



Evaluation of the Sustainability of Forensic Waste Management at Bhayangkara Hospital Level II Medan

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Abstract

*Forensic waste management at Bhayangkara Hospital Level II Medan is a multidimensional issue. The waste generated comprising human tissue, autopsy organs, and hazardous chemicals poses significant infectious and toxicological risks. This study aims to evaluate the sustainability of the forensic waste management system by analyzing technical conditions and stakeholder awareness levels to support safe, effective, and sustainable waste management. A mixed-methods approach was employed, combining descriptive quantitative and exploratory qualitative methods. Data collection involved observation, laboratory analysis, questionnaires, interviews, and document review. The results indicate that the current forensic waste management facilities are effective in controlling chemical parameters, as evidenced by the absence of detectable formalin in laboratory test results. However, microbiological control remains suboptimal, as *Escherichia coli* and *Salmonella* bacteria were still detected in the treated waste. From a social perspective, medical personnel possess a good understanding of the high-risk nature of forensic waste; however, this awareness is not yet fully reflected in the consistent application of management procedures. Overall, the sustainability of forensic waste management requires improvement particularly regarding microbiological control, adherence to operational procedures, and cost-efficiency optimization to meet the principles of safe, effective, and sustainable waste management.*

Keywords: forensic waste, hospital, staff awareness, sustainability, waste management

1. Introduction

Medical waste is a source of environmental issues typically stemming from the operations of healthcare facilities such as hospitals, clinics, community health centers, and medical laboratories. It comprises the by products or residues generated by various medical activities involving both biological and non-biological materials [1]. Examples include residual blood, body fluids, human waste, and medical equipment exposed to contamination. The volume of medical waste generated continues to rise alongside the delivery of healthcare services [2]. Infectious waste contains various pathogenic microbes that, at certain concentrations, can trigger infections and diseases in humans or animals; such waste is frequently contaminated with blood, body fluids, or biological materials carrying dangerous pathogens. In contrast, non-infectious medical waste is generated by healthcare facilities but does not contain pathogens capable of causing infection [3]. Approximately 15% of medical waste is classified as hazardous and toxic material (B3) including infectious, chemical, and radioactive waste which poses risks of disease transmission and environmental pollution [4]. Studies indicate that forensic medical personnel in hospitals offering autopsy services are at higher risk of pathogen exposure due to errors in waste segregation or disposal [5].

A primary challenge in forensic waste management is the lack of optimal, holistic, and standardized management practices. Although regulations such as the Minister of Health Regulation Number 2 of 2023 (implementing Government Regulation Number 66 of 2014 on Environmental Health) govern the management of hazardous and toxic medical waste, practical implementation often faces obstacles. Bhayangkara Hospital Level II Medan is one such facility that provides forensic services and faces challenges in managing this type of waste. The volume of forensic waste generated at Bhayangkara Hospital Level II Medan is significant, averaging 50–70 kg per month equivalent to 0.2 kg per autopsy workday. This waste consists primarily of pathological forensic waste, such as human tissue and organs from autopsies (accounting for approximately 65% of the total volume), as well as chemical waste (e.g., fixatives and reagents). This volume is attributable to the high level of forensic case handling including serious criminal cases requiring full autopsies conducted at the hospital, which serves as a primary forensic referral center in North Sumatra.

Currently, the implementation of biosecurity standards for forensic waste management at Bhayangkara Hospital Level II Medan is considered suboptimal regarding worker protection, the availability of Personal Protective Equipment (PPE) specifically designed for handling forensic pathological waste, and internal waste treatment facilities, which remain general in nature rather than

tailored to forensic-specific characteristics. Although medical waste generation data is recorded in internal hospital reports, there is limited publication, gap analysis, and data processing specifically aimed at evaluating forensic waste management performance.

While extensive research exists on general medical waste management, few studies specifically examine forensic waste. Existing research reviews forensic waste management in hospitals, analyzing the types of waste generated during forensic medical processes, potential health risks, and environmental impacts resulting from improper management [6]. Other studies analyze health risks posed by forensic waste, including biological and chemical waste [7]. Research conducted under the framework of the *Safe Management of Wastes from Health-care Activities* emphasizes that inadequate medical waste management systems can increase the disease burden, threaten the environment, and lead to long-term economic losses. Consequently, the situation at Bhayangkara Hospital Level II Medan requires a sustainability evaluation of forensic waste management, considering both environmental and social aspects [8]. The study aims to yield multidimensional recommendations that address environmental and social factors, serving as a reference for the development and management of forensic waste systems in hospitals more broadly.

2. Research Methods

This study will be conducted at Bhayangkara Hospital Level II Medan, a referral hospital that provides medicolegal and forensic services. A mixed-methods research design will be employed combining quantitative descriptive and exploratory qualitative approaches to gain in-depth insight into the dynamics of forensic waste management from both environmental and social perspectives. The study variables are categorized into environmental quality variables measured by directly assessing the concentrations of formalin, mercury, and pathogenic microorganisms at hospital waste disposal or storage sites (including the Wastewater Treatment Plant (WWTP) inlet and outlet, control chambers, and the river serving as the final disposal point and social variables, which assess environmental awareness, SOP management, SOP compliance, and participation through questionnaires and interviews.

3. Result and Discussion

The current state of the forensic waste management facility at Bhayangkara Hospital Level II Medan is a crucial aspect of ensuring environmental health protection and public safety, given that forensic waste contains hazardous chemicals and pathogenic biological agents. The initial evaluation focused on key parameters: formalin levels representing the toxic chemical contaminants commonly used in forensic preservation processes and the presence of *Escherichia coli* and *Salmonella* as indicators of microbiological

contamination and potential infection risks. Formalin concentration is a significant chemical parameter in the evaluation of forensic waste. This compound is toxic and persistent, posing potential negative impacts on human health and aquatic environments if released without adequate treatment [9].

Table 1. Laboratory analysis results regarding the presence of formalin at the forensic waste management facility of Bhayangkara Hospital Level II Medan

Location	Formalin Test Result	Unit
WWTP Inlet	Negative	mg/L
WWTP Outlet	Negative	mg/L
Control chambers	Negative	mg/L
River water	Negative	mg/L

Based on the laboratory analysis, formalin was not detected at any of the sampling points namely the WWTP inlet, WWTP outlet, control tank, and the receiving river body. These findings indicate that formalin concentrations were below the analytical detection limit and met applicable quality standards, suggesting that the forensic waste treatment system effectively controls hazardous chemical residues prior to discharge into the environment. These results align with various studies demonstrating that properly designed waste treatment systems can reduce formaldehyde concentrations to undetectable levels or levels compliant with environmental quality standards, thereby minimizing the risk of pollution to aquatic ecosystems [10], [11]. These findings indicate that the forensic waste management system at Bhayangkara Level II Hospital Medan operates effectively in minimizing the formalin pollution load; this aligns with medical waste management principles that prioritize the reduction of hazardous substances and proper treatment prior to final environmental disposal to mitigate pollution risks.

The absence of detectable formalin in the receiving water body demonstrates that the wastewater treatment plant (WWTP) is functioning effectively to prevent the release of hazardous chemical residues into the aquatic environment. These findings indicate that the treatment process successfully reduced formalin concentrations to levels below the detection limit, thereby minimizing the potential for water body pollution. This outcome aligns with research showing that hospital wastewater treatment systems adhering to operational standards can reduce chemical pollutant loads, mitigate toxicity risks to aquatic organisms, and preserve the quality of aquatic ecosystems near discharge points [12]. Furthermore, the World Health Organization (WHO) emphasizes that proper healthcare waste management is a crucial step in preventing adverse effects on public health and the environment particularly those resulting from exposure to hazardous chemicals generated by healthcare activities [13].

Table 2. Microbiological levels at the forensic waste treatment facility of Bhayangkara Hospital Level II, Medan.

Location	Parameter	Unit	Test result	Quality standards
WWTP Inlet	<i>Escherichia coli</i>	MPN/100 mL	>16000	2000

Location	Parameter	Unit	Test result	Quality standards
WWTP Outlet	<i>Salmonella</i>	Negative/25 mL	Positive	Negative
	<i>Escherichia coli</i>	MPN/100 mL	220	2000
	<i>Salmonella</i>	Negative/25 mL	Negative	Negative
Control tub	<i>Escherichia coli</i>	MPN/100 mL	>16000	2000
	<i>Salmonella</i>	Negative/25 mL	Positive	Negative
River water	<i>Escherichia coli</i>	MPN/100 mL	>16000	2000
	<i>Salmonella</i>	Negative/25 mL	Negative	Negative

Microbiological aspects serve as a key indicator in evaluating forensic waste management, given the close link to the potential spread of pathogenic microorganisms from healthcare facilities to the environment. Forensic waste generated through autopsies, pathological examinations, and the handling of biological specimens may contain pathogenic bacteria, viruses, and antibiotic-resistant microorganisms that pose risks to public health if not managed adequately. Consequently, *Escherichia coli* and *Salmonella* are used as biological contamination indicators to assess waste hygiene levels and evaluate the effectiveness of the wastewater treatment plant (WWTP) in reducing the load of pathogenic microorganisms before the effluent is discharged into receiving water bodies [14].

Microbiological analysis results reveal that untreated forensic waste exhibits extremely high levels of biological contamination; *E. coli* concentrations exceed 16,000 MPN/100 mL, and *Salmonella* is detected at both the WWTP inlet and the control chamber. These conditions indicate that forensic waste carries a significant load of pathogenic microorganisms and could become a source of biological contamination if discharged without proper treatment. These findings align with research identifying hospital wastewater as a reservoir for various pathogenic and antibiotic-resistant bacteria including *E. coli* which can heighten the risk of disease transmission and the spread of antimicrobial resistance into aquatic environments if not managed effectively [14].

Following the treatment process, the *E. coli* concentration decreased significantly to 220 MPN/100 mL, while *Salmonella* was no longer detected in the wastewater treatment plant (WWTP) outlet effluent. These results demonstrate that the waste treatment system at Bhayangkara Hospital Level II Medan is capable of substantially reducing the load of pathogenic microorganisms through the applied biological treatment and disinfection processes. This reduction reflects the WWTP's effectiveness in mitigating biological risks before the effluent is discharged into the receiving water body. These findings are consistent with reports indicating that hospital wastewater treatment plants can eliminate pathogenic bacteria to undetectable levels in the effluent, although advanced treatment

remains necessary to control antibiotic-resistant bacteria and ensure environmental safety [15].

Although test results showed that *Salmonella* was not detected in the receiving water body, the concentration of *Escherichia coli* (*E. coli*) remained at a very high level (>16,000 MPN/100 mL). This finding indicates that microbiological contamination in the water body is likely influenced not only by the hospital's WWTP effluent but also by various other pollution sources such as domestic waste, residential runoff, livestock farming activities, and surface runoff that transport fecal contaminants into the aquatic environment [15]. This situation demonstrates that the microbiological quality of the water body is influenced by various anthropogenic factors; therefore, evaluating the impact of hospital effluent requires considering the contributions of other pollution sources within the watershed.

Overall, the research findings indicate that the wastewater treatment plant (WWTP) at Bhayangkara Hospital Level II Medan has demonstrated effective performance in reducing the load of major pathogenic microorganisms originating from the hospital's waste sources. Nevertheless, periodic microbiological quality monitoring remains essential to ensure the long term effectiveness of the treatment process. Furthermore, implementing an integrated water quality management strategy through collaboration among the health and environmental sectors, local government, and the community is a crucial step toward controlling various sources of microbiological pollution, maintaining the quality of water bodies, and protecting public health.

Table 3. Level of Awareness Among Medical Personnel and the Public Regarding Forensic Waste Management at Bhayangkara Hospital Level II Medan

Indicator	Criteria	Number of Respondents	Percentage (%)
1. Environmental awareness among medical personnel	Totally agree	60	100
	Agree	0	0
	Neutral	0	0
	Disagree	0	0
	Don't agree	0	0
	Total	60	100
2. Knowledge of Standard Operating Procedures (SOPs) for Forensic Waste Management	Totally agree	51	85
	Agree	0	0
	Neutral	4	7
	Disagree	5	8
	Don't agree	0	0
	Total	60	100
3. Perception of health risks	Totally agree	60	100
	Agree	0	0
	Neutral	0	0
	Disagree	0	0
	Don't agree	0	0
	Total	60	100
4. Participation in Forensic Waste Management	Totally agree	30	50
	Agree	5	9
	Neutral	10	16
	Disagree	15	25
	Don't agree	0	0
	Total	60	100
5. Compliance with Work Safety Procedures	Totally agree	60	100
	Agree	0	0
	Neutral	0	0
	Disagree	0	0
	Don't agree	0	0
	Total	60	100

To assess the level of awareness among medical personnel and the community regarding forensic waste management at Bhayangkara Level II Hospital Medan, five parameters were measured: environmental awareness, knowledge of forensic waste management Standard Operating Procedures (SOPs), perception of health risks, participation in forensic waste management, and adherence to workplace safety procedures.

The majority of medical personnel and community members demonstrated a reasonably good level of environmental awareness regarding forensic waste management. This is reflected in their understanding of the impacts and potential risks arising from waste management practices that do not comply with SOPs. The level of understanding regarding the technical stages of forensic waste management reflects not only the cognitive aspects of the medical personnel but also directly influences their behavior and compliance in daily practice. A total of 85% of respondents strongly agreed that they were aware of the specific SOPs for forensic waste management at the hospital. These findings indicate that, in general, the majority of respondents possess basic knowledge regarding the internal regulations governing forensic waste management. This suggests that efforts to formulate and disseminate SOPs have successfully reached the majority of medical personnel. However, 7% of respondents remained neutral, and 8% expressed disagreement, indicating a subset of medical personnel who do not yet fully understand or acknowledge the existence of these SOPs. Similar findings have been observed in other studies, where some healthcare workers remained unaware of or did not fully understand policies and SOPs regarding the management of hazardous waste, despite their availability. Research results at Bhayangkara Level II Hospital Medan indicate that respondents' knowledge regarding forensic waste management SOPs falls within the moderate-to-good range, although the level of understanding is not uniform across all respondents. While respondents generally understand the importance of implementing SOPs in forensic waste management, further capacity building efforts such as dissemination, training, and periodic evaluation are still required to ensure consistent application of these SOPs by all personnel [6].

Research results indicate that respondents' perceptions of the health risks posed by forensic waste fall into the "very high" category and are relatively consistent across the entire group. These findings suggest that most personnel understand the potential biological, chemical, and physical hazards associated with forensic waste, meaning that awareness of the importance of workplace safety principles has been internalized in their daily operations. This awareness is reflected in their understanding of the necessity of using personal protective equipment (PPE), segregating waste according to its characteristics, and adhering to standard

operating procedures (SOPs) to minimize the risk of exposure to infectious agents or hazardous chemicals [4]. High risk perception also fosters safer work behaviors; healthcare personnel who clearly understand potential hazards tend to demonstrate higher levels of compliance with waste management procedures and infection prevention practices. Furthermore, the WHO emphasizes that heightened risk awareness, continuous training, and the implementation of a workplace safety culture are key components of a safe and sustainable healthcare waste management system.

The participation of medical personnel in forensic waste management is reflected not only in their adherence to established technical procedures but also in their active involvement at every stage of the process ranging from segregation, containment, and temporary storage to reporting and coordination with waste management units. This high level of participation demonstrates a collective awareness that forensic waste management is the responsibility of all healthcare workers; thus, the system's effectiveness relies not merely on sanitation staff but also on the commitment of every medical professional to implement safe, standardized waste management practices [16]. Various studies indicate that the active involvement of healthcare workers supported by knowledge, positive attitudes, and adherence to standard operating procedures contributes significantly to improved medical waste management quality, workplace safety, and environmental protection. Research results show that 50% of respondents strongly agreed and 9% agreed, resulting in a total of 59% demonstrating a positive level of active participation. These findings indicate that more than half of the medical staff have been directly involved in implementing SOPs regarding the segregation, handling, and oversight of forensic waste. However, the presence of respondents expressing neutral or negative views suggests that participation is not yet uniform across all work units. This situation may stem from heavy workloads, time constraints, and the perception that waste management is the sole responsibility of specific units [6]. Increasing healthcare worker participation requires strengthening internal hospital policies, integrating forensic waste management topics into human resource competency development programs, and implementing continuous monitoring, evaluation, and feedback mechanisms. Such efforts are expected to enhance the consistency of staff adherence to waste management procedures, strengthen the culture of workplace safety, and optimize forensic waste management practices to ensure they are effective, sustainable, and compliant with applicable regulations.

Adherence to occupational safety procedures is a key indicator for assessing the effectiveness of implementing Occupational Health and Safety (OHS) systems in forensic waste management. High levels of compliance reflect the successful integration of knowledge, risk perception, and staff participation into

daily work practices. Research results indicate that the respondents' level of compliance with safety procedures falls into the "very high" category and is relatively uniform. All respondents (100%) strongly agreed with the requirement to use personal protective equipment (PPE) when handling forensic waste, indicating that PPE usage has become an integral part of routine waste management practices at Bhayangkara Hospital Level II Medan. This high level of compliance reflects staff awareness regarding the importance of self-protection against exposure to biological agents, hazardous chemicals, and the risk of sharps injuries associated with forensic waste. Consistent use of PPE is a primary component of risk control in healthcare facilities, as it mitigates potential exposure to pathogenic microorganisms and hazardous substances during waste handling [4]. These findings align with various studies demonstrating that healthcare workers' compliance with PPE usage is closely linked to their knowledge levels, risk perceptions, the availability of facilities, and the hospital's safety culture [17]. Furthermore, regulations regarding PPE usage in medical waste management are stipulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 7 of 2019 concerning Hospital Environmental Health; this regulation mandates that all healthcare workers use PPE appropriate to their job-related risk levels as part of occupational health and safety protection measures.

The level of healthcare worker compliance with occupational safety procedures regarding forensic waste management falls into the "very good" category. Uniform responses across all compliance indicators reflect consistent behavior and a high level of commitment among respondents in adhering to occupational safety standards. These findings reinforce previous analyses indicating that a strong perception of health risks, combined with an adequate understanding of standard operating procedures (SOPs), fosters compliant work behavior in forensic waste management. This aligns with research demonstrating a strong link between a robust safety culture and increased healthcare worker compliance with operational procedures, as well as the role of management support in creating a safe work environment [18].

Nevertheless, this high level of compliance must be sustained through a continuous approach, including regular internal audits, the evaluation and updating of SOPs in line with evolving regulations and best practices, and ongoing training for all healthcare workers. Such measures are crucial for strengthening safety culture, enhancing the consistency of procedural implementation, and preventing any decline in compliance resulting from organizational changes or work routines. Therefore, continuous oversight, management commitment, and human resource capacity-building programs are key factors in maintaining sustained compliance with occupational

safety procedures for forensic waste management in hospitals [20].

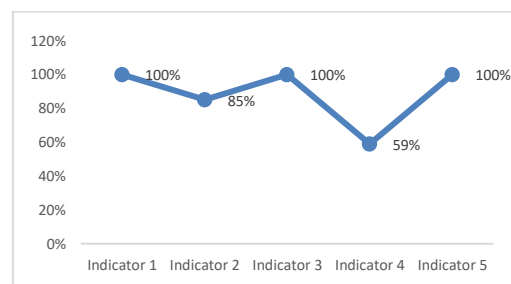


Figure 1. comparison of the values of each indicator of the social aspect

Based on the social aspect graph, environmental awareness among medical personnel (Indicator 1), health risk perception (Indicator 3), and compliance with occupational safety procedures (Indicator 5) each achieved a score of 100%, indicating that all respondents demonstrated an excellent level of awareness, risk perception, and compliance regarding forensic waste management. These findings suggest that medical personnel fully recognize the importance of environmental protection, understand the potential health risks associated with forensic waste, and consistently adhere to occupational safety procedures throughout the waste management process. This result is consistent with the findings of Motlatla and Maluleke, who reported that higher levels of knowledge and risk perception among healthcare workers contribute significantly to improved compliance with healthcare waste management practices [6]. Furthermore, the World Health Organization (WHO) emphasizes that a strong safety culture and strict adherence to operational procedures are fundamental components of sustainable and safe healthcare waste management systems [4].

Meanwhile, knowledge of the Standard Operating Procedures (SOPs) for forensic waste management (Indicator 2) reached 85%, indicating that respondents generally possessed a good understanding of the applicable procedures. However, the results also suggest that knowledge has not yet been uniformly distributed among all healthcare personnel. This finding highlights the need for continuous capacity-building initiatives, including regular training programs, dissemination of updated regulations, and periodic revision of SOPs to ensure consistent implementation of forensic waste management practices across all staff members [17].

The lowest score was observed for participation in forensic waste management activities (Indicator 4), which reached 59%. This finding indicates that although respondents demonstrated high levels of knowledge and compliance, their active involvement throughout the entire waste management process remains relatively limited. Participation in activities such as waste segregation, temporary storage, reporting, coordination, and evaluation has not yet been fully optimized among

all healthcare personnel. Previous studies have demonstrated that effective healthcare waste management depends not only on individual knowledge and compliance but also on the active participation of healthcare workers, supported by organizational commitment, a strong safety culture, and continuous monitoring systems [16]. Therefore, hospitals should strengthen internal policies, provide continuous professional development programs, and establish comprehensive monitoring and evaluation mechanisms to enhance staff participation in forensic waste management practices.

The social impact of forensic waste is primarily felt by healthcare workers and communities surrounding hospitals. Direct exposure to infectious and chemical waste increases the risk of injury and illness. Existing research indicates that nearly a quarter of medical personnel sustain injuries from sharp objects or chemical contact while working in forensic units [20]. This reflects deficiencies in hospital risk control systems, such as a lack of training and inadequate personal protective equipment (PPE). Meanwhile, communities living near hospitals also harbor concerns regarding pungent odors, pollution, and the potential spread of disease. These findings align with research showing an increase in public complaints against hospitals with poor waste management systems, which can erode public trust in healthcare institutions [21].

4. Conclusion

An assessment of the existing forensic waste management facility at Bhayangkara Hospital Level II Medan indicates that the treatment system effectively controls chemical parameters, as evidenced by the absence of detectable formalin in laboratory test results. However, treatment performance regarding microbiological parameters remains suboptimal, as *Escherichia coli* (E. coli) and *Salmonella* bacteria were still identified in the treated waste. These findings suggest that the treatment process specifically the disinfection or biological treatment stages has not fully eliminated pathogenic microorganisms. Consequently, there remains a potential risk of environmental contamination and adverse public health impacts if the effluent is discharged into the environment without further treatment or adequate system optimization. While medical personnel generally understand that forensic waste is high risk and requires special handling, this awareness is not yet fully matched by consistent behavior in the comprehensive application of waste management procedures.

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