospital also stated that sludge management is one of the hotspots that contribute to climate change risks and occupational health impacts, especially if carried out without safety equipment and advanced management systems (Sarwono et al., 2024).

No less important, the involvement of officers in liquid waste management in this hospital is not limited to sanitarians, but also involves technicians, *gardeners*, *cleaning services*, and kitchens. The lack of training and job protection for these officers increases the risk of direct exposure to hazardous materials. A study by Pratiwi (2023) in the context of the shipyard industry shows that WWTP management workers have a high susceptibility to respiratory disorders and skin disorders due to exposure to gases from anaerobic-aerobic processes and disinfection chemicals.

From the results of the thorough evaluation, it can be concluded that wastewater management at RS X is at a critical point that requires significant improvement efforts. Some of the strategic steps that are recommended based on the results of analysis and comparison with other literature include:

1. Increasing the capacity of WWTP to a minimum of 300 m³/day based on the estimated need for clean water (400–450 L/TT/day) and conversion of 85–90% to wastewater (Permenkes 07/2019).
2. Integration of all liquid waste sources into the WWTP network through the regional piping system.
3. The application of energy efficiency technology in aeration units such as *fine bubble diffusers* or *inverter blowers*.
4. Use of alternative chemicals with low toxicity and environmentally friendly levels (e.g. liquid sodium hypochlorite).
5. Automation of *the sludge dewatering* system with *geobag* or *belt press* to minimize the risk of direct exposure.
6. Improving the competence and K3 of officers through periodic training and the provision of WWTP standard PPE.

By applying a comprehensive *Life Cycle Assessment* (LCA) approach, hospitals can identify the treatment stages that have the greatest impact on the environment and occupational health, while designing more efficient, safe, and sustainable waste management systems as recommended in the national environmental health development framework.

D. Wastewater Distribution System In Hospital X

The wastewater distribution system is a critical component in hospital sanitation infrastructure because it functions to drain wastewater from its source to the Wastewater Treatment Plant (WWTP). At Hospital X, the system has characteristics that reflect the growing conditions of the facility and the limitations of a centralized treatment system.

1. Distribution Structure and Pattern

In general, the waste distribution system at RS X uses a gravity-based *closed piping system* and lift pumps in areas that require transfer to higher elevations. Liquid waste is collected from various sources such as inpatient rooms, emergency rooms, laboratories, kitchens, laundry, and toilets, then channeled through pipelines to the control basin before being channeled to the WWTP.

However, based on the results of observations in the research document, it was found that not all building units are directly connected to the WWTP system. Additional facilities such as funeral homes, crematoriums, public canteens, and radiotherapy buildings that are being built do not yet fully have integrated channels to the WWTP. In fact, some waste from these facilities is still discharged directly into the environment without going through treatment first.

This disintegration poses a serious threat to environmental health, especially since hospitals are located in close proximity to residential areas. This shows that there is a discrepancy between the existing distribution system and the principles of regional sanitation as stipulated in the Minister of Health Regulation No. 7 of 2019 which requires hospital sanitation systems to meet the standards of integration and treatment of all types of wastewater.

2. Weaknesses in System Implementation

Some of the weaknesses in the distribution system recorded in the field include:

- The lack of mapping of the piping network makes it difficult to trace the source of leaks or contamination.
- The absence of separation of medical and non-medical waste channels, which risks reducing the effectiveness of WWTP and increasing exposure to hazardous waste.
- Lack of regular monitoring of pipelines and control tanks, resulting in frequent blockages, *backflows*, or leaks that are slow to respond.

These problems were also found in a study by Yekti (2021) which examined the WWTP system in the SIER Surabaya industrial area, where a poorly organized distribution system is the main cause of pollution accumulation in the initial distribution unit (*distribution box*).

3. Related to the Health Impact of Officers

The distribution system that is not completely closed and safe is a source of direct exposure for sanitation workers. Based on the survey in this study, officers experienced various health problems when doing work such as cleaning control tanks or repairing pipes, including skin symptoms, respiratory problems, dizziness, and nausea and vomiting

This condition is consistent with *the WHO literature (2014)* which states that open or leaky sewage channels can release toxic gases such as H₂S and CH₄, as well as become a breeding ground for disease vectors such as flies and cockroaches.

4. Distribution System Improvement Strategy

To answer these challenges, strengthening the wastewater distribution system is urgently needed through several strategic steps:

- Audit and remapping of pipeline networks digitally (*GIS-based*) to facilitate improvement and development planning.

- Integration of all liquid waste generating units into one main channel system leading to WWTP.
- The application of a separation system between domestic, laboratory, and clinical waste to optimize the treatment process.
- Repair of the control basin construction and periodic maintenance to prevent damage and exposure of workers.
- K3 training and the use of standard PPE for all piping and waste control system management officers.

As suggested by Sampurno (2023) in a study on the implementation of LCA at RSPAL Dr. Ramelan, improving the waste distribution system is an important part of reducing emissions, the risk of work accidents, and improving the efficiency of waste treatment.

E. Wastewater Treatment Plant In Hospital X

Hospital X, as a type B hospital with a capacity of 255 beds and an average patient occupancy (BOR) of 85%, produces a significant amount of wastewater. Based on the measurement results in this study, the *volume* of liquid waste produced is around 89.6 m³/day, even in certain months it reaches 105.19 m³/day, which exceeds the available WWTP capacity, which is 100 m³/day.

In response to the waste load, RS X has operated a Wastewater Treatment Plant (WWTP) that uses *anaerobic-aerobic biofilter technology*. This system was chosen because it is a fairly effective method and is commonly applied in medium-scale hospitals, and does not require too much land. According to the Ministry of Health of the Republic of Indonesia (2010) and WHO (2014), *anaerobic-aerobic biofilters* are bio-based waste treatment systems that utilize microorganisms in anaerobic (without oxygen) and aerobic (with oxygen) conditions to decompose organic substances in hospital liquid waste.

1. Stages of WWTP Processing

The WWTP system at RS X consists of several main process units as follows:

- Initial collection tub (*screening & grease trap*): filters large particles and grease from the kitchen or laundry.
- Equalization tank: accommodates and equalizes the characteristics of waste before it enters the biological unit.
- Anaerobic reactor: decomposing complex organic matter into simple compounds.
- Aerobic reactor (biofilter): oxidizes organic compounds using air from the blower.
- Sedimentation: separating suspended solids and sludge from treated water.
- Disinfection: done manually with chlorine (Ca(ClO)₂) to kill pathogenic microorganisms.
- Discharge: Treated water is discharged into the environment through a closed channel.

However, from the evaluation of the system, several significant limitations were found, both in terms of technical, efficiency, and management aspects.

2. Limitations and Problems of WWTP

a. Insufficient WWTP capacity

The capacity of 100 m³/day is no longer in accordance with the actual waste load. Based on the estimated water demand from the Minister of Health Regulation No. 7 of 2019, type B hospitals require 400–450 liters/TT/day for sanitation. With high occupancy and additional non-medical facilities, the processing needs are projected to reach 300 m³/day

b. Fluctuations in *effluent quality*

The results of wastewater quality inspections show inconsistencies in BOD, COD, and TSS parameters, especially during peak loads. This indicates a decrease in reactor efficiency and *overload capacity*.

c. High and manual energy use

The aeration process relies on a blower with high energy consumption (2,238 kWh/m³), and some processes are still carried out manually, such as chlorine application and *sludge* cleaning. A study by Sampurno (2023) revealed that blowers and *sludge handling* are hotspots in the environmental impact of hospital WWTP based on LCA.

d. Sludge management is not automatic

Sludge from the sedimentation unit is cleaned manually without a *sludge dewatering* system such as a *belt press* or *sludge drying bed*. This increases the risk of biological exposure to sanitarians and worsens the work environment

e. Lack of automated monitoring and control systems

There are no SCADA systems or digital controls available to monitor pH, discharge, and chemical doses. This condition makes it difficult to detect early processing process disruptions. The results of this finding are in line with several other scientific studies that evaluated hospital WWTP through *the Life Cycle Assessment* (LCA) approach: Sarwono (2024) at Pupuk Kaltim Bontang Hospital shows that the sedimentation and disinfection unit contributes greatly to the impact of human toxicity, especially if *sludge* is not handled properly. Pratiwi (2023) identified that *anaerobic-aerobic biofilter* systems produce *high global warming potential* due to energy consumption and gas emissions such as CH₄ and H₂S. Yekti (2021) emphasized that the distribution and maintenance of the pipeline network and sludge management are critical points for the success of WWTP.

Based on the results of the evaluation and literature study, here are some suggestions for improvement for IPAL RS X:

- Upgrade the capacity of the WWTP to ≥ 300 m³/day to accommodate long-term needs.
- Application of energy efficiency technologies such as *inverter blowers*, energy-saving aerators, and solar energy.
- The use of an automatic *sludge dewatering* system to reduce the exposure of the officers and improve the efficiency of sludge transport.
- Integration of automated control system (digital monitoring) for pH, discharge, and chemical dosage.
- Re-engineer the disinfection unit to use safer chemicals or UV disinfection systems as alternatives.
- Training and capacity building of sanitarian officers, as well as enforcement of the use of PPE in WWTP management.

F. Health Problems of Wastewater Facilities Management Officers

Wastewater Treatment Plants (WWTP) are a vital component in the hospital's sanitation system. At RS X, WWTP operations involve a number of officers from various backgrounds, including environmental health workers, technicians, *cleaning services*, *gardeners*, and kitchens. They are involved in a variety of high-risk activities such as control tank cleaning, sampling, chemical administration (chlorine, lime), and manual sludge management.

1. Types of Health Disorders Found

Based on the results of a survey of 33 WWTP management officers, as many as 85% of respondents experienced health complaints, with the following types of disorders:

Table 2. Types of Health Disorders of WWTP Management Officers

Types of Complaints	Number of Respondents	Percentage (%)
Respiratory disorders	12	36%
Dizziness/nausea	7	22%

Types of Complaints	Number of Respondents	Percentage (%)
Skin problems	5	15%
Allergy	3	9%
Respiratory tract infections	1	3%
No complaints	5	15%

Source : RS X Secondary Data

Respiratory distress is the most common complaint and is most associated with the aeration process using a blower, which produces gases such as H₂S and ammonia. Dizziness and nausea often appear when officers are near chemical treatment units, while skin problems and allergies are common in officers handling mud or cleaning manually.

2. Sources of Risk Exposure

From the analysis carried out, there are three main processes that are the source of health risks:

- Aeration with a blower → emission of gases and fine particles (particulate matter formation contributors in LCA)
- Use of chemicals → potential acute and chronic toxicity (contributors to human toxicity in LCA)
- Manual sludge management → direct contact with B3 waste and pathogenic microorganisms
This condition is exacerbated by the lack of consistent use of PPE, lack of K3 training, and inadequate ventilation in the WWTP area

3. Correlation with *Life Cycle Assessment* (LCA) Results

The LCA analysis conducted in this study showed that the impact categories of *Human Toxicity* and *Particulate Matter Formation* had the highest contribution to the health risk of workers. Emissions from aeration and treatment chemicals contribute greatly to respiratory and neurological disorders, while manual sludge management is associated with dermatological complaints and infections.

Based on the mapping of work activities and the results of the *Life Cycle Assessment* (LCA), there are three stages of the process in WWTP that contribute the most to the risk of health problems:

- a. Aeration process: produces bioaerosols and toxic gases (ammonia, H₂S), as well as particulates that can cause airway irritation and central nervous system disorders. A study by *Moya et al. (2011)* in the *International Journal of Hygiene and Environmental Health* showed that hospital WWTP operators face the risk of exposure to H₂S and airborne endotoxins that can lead to chronic bronchitis, persistent cough, and shortness of breath.
- b. Handling of chemicals: such as chlorine (calcium hypochlorite) used in disinfection produces active chlorine compounds that are strong oxidizers and can irritate the skin and respiratory tract. *WHO (2014)* states that chronic exposure to chlorine can cause corrosive effects on the respiratory system and skin, especially in poorly ventilated working conditions. *Kümmerer (2018)* in *Science of the Total Environment* also warned that disinfectant chemicals in hospital WWTP contribute to *human toxicity* and can trigger long-term hypersensitivity reactions.
- c. Sludge management: carried out manually without a closed system, causing direct contact with pathogenic microorganisms (*E. coli, Salmonella, viruses*) and harmful chemicals absorbed in the sludge. Workers who handle sludge without PPE have a higher risk of gastrointestinal and skin infections due to constant biological exposure.

Despite the high potential risk, the labor protection system in the management of WWTP at RS X is still not optimal. Based on observations, the use of PPE is inconsistent, some officers do not use masks or gloves when handling liquid waste and sludge, There is no routine K3

training specifically for WWTP management, Open work system without *exhaust fans* or adequate ventilation in the chemical room and aeration room.

Muhammad Abdul Rofiq (2019) emphasized that the behavior of using PPE is highly determined by the perception of risk and training received by officers. Without regular training, officers' understanding of occupational hazards remains low (Mu'afiah et al., 2021; Nurmala et al., 2022). Sampurno (2023) in the LCA WWTP study at RSPAL Surabaya concluded that the health risks of officers can be significantly reduced with the automation of *the sludge handling* system, the use of low-toxicity chemicals, and good ventilation technical engineering.

Repeated exposure to WWTP contaminants not only causes acute distress, but also risks causing chronic diseases. Mild neurological symptoms (such as dizziness, impaired concentration, and fatigue) experienced by some respondents may be indicative of chronic exposure to *volatile organic compounds* (VOCs) or hydrogen sulfide gas (H₂S) (Rahim, 2020).

In addition, the number of non-medical units that have not been integrated into WWTP, such as crematoriums and funeral homes, expands the scope of work of officers, but is not balanced with increased protection and support personnel.

To reduce the risk of health problems in hospital liquid waste facility management officers, it is necessary to implement strategic measures based on technical and behavioral approaches:

- Periodic work risk audits based on LCA and HIRA (*Hazard Identification and Risk Assessment*).
- Implementation of SOP for the management of K3-based WWTP, especially at the stage of handling sludge and disinfection.
- Provision and monitoring of the use of complete PPE on a regular basis.
- Periodic training for all officers, including non-health workers, on waste management and prevention of occupational diseases.
- Routine health monitoring (examination of lungs, skin, and liver function) for early detection of diseases due to WWTP exposure.

G. Life Cycle Assessment (LCA) Results

This study uses the *Life Cycle Assessment* (LCA) approach with the scope of *the cradle to gate system*, which covers the entire wastewater management process from collection, biological and chemical treatment, to the release of treated water into the environment.

The software used is *SimaPro 9.0* with the characterization method applied is *ReCiPe 2016 Midpoint*, which allows detailed analysis of impact categories such as *Global Warming Potential, Human Toxicity, Ecotoxicity, and Particulate Matter Formation*.

The results of the LCA simulation show that the largest total environmental impact comes from electrical energy consumption, chemical use, and sludge management processes. The previous infographic graph shows that:

1. Aeration blowers contribute up to 45% to the total *Global Warming Potential* (GWP) due to electrical energy consumption of 2,238 kWh/m³.
2. Transfer pumps and *backwash* also account for around 15% of GWP and contribute to the use of fossil resources by 8%, as electricity in Indonesia is still coal-based.
3. Chemicals such as chlorine (Ca(ClO)₂) and lime (CaO) are the dominant contributors in the *Human Toxicity category* (up to 20%) due to their direct and cumulative toxicity effects on workers and the environment.
4. Manual sludge management without a closed system results in a contribution to *Particulate Matter Formation* (8%) and the risk of biological exposure.
5. The regular use of PPE (masks, nitrile gloves) even though small in quantity still contributes to plastic waste and depletion of fossil resources.

The results of this LCA are consistent with various other studies that assess hospital and industrial wastewater treatment systems, including: Sampurno (2023) in Dr. Ramelan's RSPAL WWTP LCA STUDY showed that blowers and *sludge handling units* account for more than 60% of the total environmental impact, especially on GWP and *Human Toxicity*. The use of chlorine and manual processes exacerbates the impact on workers and the environment. Sarwono (2024) at Pupuk Kaltim Hospital revealed that the WWTP biological unit contributes CO₂ emissions of 252,000 kg eq per year, and the *Respiratory Inorganics (PM Formation)* category is the highest contributor to the impact on health (DALY). Kümmerer et al. (2018) in *Science of the Total Environment* emphasizes that hospital WWTP systems that use chlorine (chlorine) disinfectants produce derivative compounds such as AOX (*Adsorbable Organic Halides*) which can cause carcinogenic and mutagenic effects, as well as increase the value of *freshwater ecotoxicity*. Pratiwi (2023) assessed LCA in the shipyard industry using *aerobic-anaerobic biofilters* and found that the sludge management process contributed the most to the *particulate matter* category and caused long-term respiratory distress.

Based on the results of the LCA and comparison with the literature, here are the strategic recommendations to reduce the impact:

1. Energy efficiency: Replacing conventional blowers with efficient technologies such as *inverter blowers* or *fine bubble diffusers*. Consider solar panels for partial power supply.
2. Chemical alternatives: Reduce dependence on chlorine and switch to liquid sodium hypochlorite or UV disinfection to lower *human toxicity* and exposure risk.
3. Sludge management: Implement a closed *sludge drying bed* system or automatic belt press to reduce manual workload and risk of pathogen exposure.
4. Automated monitoring system (SCADA): For real-time control of chemical doses, water discharge, temperature, and pH, to prevent chemical overdoses and process disruptions.
5. Integration of LCA in hospital management: Use LCA results as material for environmental and occupational health evaluations, as well as for sustainable long-term WWTP technology planning.

CONCLUSION

The study on Hospital X's wastewater management using Life Cycle Assessment (LCA) revealed that wastewater from medical and non-medical activities (averaging >100 m³/day) contains organic, microbial, and chemical contaminants, exceeding the WWTP's capacity. The current anaerobic-aerobic biofilter system, while functional, poses health risks to workers (85% reported respiratory, skin, or nausea issues) and significant environmental impacts from energy-intensive aeration (2,238 kWh/m³) and chemical use. LCA identified key hotspots in human toxicity and ecotoxicity, demonstrating its effectiveness for holistic evaluation. Future research should expand to cradle-to-grave assessments, compare advanced treatment technologies, improve worker safety through PPE/automation, optimize energy use with renewables, monitor pharmaceutical residues/AMR risks, strengthen policy compliance, assess community health impacts, and implement IoT-based real-time monitoring to develop sustainable wastewater solutions for healthcare facilities.

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