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Occupational Health and Safety Risk Analysis Using Hazard Identification, Risk Assessment, and Risk Control Method at Final Waste Disposal Site Suwung, Bali

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ABSTRACT: The Suwung Final Waste Processing Site, the largest landfill in Bali, faced major challenges, including overcapacity of waste piles, high fire risks due to methane gas accumulation, and the lack of a structured Occupational Health and Safety (OHS) system. These conditions posed significant hazards that directly affected the safety and health of workers. This study aimed to identify hazards, assess risk levels, and recommend appropriate risk control measures for operational activities at TPA Suwung. This research was conducted at TPA Suwung from March to April 2025, involving 18 workers as respondents. The study focused on four key operational activities: waste truck mobilization, waste reception, landfill structuring, and heavy equipment maintenance. The analysis was carried out using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method to systematically evaluate and manage occupational risks. A total of 30 potential hazards were identified, classified into five categories: physical, mechanical, chemical, biological, and ergonomic. The risk assessment indicated that 3.33% of the risks were low, 36.67% medium, 56.67% high, and 3.33% extreme. The recommended control measures included one elimination, two substitutions, eight engineering controls, twelve administrative controls, and five uses of personal protective equipment (PPE). The findings indicated a high proportion of hazards with significant risk levels, underscoring the urgent need for comprehensive risk mitigation. Effective implementation of the recommended control measures was expected to improve occupational safety and health at TPA Suwung. Strengthening OHS management systems and conducting regular monitoring were crucial to sustaining a safe and healthy work environment.

KEYWORDS: Hazard identification; occupational health and safety; Risk Assessment; risk control; waste management

1. Introduction

Final Waste Disposal Sites played a crucial role in integrated waste management systems worldwide [1]. In Indonesia, the majority of TPAs (56%) still employed the open dumping method, which involved piling waste without soil coverage and posed significant

environmental and health hazards [2, 3]. The growth of the global population, rapid industrial development, expanding economic activity, increasing urbanization, and changing consumption patterns jointly led to a significant rise in both the quantity and complexity of solid waste [4]. The World Bank projected that global municipal solid waste (MSW) generation would increase from 2.01 billion tons in 2016 to 3.4 billion tons by 2050 [5]. The continuous increase in waste volume led to overloaded landfills, further exacerbating waste management challenges and contributing to negative environmental impacts as well as risks to the safety and health of landfill workers [6, 7].

Worldwide, approximately 20 million individuals were engaged in the informal waste sector [8]. Workers in waste treatment were exposed to various occupational health and safety (OHS) hazards, including physical hazards (such as cuts and lacerations from sharp objects), ergonomic hazards (for example, heavy lifting), as well as chemical, biological, psychological, and social risks. Injuries caused by sharp objects were common among industrial waste treatment workers, with a high prevalence ranging from 80% to 90% [9]. Workers were exposed to three major categories of occupational hazards: infections, chronic illnesses, and physical injuries [10]. Workers at a landfill in Himachal Pradesh, India, frequently experienced respiratory illnesses, injuries, and allergic reactions [11]. A study at the Bantar Gerbang Waste Processing Site found that many workers suffered from skin disorders due to poor personal hygiene practices [12]. These findings highlighted the urgent need for effective Occupational Health and Safety (OHS) management to ensure a safe and healthy working environment for landfill workers.

The Suwung Final Waste Disposal Site, the largest landfill in Bali, faced similar challenges. Serving the Denpasar and Badung areas, this site spanned approximately 32.4 hectares and received 1,100 to 1,200 tons of waste daily [13]. The landfill, which operated using an open dumping system, exceeded its capacity and experienced fires due to methane gas buildup within the waste piles. Open dumping practices intensified public health risks, including vector-borne diseases and respiratory illnesses, while also degrading the quality of water bodies, soil, and air [14]. Moreover, TPA Suwung lacked an OHS Committee and formal OHS policies, making it difficult to manage workplace risks effectively. Physical injuries were common due to the insufficient use of personal protective equipment (PPE). Safety practices remained largely informal, and PPE utilization was low because of its cost and the discomfort associated with wearing it. Many waste pickers reported that they did not use PPE due to financial limitations, despite the heightened health risks [15]. In response to these issues, this study aimed to identify hazards, assess risk levels, and provide appropriate recommendations for the control of occupational health and safety risks at TPA Suwung.

2. Materials and Methods

2.1. Participants and study design.

This study adopted a mixed-method research design to provide a comprehensive assessment of occupational health and safety risks at the Suwung Final Waste Processing Site (TPA Suwung). The qualitative component involved field observations, semi-structured interviews, and secondary data analysis to systematically identify hazards and capture contextual workplace conditions. The quantitative component was conducted using the HIRARC (Hazard Identification, Risk Assessment, and Risk Control) framework, where identified hazards were

evaluated through structured scoring of likelihood and severity to determine risk levels. A total of 18 respondents participated in the study, consisting of 2 landfill managers, 2 heavy equipment operators, 2 site security personnel, 2 operational staff, 8 truck drivers and waste collectors, and 2 informal waste pickers. Additional expert input from an occupational health and safety (OHS) specialist was incorporated to strengthen the determination of appropriate risk control measures.

2.2. Measurement and procedure.

The measurement process in this study consisted of three main stages: hazard identification, risk assessment, and risk control recommendation, which were conducted systematically using the HIRARC (Hazard Identification, Risk Assessment, and Risk Control) approach. Hazard identification was carried out through direct field observations, semi-structured interviews with workers, literature review, and analysis of operational documents at the Suwung Final Waste Processing Site (TPA Suwung). To ensure the rigor of the measurement and procedure, data triangulation was applied by cross-validating information obtained from these multiple sources. The identified hazards were then classified into five categories: physical hazards (e.g., extreme heat, noise, and sharp objects), mechanical hazards (e.g., moving machinery and vehicle operation), chemical hazards (e.g., exposure to toxic gases and waste), biological hazards (e.g., bacteria, viruses, and decomposing organic matter), and ergonomic hazards (e.g., repetitive movements and improper working posture).

The risk assessment stage was performed using a quantitative HIRARC scoring system based on likelihood and severity parameters, supported by predefined assessment criteria to ensure consistency across evaluations. Furthermore, methodological triangulation was applied by integrating qualitative findings with quantitative risk scoring. The reliability of the assessment results was strengthened through expert validation involving an occupational health and safety (OHS) specialist, as well as inter-source consistency checks between respondent inputs and actual field conditions. This procedure minimized subjectivity in risk scoring and ensured that the resulting risk levels accurately reflected real workplace hazards, thereby enhancing the validity and robustness of the overall risk assessment.

2.3. Statistical analysis.

The risk assessment process in this study involved a structured scoring system to evaluate each identified hazard based on two dimensions: the probability of occurrence (Table 1) and the severity of impact if the hazard were to occur (Table 2) [16, 17]. The two scores were multiplied to generate a risk rating, which was then assessed using a risk level (Table 3) to classify the overall risk into four categories: low, medium, high, and extreme. This quantitative approach allowed for systematic prioritization of occupational health and safety risks based on their urgency and potential harm to workers.

Table 1. Probability criteria (likelihood).

Criteria	Information
Rare	Only likely to occur under certain conditions. The frequency of occurrence is estimated at once or several times per year.
Unlikely	Not expected to occur, but still possible on some occasions. The frequency of occurrence is estimated at once or several times every six months to a year.
Possible	Likely to occur at certain times. The frequency of occurrence is estimated at once or several times within one to six months.
Likely	Tends to occur in most situations or conditions. The frequency of occurrence is estimated at once or several times per month.
Almost Certain	Expected to occur or has previously occurred and continues to have an impact. The frequency of occurrence is estimated at once or several times per week.

Table 2. Criteria impact.

Criteria	Information
Insignificant	Does not cause injury or significant impact, and does not disrupt operations or result in lost work time.
Minor	Causes minor injury or temporary health disturbance that only requires first aid treatment.
Moderate	Causes serious injury, wounds, or illness requiring medical treatment and resulting in lost work time.
Major	Causes significant impact, including severe injury or wounds, potentially leading to partial permanent disability and/or chronic health conditions.
Critical	Causes fatal consequences, such as total permanent disability or death.

Risk control recommendations were formulated based on the hierarchy of controls, which included elimination, substitution, engineering controls, administrative controls, and the use of personal protective equipment (PPE). The development of control measures was supported by triangulated data, including interviews with landfill workers, site managers at TPA Suwung, an occupational health and safety (OHS) expert, and relevant literature reviews. This multi-source input ensured that the proposed controls were both practical and aligned with best practices in workplace safety management.

Table 3. Risk level value.

		Probability (Likelihood)				
		Rare	**Unlikely**	**Possible**	**Likely**	**Almost Certain**
Impact	Critical	Medium	High	High	Extreme	Extreme
	Major	Low	Medium	High	High	Extreme
	Moderate	Low	Medium	Medium	High	High
	Minor	Low	Low	Medium	Medium	High
	Insignificant	Low	Low	Low	Low	Medium

3. Results and Discussion

3.1. Hazard identification.

Based on the research findings, five main types of occupational hazards were identified at the Suwung Final Waste Processing Site (TPA Suwung), namely physical, mechanical, chemical, biological, and ergonomic hazards. These hazard categories reflected the complex and high-risk nature of landfill operations, where environmental conditions, waste characteristics, and human activities interacted simultaneously. Similar hazard profiles were reported in other landfill studies, such as those conducted at TPA Bantar Gebang, TPA Piyungan, and TPA Terjun, indicating that landfill environments consistently exposed workers to multi-dimensional occupational risks, particularly in developing country contexts with limited infrastructure and safety management systems.

Physical hazards at TPA Suwung primarily arose from prolonged exposure to environmental conditions and unsafe waste handling practices. Outdoor workers such as scavengers, operational staff, and heavy equipment operators were exposed to excessive

sunlight for approximately 8 hours per shift, posing risks of heat exhaustion, heat stroke, skin disorders, and even death [18]. In addition, noise generated from excavators (98.8 dBA) and bulldozers (115.4 dBA) exceeded the permitted threshold of 85 dBA for an 8-hour exposure [19], which could lead to hearing loss, stress, and decreased alertness, thereby increasing accident risk [20]. Similar findings were reported in landfill studies where excessive noise and heat exposure significantly affected worker health and productivity. Furthermore, unsorted waste increased the risk of injury from sharp objects such as glass shards and metal, particularly during unloading activities.

Mechanical hazards represented one of the most dominant risk categories, driven by poor infrastructure conditions and intensive use of heavy equipment. Unpaved roads that became dusty during the dry season and muddy during the rainy season increased the likelihood of vehicle accidents, while steep and uneven access roads further elevated collision risks. Waste piles reaching heights of 35–40 meters could collapse due to instability, rainfall, or poor compaction, posing serious threats to both workers and machinery. Workers climbing onto trucks and scavengers operating near heavy equipment were also exposed to fall and struck-by hazards. These findings were consistent with studies conducted at TPA Bantar Gebang, where inadequate zoning and high operational density significantly contributed to accident risks, highlighting the importance of engineering controls in landfill safety management.

Chemical hazards at TPA Suwung were associated with exposure to dust, landfill gases, leachate, and chemical substances from operational activities. Dust generated from unpaved roads and waste handling contained particulate matter (PM10), which posed respiratory health risks, especially for workers not using PPE [21, 22]. Methane (CH_4) and carbon dioxide (CO_2), released from decomposing waste, presented fire and explosion risks when methane concentrations reached 5–15% and were exposed to ignition sources [23]. Hydrogen sulfide (H_2S) and ammonia (NH_3) contributed to strong odors and could cause poisoning, respiratory damage, or death [24]. In addition, leachate containing heavy metals, organic pollutants, and microorganisms could cause skin irritation, infections, and gastrointestinal disorders upon contact [25], while lubricants and oils used in machinery maintenance might lead to dermatitis [26]. These findings aligned with previous studies emphasizing that gas emissions and leachate exposure were critical hazards in landfill environments lacking adequate control systems.

Biological hazards arose from the presence of pathogenic microorganisms and disease vectors in decomposing waste. Bioaerosols generated during waste handling exposed workers—particularly those without PPE—to respiratory, skin, and digestive diseases [27]. Waste piles also served as breeding grounds for vectors such as flies, mosquitoes, and rodents, which could transmit diseases including cholera, malaria, and dengue fever [28]. Similar patterns were observed in tropical landfill environments, where climatic conditions accelerated microbial growth and vector proliferation, thereby increasing occupational health risks.

Ergonomic hazards at TPA Suwung were primarily related to prolonged static postures, repetitive movements, and inadequate workstation design. Workers involved in data recording and heavy equipment operation often maintained static sitting positions for extended periods without sufficient rest, leading to musculoskeletal disorders affecting the neck, back, and shoulders [29, 30]. Poor ergonomic conditions also contributed to physical and mental fatigue, which could reduce concentration and increase the likelihood of workplace accidents. A systematic assessment of fatigue and its impact on safety performance indicators was therefore essential for developing effective preventive strategies in industrial settings [31].

3.2. Risk assessment.

The results of the risk assessment of identified hazards in the operational activities of TPA Suwung were presented in Table 4. The risk assessment showed that operational activities at TPA Suwung were dominated by high-risk hazards, particularly in waste reception and landfill management processes. Mechanical hazards, such as landslides, collisions, and workers being struck by heavy equipment, represented the most critical risks, with severe consequences, including fatalities. Chemical hazards, including gas exposure, dust, and leachate, also contributed significantly to health and safety risks. Biological hazards further increased exposure to disease, while physical and ergonomic hazards, although mostly categorized as medium risk, could lead to long-term health problems and indirectly increase accident risk. Overall, high-risk hazards were concentrated in core operations, indicating the need for prioritized and effective risk control measures.

Table 4. Risk assessment in TPA Suwung.

Activity	Potensial Hazards	Impact	Hazard Types	Risk Assessment		
				Pr	Im	Rl
Waste Mobilization	Excessive dust exposure while driving in the landfill	Eye irritation, respiratory problems	Chemical	LI	MO	H
	Trucks slipping or getting stuck in mud	Operational disruption, workplace accidents	Mechanical	P	MI	M
	Truck collisions on steep roads	Severe injuries (fractures, partial permanent disability)	Mechanical	LI	MA	H
	Accidents due to damaged or debris-covered roads	Minor to moderate injuries (bruises, abrasions, muscle pain)	Mechanical	P	MO	M
Waste Reception	Gas explosion from waste piles	Fire, serious injury, large-scale operational and social disruption	Chemical	P	C	H
	Exposure to foul odors and gases from waste piles	Nausea, dizziness, vomiting, respiratory irritation	Chemical	P	MO	M
	Exposure to pathogenic microorganisms from waste piles	Skin infections, respiratory disorders, eye irritation, diarrhea, nausea	Biological	LI	MO	H
	Injury from sharp waste materials	Cuts to deep wounds, serious infections (tetanus)	Physical	AC	MO	H
	Falling from truck bed during unloading	Fractures, back or head injuries	Mechanical	P	MA	H
	Dust exposure in unloading area	Eye irritation, respiratory problems	Chemical	LI	MO	H
	Exposure to leachate	Skin disorders (rash, irritation), allergic reactions	Chemical	LI	MO	H
	Landslide causing heavy equipment to slip/sink	Serious injury to death, operational disruption	Mechanical	P	C	H
	Scavenger struck or hit by heavy equipment	Serious injuries (fractures, head trauma, disability), up to death	Mechanical	LI	C	E
	Noise exposure from heavy equipment	Hearing loss, stress, fatigue	Physical	P	MA	H
	Ergonomic hazards for operators and data clerks	Musculoskeletal disorders	Ergonomic	P	MO	M
	Exposure to disease vectors (flies, mosquitoes, rats)	Digestive disorders (diarrhea), malaria, dengue	Biological	LI	MO	H
	Excessive sun exposure	Heat exhaustion, heat cramps, skin disorders	Physical	P	MO	M

Activity	Potensial Hazards	Impact	Hazard Types	Risk Assessment		
				Pr	Im	Rl
Waste Landfill Management	Injury from sharp waste materials	Cuts to deep wounds, serious infections (tetanus)	Physical	U	MO	M
	Exposure to pathogenic microorganisms from waste piles	Skin infections, respiratory disorders, eye irritation, diarrhea, nausea	Biological	LI	MO	H
	Gas explosion from waste piles	Fire, serious injury, large-scale operational and social disruption	Chemical	P	C	H
	Exposure to foul odors and gases from waste piles	Nausea, dizziness, vomiting, respiratory irritation	Chemical	P	MO	M
	Dust exposure in waste pile area	Eye irritation, respiratory problems	Chemical	LI	MO	H
	Landslide causing heavy equipment to slip/sink	Serious injury to death, operational disruption	Mechanical	P	C	H
	Ergonomic hazards for operators and data clerks	Musculoskeletal disorders	Ergonomic	P	MO	M
	Noise exposure from heavy equipment	Hearing loss, stress, fatigue	Physical	P	MA	H
	Exposure to disease vectors (flies, mosquitoes, rats)	Digestive disorders (diarrhea), malaria, dengue	Biological	LI	MO	H
	Excessive sun exposure	Heat exhaustion, heat cramps, skin disorders	Biological	P	MO	M
Heavy Equipment Maintenance	Being crushed/injured by equipment parts	Open wounds, bruises, or muscle pain	Mechanical	U	MO	M
	Exposure to pathogenic microorganisms from waste	Skin infections, respiratory disorders, eye irritation, diarrhea, nausea	Biological	U	MO	M
	Exposure to oil or lubricants	Skin irritation such as itching and redness	Chemical	R	MI	L

Notes/Legend: Pr = Probability; Im = Impact; Rl = Risk Level; R = Rare; U = Unlikely; P = Possible; Li = Likely; AC = Almost Certain; Mi = Minor; Mo = Moderate; Ma = Major; C = Critical; L = Low Risk; M = Medium Risk; H = High Risk.

3.3. Risk level.

The results of the occupational health and safety (OHS) risk assessment for operational activities at TPA Suwung indicated that the majority of the 17 identified potential hazards (56.67%) fell into the high-risk category, followed by medium (36.67%), while low and extreme risks each accounted for 3.33% (Table 5). This dominance of high-risk hazards suggested that operational activities at TPA Suwung involved significant exposure to severe and frequent hazards, particularly related to mechanical and chemical factors. In the context of the HIRARC framework, high-risk classification reflected conditions where both likelihood and severity were considerable, implying an urgent need for immediate and prioritized control measures to prevent serious workplace accidents and long-term health impacts.

Compared to similar studies conducted at TPA Piyungan and TPA Bantar Gebang, the proportion of high-risk hazards at TPA Suwung was relatively higher, indicating greater exposure intensity and potential gaps in existing control measures, particularly in engineering and operational management. According to OHS risk management principles, hazards classified as high risk required immediate intervention through higher-level controls such as elimination, substitution, and engineering measures before relying on administrative controls or personal protective equipment. Therefore, these findings highlighted the need for a more structured and proactive risk management approach to reduce the dominance of high-risk hazards and improve overall occupational safety and health performance at TPA Suwung.

Table 5. Risk level.

No	Risk Level	Total	Percentage
1.	Low	1	3,33%
2.	Medium	11	36,67%
3.	High	17	56,67%
4.	Extreme	1	3,33%
	Total	30	100%

3.4. Risk control.

Risk control recommendations for operational activities at the Suwung Final Waste Processing Site (TPA Suwung) were developed based on the hierarchy of controls, including elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). Elimination efforts could be implemented through the revitalization of overloaded landfill areas, such as capping waste piles with soil, slope terracing, and vegetation planting. This approach was technically feasible in the long term and provided multiple benefits, including reducing gas emissions, odors, disease vectors, fire hazards, and landslide risks. However, its implementation required substantial financial investment, land management planning, and coordination with local authorities, making it a priority for strategic, long-term risk reduction rather than immediate intervention.

Substitution measures focused on improving ergonomic conditions and gas management systems, such as replacing non-ergonomic chairs with adjustable ergonomic seating [32] and ensuring proper installation and maintenance of gas vent pipes. These measures were relatively feasible and cost-effective compared to elimination controls, making them suitable for medium-term implementation. Engineering controls represented the most critical priority due to their direct impact on reducing high-risk hazards. Key measures included improving road infrastructure, implementing zoning systems to separate workers from heavy equipment, increasing the number and maintenance of gas vent pipes, and enhancing drainage and dust control systems. While these interventions were highly effective, their implementation might face challenges related to budget constraints, technical capacity, and the need for continuous maintenance to ensure long-term effectiveness.

Administrative controls and PPE served as supporting measures to strengthen overall risk management. Administrative actions, such as establishing an Occupational Health and Safety (OHS) committee, conducting routine inspections, providing regular training, and enforcing safety regulations, were relatively feasible and could be implemented in the short term with strong managerial commitment. However, their effectiveness largely depended on worker compliance and organizational discipline. Similarly, PPE provision—such as masks, gloves, protective clothing, and hearing protection—was essential for minimizing exposure to residual risks, but challenges remained in ensuring consistent usage due to behavioral factors and supervision limitations. Therefore, an integrated approach that prioritized engineering controls, supported by administrative measures and PPE, was necessary to ensure both feasibility and effectiveness in reducing occupational risks at TPA Suwung.

The findings of this study indicated that high-risk hazards dominated operational activities at TPA Suwung (56.67%), particularly those associated with mechanical and chemical hazards. This pattern was consistent with observations from other landfill sites in Indonesia, including TPA Piyungan, TPA Bantar Gebang, and TPA Terjun. At TPA Piyungan and Bantar Gebang, dominant risks were largely related to heavy equipment operation,

transportation activities, and unstable landfill surfaces, which contributed to medium and high-risk classifications [33]. Similarly, findings from TPA Terjun revealed a broad spectrum of hazards, including physical (sharp objects, slips, noise), chemical (toxic exposure), biological (vectors such as flies and rats), ergonomic (musculoskeletal disorders), psychological (social pressure among workers), environmental, and behavioral hazards (low PPE compliance) [34]. This indicated that landfill environments consistently presented multi-dimensional hazards, combining operational, environmental, and behavioral risk factors.

Compared to these sites, TPA Suwung showed a higher dominance of high-risk hazards, suggesting greater exposure intensity and gaps in the effectiveness of existing control measures, particularly in engineering and administrative aspects. This comparison demonstrated that although landfill sites shared similar hazard characteristics, the distribution and severity of risks were strongly influenced by the level of risk control implementation, worker behavior, and institutional safety management systems.

4. Conclusions

This study revealed that occupational risks at TPA Suwung were critically dominated by mechanical and chemical hazards arising from heavy equipment operations, unstable waste conditions, and exposure to hazardous gases, with 56.67% of identified hazards classified as high risk. This risk profile underscored a structurally unsafe working environment that required immediate and prioritized intervention. The proposed control measures, grounded in the hierarchy of controls, emphasized the urgent need to strengthen engineering and administrative controls as primary risk reduction strategies, supported by consistent and adequate use of personal protective equipment (PPE). These findings highlighted not only operational deficiencies but also systemic gaps in safety management practices. Therefore, from a policy and governance perspective, it was imperative to institutionalize occupational health and safety through the establishment of a formal OHS committee, enforcement of standardized safety regulations, and integration of continuous training, supervision, and monitoring systems. Without such structural and regulatory improvements, the persistence of high-risk conditions would continue to pose significant threats to worker safety and long-term environmental health sustainability at TPA Suwung.

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Author Contribution

Ida Bagus Made Baskara Andika: Conceptualization, Methodology, Supervision, Analysis, and Writing. Ida Ayu Rai Widhiawati: Conceptualization and Supervision. Muhammad Zuvisco Sauqi: Conceptualization, Data Collection, Data Analysis, and Writing.

Competing Interests

The authors declare that they have no competing interests.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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