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INTEGRATED EVALUATION OF HAZARDOUS AND TOXIC WASTE (B3) MANAGEMENT IN A MULTI-CLUSTER UNIVERSITY: FACILITY-BASED ESTIMATION AND COMPLIANCE ANALYSIS

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Abstract
Operational activities of higher education institutions generate various hazardous and toxic wastes, originating not only from laboratory activities but also from administrative and supporting operations. Previous studies and institutional practices have predominantly focused on laboratory-generated hazardous waste, resulting in limited recognition and management of non-laboratory hazardous waste streams within universities. This study hypothesizes that hazardous waste management performance in higher education institutions remains fragmented and activity-based due to the absence of integrated identification, governance, and institutional coordination systems. Therefore, this research aimed to evaluate hazardous and toxic waste management performance at Universitas Hasanuddin Tamalanrea Campus and to identify root causes of non-optimal implementation as the basis for improvement strategies. The study employed a descriptive–evaluative design using a total population approach covering 15 faculties. Performance evaluation was conducted using an evidence-based scoring system (0–3) across 20 technical and administrative indicators derived from national regulations. Data were collected through field observations, structured interviews, and document reviews, while root cause analysis was performed using a Fishbone Diagram with a 6M framework. The results show that hazardous waste management performance scores ranged from 3 to 37 out of a maximum of 60. Only one faculty achieved a "Good" category, four faculties were classified as "Moderate," two as "Low," and eight faculties (53.33%) fell into the "Poor" category. Faculties with intensive laboratory activities demonstrated relatively higher compliance, whereas non-laboratory faculties exhibited minimal implementation. Root cause analysis revealed that deficiencies were primarily driven by inadequate standardized procedures, limited infrastructure, insufficient human resource capacity, fragmented documentation, and weak institutional coordination. These findings confirm the proposed hypothesis that fragmented governance systems undermine effective hazardous waste management. In conclusion, hazardous waste management at Universitas Hasanuddin remains uneven and non-integrated across faculties. Strengthening institutional-level systems, standardized procedures, and coordinated governance is essential to improve regulatory compliance and environmental safety in higher education institutions.
Keywords: Environmental management; Hazardous waste; Higher education institutions; Performance evaluation; Root cause analysis; Waste governance

Introduction

Operational activities of higher education institutions are inseparable from potential environmental pollution. Universities, as centers of research and education, conduct intensive laboratory activities alongside extensive administrative operations, which cumulatively generate various types of waste. According to Government Regulation of the Republic of Indonesia No. 22 of 2021 on Environmental Protection and Management, hazardous and toxic waste (Bahan Berbahaya dan Beracun, B3) is defined as residues from activities or processes containing hazardous and toxic substances that, due to their properties, concentration, or quantity, may pollute the environment and endanger human health.

At the global level, hazardous waste management in the education sector has attracted serious attention. The World Health Organization (WHO, 2018) highlights significant environmental and occupational health risks arising from improper management of laboratory waste. Similarly, the United Nations Environment Programme (UNEP, 2019) identifies universities as major contributors to chemical waste generation. Beyond laboratory activities, studies by UNEP (2007) and Garlapati (2016) emphasize the increasing volume of electronic waste (e-waste) and domestic hazardous waste—such as batteries and used lamps—originating from campus administrative activities, which are often overlooked in institutional waste management systems.In Indonesia, the regulatory framework for hazardous waste management has been strengthened through Government Regulation No. 22 of 2021 as the principal legal instrument, supported by technical implementing regulations including Ministry of Environment and Forestry Regulation No. 6 of 2021 on B3 Waste Management Procedures and Regulation No. 9 of 2024 on the Management of Waste Containing Hazardous Substances. These regulations require all waste generators, including higher education institutions, to implement risk-based waste management from upstream to downstream processes. However, previous studies indicate that practical implementation remains challenging. Sidik and Damanhuri (2012) reported B3 waste generation of 457.54 kg per week at Institut Teknologi Bandung with suboptimal management practices, while Pourzamani et al. (2019) recorded an annual generation of 2,609.9 kg at Isfahan University of Medical Sciences, dominated by pharmaceutical laboratories.Universitas Hasanuddin, as the largest university in Eastern Indonesia, implements a laboratory-based education system with highly complex activities. Faculties within the university—ranging from science, engineering, and health clusters to social sciences and humanities—possess distinct waste generation profiles. Laboratory-based faculties generate specific hazardous waste such as chemical reagents and infectious waste, whereas non-laboratory faculties produce hazardous waste associated with administrative

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activities, including electronic waste, cartridges, toner, and hazardous packaging materials. These non-laboratory waste streams are frequently not identified systematically in institutional waste management practices.Despite the evident risks, a major challenge faced by the university is the lack of validated and comprehensive data regarding hazardous waste sources and management performance. To date, no integrated, activity-based mapping of B3 waste generation across faculties at Universitas Hasanuddin has been conducted. In addition, standardized evaluation of existing management practices has not been systematically implemented. This absence of verified data constrains the university's efforts to ensure environmental safety and support the development of an eco-campus system.Accordingly, this study aims to evaluate the performance of hazardous waste management at Universitas Hasanuddin Kampus Tamalanrea using a structured scoring-based assessment (0–3) that requires physical evidence in the form of documents and field observations. The study focuses on identifying waste sources and types, assessing compliance with regulatory requirements, analyzing root causes of non-optimal management through fishbone analysis, and formulating evidence-based improvement strategies. Through this approach, the research seeks to support the development of an effective, accountable, and regulation-compliant hazardous waste management system in higher education institutions.

Methodology

Study Area and Research Design

This study was conducted at Universitas Hasanuddin, Tamalanrea Campus, located in Makassar, South Sulawesi, Indonesia. The campus represents a multi-cluster university environment consisting of laboratory-intensive faculties as well as non-laboratory faculties, which together generate diverse types of hazardous and toxic waste (B3) from academic, research, and administrative activities. The research applied a descriptive–evaluative design to assess the performance of hazardous waste management systems at the faculty level. This approach was selected to systematically evaluate existing management practices, measure compliance with national environmental regulations, and identify operational gaps based on observable conditions and verifiable evidence. The evaluation focused on the implementation of hazardous waste management stages, including identification and classification, containment, labeling, temporary storage, transportation, emergency preparedness, and administrative management. The assessment was conducted cross-sectionally during the research period from September to December 2025.

Population and Units of Analysis

The population of this study consisted of all faculties located at Universitas Hasanuddin, Tamalanrea Campus, Indonesia. A total of fifteen (15) faculties were included in the study and simultaneously designated as the units of analysis. The faculty level was selected as the unit of analysis because each faculty functions as an independent generator of hazardous and toxic waste (B3), with variations in academic activities, laboratory intensity, infrastructure availability, and administrative management practices. Faculties within laboratory-based academic clusters generate specific B3 waste streams, including chemical, infectious, and reagent waste, whereas non-laboratory faculties predominantly generate B3 waste associated with office and administrative activities, such as electronic waste, toner cartridges, and chemical cleaning agents. This study employed a total population (census) approach, whereby all faculties were evaluated without sampling. This approach ensured comprehensive institutional coverage, minimized selection bias, and enabled direct comparison of B3 waste management performance across different faculty clusters within the university. The list of faculties included as the units of analysis and their academic classification is presented in Table 1.

Table 1. Faculties included as units of analysis

No.	Faculty	Academic Cluster
1.	Faculty of Medicine	Laboratory-based
2.	Faculty of Dentistry	Laboratory-based
3.	Faculty of Pharmacy	Laboratory-based
4.	Faculty of Public Helath	Laboratory-based
5.	Faculty of Nursing	Laboratory-based
6.	Faculty of Agriculture	Laboratory-based
7.	Faculty of Animal Science	Laboratory-based
8.	Faculty of Forestry	Laboratory-based
9.	Faculty of Marine Science and Fisheries	Laboratory-based
10.	Faculty of Mathematics and Natural Sciences	Laboratory-based
11.	Faculty of Economics and Business	Non-laboratory
12.	Faculty of Law	Non-laboratory
13.	Faculty of Social and Political Sciences	Non-laboratory
14.	Faculty of Cultural Sciences	Non-laboratory
15.	Faculty of Vocational Studies	Non-laboratory

Source: Author's own compilation based on field observation (2025)

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Data Collection

Data collection was conducted using a multiple-method approach to ensure comprehensive and verifiable information regarding hazardous and toxic waste (B3) management practices across faculties. The methods included direct field observation, structured interviews, and document review, conducted between September and December 2025 at Universitas Hasanuddin, Tamalanrea Campus.Direct field observations were carried out in laboratories, temporary hazardous waste storage areas (TPS B3), and selected administrative units within each faculty. Observations focused on physical conditions and practices related to B3 waste management, including waste segregation, container suitability, labeling and hazard symbols, storage conditions, availability of personal protective equipment (PPE), emergency preparedness facilities, and compliance with technical storage requirements. Observational data were supported by photographic documentation to verify field findings. Structured interviews were conducted with personnel responsible for laboratory management, waste handling, or faculty-level administration. The interviews aimed to obtain information on waste identification practices, internal management procedures, coordination mechanisms, training experiences, and challenges encountered in implementing B3 waste management. Interview responses were used to complement observation results and to clarify administrative and procedural aspects that could not be directly observed. Document review was performed to examine administrative records related to B3 waste management, including waste manifests, transportation documents, handover reports, internal records of waste generation and shipment, and coordination correspondence with licensed third-party waste handlers. The availability, completeness, and consistency of documentation were assessed as part of the administrative compliance indicators. All data collected from observations, interviews, and document review were cross-checked to ensure consistency and accuracy. This triangulation approach was applied to strengthen the reliability of the evaluation results and to support evidence-based scoring of each performance indicator.

Table 2. Data collection methods and sources

Method	Data Source	Information Collected
Field observation	Laboratories, TPS B3, offices	Physical condition, compliance, facilites
Structured interviews	Laboratory managers, faculty staff	Procedures, coordination, challenge
Document review	Manifests, transport records	Administrative compliance

Source: Author's own compilation based on field observation (2025)

Performance Evaluation and Scoring System

The performance evaluation of hazardous and toxic waste (B3) management was conducted using an evidence-based scoring system to assess compliance with national environmental regulations and technical standards. The evaluation framework was developed based on Government Regulation No. 22 of 2021 and Minister of Environment and Forestry Regulation No. 6 of 2021, which govern the management of hazardous waste in Indonesia. A total of 20 performance indicators were applied to each faculty, covering six main aspects of B3 waste management: (1) identification and classification, (2) containment, labeling, and hazard symbols, (3) temporary storage (TPS B3), (4) transportation and documentation, (5) human resources and emergency preparedness, and (6) coordination and management. Each indicator was evaluated independently using a four-point scoring scale (0–3).

The scoring criteria were defined as follows:

a) Score 0 (Not implemented): The required activity or facility was not available or not implemented at the faculty.
b) Score 1 (Implemented without evidence): The activity or facility was claimed to be implemented, but no physical evidence (documents or photographs) could be presented during evaluation.
c) Score 2 (Implemented with incomplete evidence): The activity or facility was implemented, but supporting evidence was incomplete or did not fully comply with technical requirements.
d) Score 3 (Implemented with complete evidence): The activity or facility was fully implemented and supported by complete and verifiable physical evidence, including documentation and field observations.

For each faculty, the total score was calculated by summing the scores of all 20 indicators, with a maximum possible score of 60. The overall performance of B3 waste management was then classified into five categories based on total score ranges, as shown in Table 3.

Table 3. Performance evaluation criteria and scoring system

Total Score Range	Performance Category
0 - 12	Poor
13 - 24	Low
25 - 36	Moderate
37 - 48	Good
49 - 60	Very Good

Source: Authors' compilation based on PP No. 22/2021 and PermenLHK No. 6/2021

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This scoring approach ensured an objective and transparent evaluation process by emphasizing verifiable evidence rather than self-reported compliance. The results of the scoring system were used as the primary basis for inter-faculty comparison, root cause analysis, and formulation of improvement strategies.

Root Cause Analysis (Fishbone Diagram)

Root cause analysis was conducted to identify the fundamental factors contributing to the suboptimal performance of hazardous and toxic waste (B3) management at Universitas Hasanuddin Tamalanrea Campus. This analysis employed the Fishbone Diagram (Ishikawa Diagram) as a systematic cause–effect tool to structure and interpret the findings obtained from the performance evaluation and compliance assessment stages. The central problem analyzed in the fishbone diagram was defined as "Suboptimal performance of B3 waste management across faculties", as reflected by low to moderate fulfillment of technical and administrative indicators. The fishbone framework was developed using the 6M approach, which is commonly applied in environmental management system evaluations and institutional performance analysis, consisting of Method, Material, Machine, Man, Management, and Environment. Each branch of the diagram was populated using empirical findings derived from indicator scores, field observations, interviews, and document reviews. The categorization of root causes was carried out as follows:

a) Method: Inadequate implementation of standardized procedures, including incomplete identification and classification of B3 waste sources and the absence of comprehensive operational guidelines covering laboratory and non-laboratory activities.
b) Material: Insufficient availability of appropriate containers, hazard labels, safety signage, personal protective equipment (PPE), and spill response materials required for safe B3 waste handling.
c) Machine: Limited supporting infrastructure, particularly the absence or non-compliance of temporary storage facilities (TPS B3), lack of internal transport equipment, and inadequate emergency response facilities.
d) Man: Insufficient human resource capacity, reflected by the absence of formally appointed B3 waste management personnel and limited technical training related to hazardous waste handling.
e) Management: Weak institutional governance, including the absence of integrated documentation systems, inconsistent reporting practices, and limited coordination between faculties and the university's environmental management unit.
f) Environment: Inappropriate placement and design of storage areas, including proximity to public spaces, insufficient physical separation, and inadequate protection from environmental exposure.

The fishbone analysis enabled the integration of quantitative performance evaluation results with qualitative institutional conditions, allowing systematic identification of root causes rather than surface-level symptoms. The outputs of this analysis were subsequently used as the basis for formulating targeted and evidence-based improvement strategies presented in Section 3.

Strategy Formulation

Strategy formulation was conducted as the final analytical stage of this study to develop evidence-based recommendations for improving hazardous and toxic waste (B3) management at Universitas Hasanuddin Tamalanrea Campus. The strategies were formulated by integrating the results of performance evaluation, compliance analysis, and root cause analysis derived from the fishbone diagram. The formulation process employed a gap analysis approach, in which the existing conditions of B3 waste management practices at the faculty level were systematically compared with the ideal conditions stipulated in national regulatory frameworks, particularly Government Regulation No. 22/2021 and Minister of Environment and Forestry Regulation No. 6/2021. Identified gaps between actual practices and regulatory requirements were used to determine priority areas for intervention. To ensure consistency and traceability, strategy formulation followed a one-to-one mapping principle, whereby each identified root cause was directly linked to a corresponding corrective strategy. This approach ensured that every recommended action addressed a specific and empirically identified weakness within the management system, rather than providing generic or normative recommendations.

Results and Discussions

Overview of B3 Waste Management Performance Across Faculties

Hasanuddin University, Tamalanrea Campus, hosts a wide range of academic activities, encompassing faculties with intensive laboratory operations as well as faculties dominated by office-based and administrative activities. This diversity results in variations in the sources, types, and potential generation of hazardous and toxic waste (B3), which in turn affects the level of implementation of B3 waste management practices across faculties. The evaluation of B3 waste management performance conducted across 15 faculties indicates that the implementation of B3 waste management systems has not been uniformly established at the institutional level. Faculties with intensive laboratory activities generally demonstrate more structured waste management practices, particularly in technical aspects such as waste segregation, containerization, and transportation through licensed third parties. In contrast, non-laboratory faculties tend to show limited implementation, especially regarding administrative procedures, documentation, and the availability of supporting facilities. Overall, the

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initial evaluation reveals clear disparities in B3 waste management performance among faculties, both in terms of technical compliance and administrative fulfillment. These disparities reflect the absence of an integrated university-wide B3 waste management system, as well as differences in institutional capacity and managerial commitment at the faculty level. This general overview serves as a foundation for the subsequent sections, which present a detailed quantitative assessment of performance scores, compliance levels, and classification of B3 waste management practices across faculties based on the established evaluation indicators.

a) Identification and Sources of Hazardous and Toxic Waste (B3)

Hazardous and toxic waste (B3) generated at Hasanuddin University, Tamalanrea Campus originates from diverse academic and supporting activities conducted across faculties with different functional characteristics. Based on field observations, structured interviews, and document reviews, B3 waste sources were identified from both laboratory-based activities and non-laboratory (administrative and office-related) activities. Laboratory-based faculties generate B3 waste primarily from teaching, research, and practical activities. The identified waste types include chemical reagent residues, contaminated chemical containers, expired laboratory chemicals, infectious and biomedical waste, and laboratory sharps. These waste streams are mainly associated with faculties in the health sciences, natural sciences, agriculture, and marine-related disciplines, where laboratory utilization is intensive and continuous. In contrast, faculties with limited or no laboratory activities were found to generate B3 waste predominantly from administrative and supporting activities. This category includes electronic waste (e-waste) such as damaged electronic equipment, used batteries, fluorescent lamps, printer toner and ink cartridges, and cleaning chemicals containing hazardous substances. Although generated in smaller quantities compared to laboratory waste, these waste types pose potential environmental and health risks if not properly managed. The identification process further revealed that B3 waste recognition across faculties remains uneven. Waste identification practices are predominantly focused on laboratory-generated B3 waste, while B3 waste originating from office and administrative activities is largely undocumented and unmanaged within formal waste management systems. As a result, no faculty demonstrated comprehensive identification of B3 waste covering all operational activities. These findings indicate that the identification and classification of B3 waste at Hasanuddin University are still partial and activity-specific. The absence of comprehensive identification covering both laboratory and non-laboratory sources represents a critical gap at the initial stage of B3 waste management. This gap directly affects subsequent management stages, including classification, containerization, storage, transportation, and documentation, and underscores the need for an integrated identification framework at the university level.

This section provides an overview of hazardous and toxic waste (B3) management performance across faculties at Universitas Hasanuddin Tamalanrea Campus. Performance evaluation was conducted using a standardized scoring system consisting of 20 technical and administrative indicators, with a maximum score of 60 for each faculty.

b) Performance Evaluation and Compliance Level of B3 Waste Management

The performance evaluation of hazardous and toxic waste (B3) management at Hasanuddin University, Tamalanrea Campus was conducted using a structured scoring system based on regulatory compliance and physical evidence. The assessment covered 15 faculties and employed 20 indicators representing technical, administrative, and institutional aspects of B3 waste management. Each indicator was scored on a scale of 0 to 3, reflecting the level of implementation and availability of supporting evidence. The evaluation results demonstrate substantial variability in B3 waste management performance across faculties. Overall performance scores ranged from 3 to 37 out of a maximum score of 60, indicating uneven levels of compliance with national regulations. Based on predefined classification thresholds, faculties were grouped into five performance categories: *Poor, Low, Moderate, Good, and Very Good*.

Table 4. Performance scores and compliance classification of B3 waste management across faculties

No.	Faculty	Total Score (Max. 60)	Performance Category
1.	Faculty of Medicine	36	Moderate
2.	Faculty of Dentistry	18	Low
3.	Faculty of Pharmacy	34	Moderate
4.	Faculty of Public Health	28	Moderate
5.	Faculty of Nursing	21	Low
6.	Faculty of Agriculture	6	Poor
7.	Faculty of Animal Science	7	Poor
8.	Faculty of Forestry	6	Poor
9.	Faculty of Marine and Fisheries Sciences	32	Moderate
10.	Faculty of Mathematics and Natural Sciences	37	Good

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11.	Faculty of Economics and Business	3	Poor
12.	Faculty of Law	3	Poor
13.	Faculty of Social and Political Sciences	3	Poor
14.	Faculty of Cultural Sciences	3	Poor
15.	Faculty of Vocational Studies	3	Poor

Source: Primary data analysis (field observation, interviews, and document review), 2025

Only one faculty (6.67%), the Faculty of Mathematics and Natural Sciences, achieved a "Good" performance classification, with a score of 37. This faculty demonstrated relatively consistent compliance across multiple indicators, particularly in waste segregation, temporary storage facilities, documentation, and coordination with licensed third-party waste handlers. Four faculties (26.67%) were classified as "Moderate", namely the Faculties of Medicine, Pharmacy, Public Health, and Marine and Fisheries Sciences. These faculties showed partial compliance, particularly in laboratory waste identification, containerization, and transportation practices. However, significant gaps remained in administrative documentation, comprehensive classification, and emergency preparedness. Two faculties (13.33%) fell into the "Low" category, while the majority—eight faculties (53.33%)—were classified as "Poor" Faculties in the poor category were predominantly non-laboratory-based units or faculties with limited hazardous waste awareness and infrastructure. These faculties exhibited minimal compliance, characterized by the absence of standardized procedures, inadequate storage facilities, lack of trained personnel, and missing documentation.

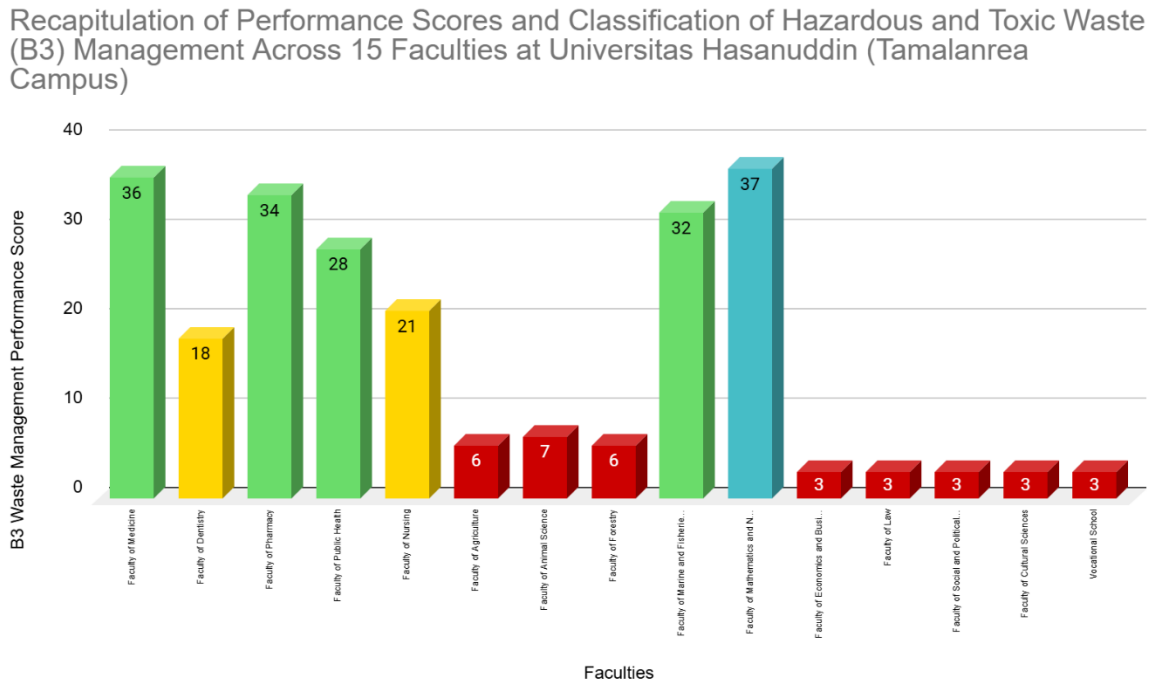

Figure 1. Distribution of B3 waste management performance categories across faculties

To further illustrate the distribution of performance categories, Figure 1 depicts the proportion of faculties across each performance classification. The dominance of the "Poor" category highlights that B3 waste management practices at Universitas Hasanuddin remain largely fragmented, unit-based, and dependent on laboratory operational needs, rather than being guided by a comprehensive and integrated university-wide management system.

This pattern is consistent with previous studies in higher education institutions, which reported higher compliance levels in laboratory-intensive faculties compared to non-experimental units due to regulatory pressure and operational risk considerations (Sidik & Damanhuri, 2012; Pourzamani et al., 2019).

Analysis of individual indicators further revealed that compliance was generally higher for operational laboratory practices, such as waste segregation and basic container use, while administrative and institutional indicators—including formal documentation, reporting, routine coordination, and emergency preparedness—consistently received low scores across most faculties. Notably, no faculty achieved full compliance (score 3) for indicators related to comprehensive identification covering both laboratory and office-generated B3 waste.

These results indicate that B3 waste management at Hasanuddin University remains fragmented and predominantly

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activity-driven rather than system-based. While certain faculties have developed partial compliance through laboratory operations, the absence of an integrated institutional framework limits consistency and regulatory adherence across the university. This performance disparity highlights the need for standardized policies, centralized coordination, and capacity-building measures to enhance compliance levels uniformly across faculties.

Root Cause Analysis of B3 Waste Management Deficiencies

The deficiencies identified in the performance evaluation of B3 waste management across faculties were further examined through a root cause analysis using the Fishbone Diagram (6M approach), encompassing Method, Material, Machine, Man, Management, and Environment. This analysis was conducted to systematically identify the fundamental factors contributing to the low level of compliance observed in most faculties.

a) Method (Procedures and Operational Systems)

Method-related deficiencies represent the most dominant root cause affecting B3 waste management performance. The evaluation results indicate that 100% of faculties have not implemented comprehensive identification and classification procedures covering all waste sources, particularly non-laboratory activities. Identification and classification practices were limited exclusively to laboratory-generated B3 waste, while office-based B3 waste—such as electronic waste, printer toner, used lamps, and chemical cleaning agents—was not formally identified or classified. Additionally, no faculty achieved full compliance (score 3) for indicators related to waste identification, classification based on regulatory codes, or standardized operational procedures. The absence of written standard operating procedures (SOPs) governing identification, classification, and initial handling of B3 waste has resulted in inconsistent implementation across faculties and has weakened subsequent stages of waste management, including packaging, storage, and transportation.

b) **Material (Containers, Labels, and Safety Equipment)**

Method-related deficiencies represent the most dominant root cause affecting B3 waste management performance. The evaluation results indicate that 100% of faculties have not implemented comprehensive identification and classification procedures covering all waste sources, particularly non-laboratory activities. Identification and classification practices were limited exclusively to laboratory-generated B3 waste, while office-based B3 waste—such as electronic waste, printer toner, used lamps, and chemical cleaning agents—was not formally identified or classified. Additionally, no faculty achieved full compliance (score 3) for indicators related to waste identification, classification based on regulatory codes, or standardized operational procedures. The absence of written standard operating procedures (SOPs) governing identification, classification, and initial handling of B3 waste has resulted in inconsistent implementation across faculties and has weakened subsequent stages of waste management, including packaging, storage, and transportation.

c) Machine (Infrastructure and Supporting Facilities)

Material-related deficiencies were evident in the limited availability and improper use of waste containers, hazard labels, and safety equipment. The performance evaluation shows that 40% of faculties did not apply hazard symbols or labels on B3 waste containers, while 80% of faculties did not provide personal protective equipment (PPE) or spill response tools at B3 waste storage locations. Even in faculties that demonstrated partial compliance, appropriate containers and labeling were generally applied only to specific laboratory waste streams. The lack of standardized container specifications and insufficient safety equipment indicates that material support for B3 waste management remains inadequate and unevenly distributed across faculties, increasing operational and safety risks.

d) Man (Human Resources Capacity)

Machine-related deficiencies are primarily associated with the limited availability of compliant Temporary Storage Facilities (TPS B3). The evaluation revealed that 60% of faculties do not have a TPS B3 that meets technical requirements, while only 3 out of 15 faculties were equipped with adequately marked and properly supported storage facilities. In faculties without TPS B3, hazardous waste was stored in laboratories, general storage rooms, or utility spaces not designed for B3 waste handling. This condition demonstrates that infrastructure provision for B3 waste management has not yet been institutionalized as a standard facility requirement at the faculty level.

e) Management (Governance, Documentation, and Coordination)

Human resource limitations significantly contribute to the deficiencies observed. The results show that 53.33% of faculties have not officially appointed B3 waste management personnel, and 53.33% of faculties do not have staff with formal training in B3 waste handling. Where personnel were present, responsibilities were often limited to laboratory staff without

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formal designation or adequate training certification. This lack of clear role assignment and competency development directly affects procedural compliance, documentation quality, and emergency preparedness related to B3 waste management.

f) Environment (Spatial and Environmental Conditions)

Environmental factors further exacerbate existing deficiencies. Several TPS B3 locations were found to be adjacent to public activity areas, lacked sufficient physical barriers, or were inadequately protected from weather exposure. These conditions increase the potential for accidental exposure, spills, and unauthorized access, reinforcing the deficiencies identified under Machine and Management categories.

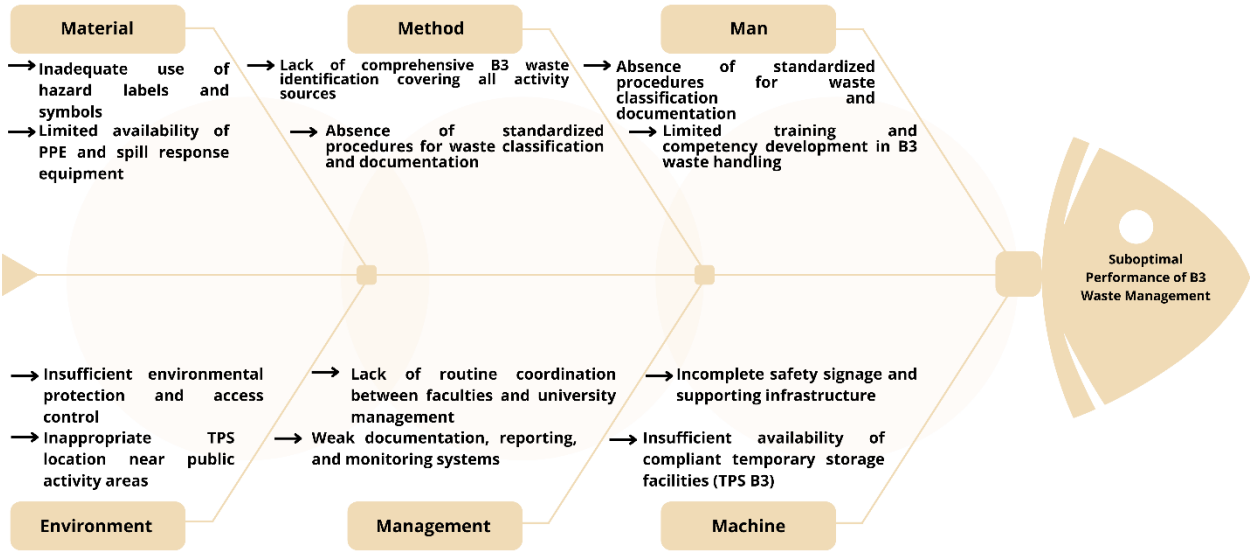

Figure 2. Root Cause Analysis of B3 Waste Management Deficiencies Using Fishbone Diagram (6M Approach)
Source: Authors' analysis based on performance evaluation results (2025)

To synthesize the findings from the root cause analysis, the identified deficiencies across Method, Material, Machine, Man, Management, and Environment were visually mapped using a Fishbone Diagram. This diagram illustrates the cause–effect relationship between the observed performance gaps in B3 waste management and the underlying institutional, technical, and operational factors identified through performance evaluation and compliance assessment.

Overall, the root cause analysis demonstrates that the low performance of B3 waste management at Universitas Hasanuddin is not driven by a single factor, but by interrelated deficiencies across procedural systems, infrastructure, human resources, governance, and environmental controls. The dominance of Method and Management issues indicates that institutional-level intervention is essential to improve compliance and ensure consistent implementation across faculties. These root causes provide a structured foundation for the development of targeted improvement strategies, which are presented in the subsequent section.

Strategy Recommendations Based on Root Cause Mapping

Based on the root cause analysis presented in Section 3.4, strategy recommendations were formulated through a direct one-to-one mapping between identified deficiencies and targeted corrective actions. This approach ensures that each proposed strategy responds explicitly to verified performance gaps in hazardous and toxic waste (B3) management at Universitas Hasanuddin Tamalanrea Campus. The strategy formulation emphasizes institutional integration, regulatory compliance, and practical feasibility, taking into account the heterogeneity of academic activities across faculties.

a) Streghtening Identification and Classification Procedures (Method)

To address deficiencies in waste identification and classification, the primary strategy recommended is the development and implementation of standardized operating procedures (SOPs) for B3 waste identification covering all activity sources, including laboratory, administrative, and supporting facilities. This includes the preparation of a faculty-level B3 waste inventory document specifying waste type, source, hazard characteristics, and regulatory code in accordance with PP No.

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22/2021 and Permen LHK No. 6/2021.
The adoption of standardized documentation is expected to improve traceability and provide a structured foundation for subsequent management stages.

b) Improvement of Waste Containers, Labeling, and Safety Equipment (Material)
To overcome the limited availability of compliant containers, labels, and safety equipment, it is recommended that each faculty implement minimum technical standards for B3 waste containers, hazard labeling, and symbol placement. In addition, faculties should ensure the provision of basic personal protective equipment (PPE) and spill response kits at waste generation points and temporary storage areas. This strategy directly supports risk control at the source and enhances occupational safety during waste handling activities.

c) Development of Adequate Temporary Storage Facilities (Machine)
Given the limited availability of compliant Temporary Storage Facilities (TPS B3), the recommended strategy prioritizes the development of either faculty-based or centralized TPS B3 that meet technical and environmental safety requirements. These facilities should include impermeable flooring, ventilation, weather protection, restricted access, and clear hazard signage.
Centralized TPS development is particularly recommended for faculties with low waste generation rates to optimize resource utilization while maintaining regulatory compliance.

d) Strengthening Human Resources Capacity (Man)
To address deficiencies in waste identification and classification, the primary strategy recommended is the development and implementation of standardized operating procedures (SOPs) for B3 waste identification covering all activity sources, including laboratory, administrative, and supporting facilities. This includes the preparation of a faculty-level B3 waste inventory document specifying waste type, source, hazard characteristics, and regulatory code in accordance with PP No. 22/2021 and Permen LHK No. 6/2021. The adoption of standardized documentation is expected to improve traceability and provide a structured foundation for subsequent management stages.

e) Integration of Docomentation, Reporting, and Institutional Coordination (Management)
To overcome fragmented documentation and weak coordination, this study recommends the establishment of an integrated B3 waste management system at the university level. This system should standardize waste recording, manifest archiving, reporting schedules, and internal audits across all faculties.
Routine coordination meetings between faculties and the university's environmental management unit are recommended to ensure alignment of operational practices, monitoring, and continuous improvement.

f) Improvement of Environmental Safety and Spatial Planning (Environment)
To mitigate environmental and safety risks associated with TPS location, it is recommended that waste storage areas be spatially separated from public and academic activity zones. Environmental controls such as access restriction, protective barriers, and weatherproofing should be incorporated into TPS design to minimize exposure risks. These measures support both environmental protection and campus-wide safety assurance.
Overall, the proposed strategies offer a structured and evidence-based pathway for improving B3 waste management performance at Universitas Hasanuddin. By directly linking root causes to corrective actions, the recommendations support gradual system integration, regulatory compliance, and sustainable environmental governance within a multi-faculty university setting.

Conclusion
Based on the research findings regarding the management of Hazardous and Toxic Waste (B3) at Hasanuddin University, Tamalanrea Campus, the following conclusions are drawn:
First, B3 waste at the study site originates from laboratory and office activities across 15 faculties, encompassing laboratory chemicals, infectious and medical waste, reagents, chemical packaging, and office-related hazardous waste such as toner and ink. The volume and variety of waste are highly dependent on the intensity of academic activities and the specific characteristics of each faculty.
Second, the performance levels of B3 waste management across faculties remain low and uneven. Evaluation results indicate that only one faculty (6.67%) achieved a "Good" rating (Faculty of Mathematics and Natural Sciences), while four faculties (26.67%) were categorized as "Fair," and two (13.33%) as "Poor." Significantly, the majority of faculties (53.33%)

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fall into the "Very Poor" category, indicating substantial non-compliance with the technical and administrative standards mandated by current environmental regulations.

Third, the root cause analysis using the Fishbone Diagram (6M) identified several critical constraints: a total absence of standardized identification and classification procedures (100% of faculties), a lack of Personal Protective Equipment (PPE) and emergency response tools (80%), and the unavailability of Temporary Storage Facilities (TPS) that meet technical standards (60%). Furthermore, human resources and management aspects pose serious challenges, with over half of the faculties lacking officially appointed competent personnel and demonstrating weaknesses in routine recording and reporting.

As a recommendation, Hasanuddin University requires an integrated improvement strategy at the university level. This includes the standardization of Standard Operating Procedures (SOPs), the fulfillment of storage infrastructure according to technical specifications, the enhancement of human resource capacity through certified training, and the strengthening of management coordination and oversight to ensure sustainable and environmentally safe B3 waste management.

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