



Compliance of hazardous waste storage facilities at gas stations with hazardous waste management regulations

Innes Gianticha Sara^{1,*}, Suyud Warno Utomo¹, Fatmah¹

¹ Department of Environmental Science, Graduate School of Sustainable Development, Universitas Indonesia, Central Jakarta, Special Capital Region of Jakarta 10430, Indonesia.

*Correspondence: innesgisara@gmail.com

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ABSTRACT

Background: Gas stations generate hazardous waste, including contaminated rags, used oil, waste batteries (accumulators), and electronic waste. Under Government Regulation No. 22 of 2021 on Environmental Protection and Management Implementation (PP 22/2021) and Regulation of the Minister of Environment and Forestry (*Peraturan Menteri Lingkungan Hidup dan Kehutanan*) No. 6 of 2021, these wastes must be stored in Hazardous Waste Temporary Storage Facilities (*Tempat Penyimpanan Sementara Limbah Bahan Berbahaya dan Beracun/TPS LB3*). Previous studies have examined contamination risks and fire safety. However, limited studies have evaluated compliance with the updated TPS LB3 regulations. This study aims to analyze hazardous waste management and TPS LB3 availability at gas stations in Jakarta. **Methods:** This study uses quantitative descriptive methods complemented by qualitative analysis (mixed methods). The sample comprised nine purposively selected gas stations in Jakarta. Data were collected through questionnaires, field observations, and interviews with gas station operators and managers, then analyzed using a checklist based on the technical specifications of Minister of Environment and Forestry No. 6 of 2021. **Findings:** Among nine gas stations, three (33.3%) had TPS LB3, while six (66.7%) did not. Compliance with the regulation reached 78.9%; however, no station met the permanent building requirement, and only 33.3% implemented hazardous waste logbook documentation. Gas stations without TPS LB3 achieved only 26.9% compliance. **Conclusion:** TPS LB3 implementation at gas stations in Jakarta generally does not comply with Minister of Environment and Forestry No. 6 of 2021. The main deficiencies involve permanent buildings, drainage systems, and hazardous waste documentation. **Novelty/Originality of this article:** This study provides empirical evidence of compliance gaps in TPS LB3 implementation under Indonesia's updated hazardous waste regulations, identifying priority aspects for improving hazardous waste management at gas stations.

KEYWORDS: hazardous waste; gas station; regulatory compliance; temporary storage facility for hazardous and toxic waste.

1. Introduction

The growth of industrial activity and motor vehicle mobility globally has led to a significant accumulation of hazardous waste. In Indonesia, the expansion of infrastructure, and energy distribution, particularly the network of gas stations, has become one of the factors contributing to increased hazardous waste generation from operational activities (Irawan et al., 2023). According to data from the national waste management information system, the oil and gas and mining sectors generated approximately 58.52 million tons of hazardous waste in 2023, of which approximately 4.8 million tons were inadequately managed, posing a significant risk to the environment (Zhang et al., 2022). The number is

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even higher according to records from the Institute for Essential Service Reform, which reported that the total generation of hazardous waste from all business operators during the same period reached 86.84 million tons (Aprili et al., 2023). This figure underscores the significance of hazardous waste management as a priority environmental issue that requires a systematic attention from national policy level to operational facilities (Carattini et al., 2023).

Hazardous waste generated by the oil and gas sectors includes used lubricating oil, tank sludge, hydrocarbon-contaminated rags, and used chemical containers, all of which exhibit toxic, flammable, and corrosive properties (Wang et al., 2023). If not properly managed, these materials have the potential to contaminate water, soil and air while posing health risks to both workers and communities surrounding the facilities (Exposto & Sujaya, 2021). Hazardous waste management based on a life-cycle approach in the oil and gas industry requires an integrated control system spanning the production and distribution stage, rather than focusing solely on end of pipe treatment and disposal. Within the fuel distribution stage, gas stations constitute operational points that inherently generate various types of hazardous waste streams through fuel storage, fuel dispensing, and routine supporting activities (Ulakpa et al., 2022). Cross-national studies have confirmed that fuel filling stations are a significant source of exposure to benzene, toluene, ethylbenzene, and xylene (BTEX) compounds for both station officer and communities located near these facilities (Chaiklieng, 2021; Moolla et al., 2015). Fire and explosion risk from the underground fuel storage tanks and fuel loading and unloading operations are also characterized by a high hazard potential (Aferdiansyah et al., 2022). As high-risk operational facilities, fuel filling stations also generate hazardous waste that constitutes a hazard in its own right. If hazardous waste from gas station operations is not managed in accordance applicable standards, residues such as used lubricating oil containing Polycyclic Aromatic Hydrocarbon (PAH) may infiltrate the soil through damaged or permeable surfaces and could potentially affect groundwater aquifers surrounding the facility (Afolabi et al., 2025).

Hazardous waste management in Indonesia is comprehensively regulated under the Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management, which requires every hazardous waste generator to implement the full waste management cycle, from source reduction and temporary storage to transportation, treatment, and final disposal (Lestari et al., 2025). Further technical provisions are stipulated in the PermenLHK No. 6 of 2021 regarding Procedures and Requirements for Hazardous Waste Management (Putri, 2025). The Monitoring mechanisms and administrative sanctions are further reinforced through PermenLHK No. 14 of 2024. This framework clearly positions each hazardous waste generator as the primary responsible party for the environmental impacts arising from its activities, in accordance with the polluter pays principle (Yurnalisdel, 2023). Despite the existence of a regulatory framework, numerous empirical studies have shown that its implementation remains inadequate, revealing significant gaps between regulatory requirements and actual hazardous waste management practices in Indonesia, particularly with regard to the aspects of temporary storage and documentation (Nursabrina et al., 2021). The storage and collection of used lubricating oil in the industrial facilities has not fully complied with the applicable technical requirements (Hidayat & Jawwad, 2023). Studies conducted in other facilities including hospital, gas companies and manufacturing industries, have consistently reported inadequate levels of technical compliance (Zakianis et al., 2023; Indawati et al., 2022; Berliana et al., 2023). This condition indicates that compliance problems related to hazardous waste regulation are cross-sectoral issues and have not been systematically addressed.

Hazardous Waste Temporary Storage Facility (TPS LB3) is a critical infrastructure element in the hazardous waste management chain (Mujtaba et al., 2024), as it serves as the first control point before the waste is transferred to licensed transporters and treatment operators. Several studies have documented the condition of hazardous waste temporary storage facilities across industrial facilities and have identified non-compliance in the

construction aspect and safety systems in hazardous waste temporary storage in construction and safety system in manufacturing facilities (Hidayatullah, 2023). The absence of hazardous waste temporary storage facilities that comply with the standard in high-risk-waste-generating facilities such as gas stations may create potential exposure pathways that could lead to soil and groundwater contamination (Fei-Baffoe et al., 2024).

Despite studies on the risk of BTX (Chaiklieng, 2021), fire risk and used lubricating oil management at gas stations have been conducted in several countries, the empirical evaluation that specifically measures the compliance of hazardous waste temporary storage in gas stations against the technical requirements of PermenLHK no. 6 of 2021 using a multi-criteria have not yet been conducted. The existing studies on hazardous waste compliance in Indonesia have predominantly focused on the manufacturing, hospital and gas industries (Gochfeld et al., 1990; Hidayat & Sutrisna et al., 2018). As a result, the specific compliance profile for downstream of fuel distribution sector– which intersects with urban settlements and face distinctive land constraint– has not yet been systematically mapped (Desta et al., 2025). These gaps in the literature serve as the main justification for this study, while also highlighting its contribution in expanding the evaluation instrument based on the provisions of PermenLHK No. 6 of 202, enabling the identification of critical compliance gaps down to the level of individual technical criteria, an approach that has not been applied in the previous evaluations of hazardous waste temporary storage at gas stations (Hidayat & Jawwad, 2023).

The gaps between regulatory obligations and the conditions of implementation in the field, particularly in the availability of hazardous waste temporary storage facilities, accuracy of waste handling, and partnerships with licensed transporters and treatment facilities, indicate that hazardous waste management at gas station has not been implemented systematically as mandated under the Government Regulation No. 22 of 2021 and Regulation of the Minister of Environment and Forestry Number 6 of 2021 (Susanto et al., 2023). Therefore, this study was conducted to analyze the existing conduction of hazardous waste temporary storage facilities against the available technical standard. The findings from this study are expected to provide an empirical foundation for gas stations operators to fulfill their environment obligations (Zhu et al., 2021).

This study aims to analyze the availability and compliance of hazardous waste temporary storage facilities at gas stations in Jakarta with the technical standards that are stipulated in Regulation of the Minister of Environment and Forestry Number 6 of 2021 using this multi-criteria evaluation approach. Specifically, this study addresses two main questions: (1) to what extent the availability of hazardous waste temporary storage facilities at gas stations corresponds to their actual physical condition in the field; (2) what the level of compliance of hazardous waste temporary storage facilities with the applicable technical criteria (Nursabrina et al., 2021). The findings are expected to serve as the empirical basis for gas station operators/ managers in fulfilling their environmental obligations and meeting the minimum hazardous waste management standards applicable across gas station networks.

2. Methods

This study uses a descriptive evaluation design with a mixed-methods approach that combines quantitative and qualitative components in a complementary manner (Campitelli et al., 2022; Liu et al., 2025). This approach is chosen because the main object of this study– the availability and compliance of TPS LB3 requires two different but complementary research dimensions the quantitative assessment of binary factual information on the availability of hazardous waste temporary storage facilities, and the in-depth analysis of physical condition failures deficiencies and administrative issues through observational qualitative approaches and interview. The study focused specifically on evaluating the compliance of TPS LB3 with the technical requirements stipulated under Regulation of the Minister of Environment and Forestry Number 6 of 2021 regarding Procedures and Requirements for Hazardous Waste Management. Specifically, a convergent (concurrent)

mixed-methods design was applied. The quantitative strand consisted of a structured observation checklist scored dichotomously (1 = fulfilled, 0 = not fulfilled) for each technical criterion, from which compliance percentages were computed per criterion, per category, and per station. The qualitative strand consisted of field observation notes and semi-structured interviews with station managers, used to explain why particular criteria were not fulfilled. The two strands were collected during the same field visits and integrated at the interpretation stage: each quantitative compliance gap was matched with the corresponding qualitative evidence, and the two data sets were triangulated against the questionnaire responses. The qualitative component is therefore explanatory and supporting; no qualitative coding scheme or inferential statistical test was applied.

The study was conducted in Jakarta because it has the highest concentration of gas station operations within the PT Pertamina (Persero) network and is characterized by dense urban development and limited land availability- conditions that are relevant for analyzing the ability of fuel filling stations to comply with the physical requirements for hazardous waste temporary storage. The location of fuel filling stations in Jakarta are often located near urban and commercial areas, posing a challenge for hazardous waste management because they directly risk the environment and affect surrounding communities.

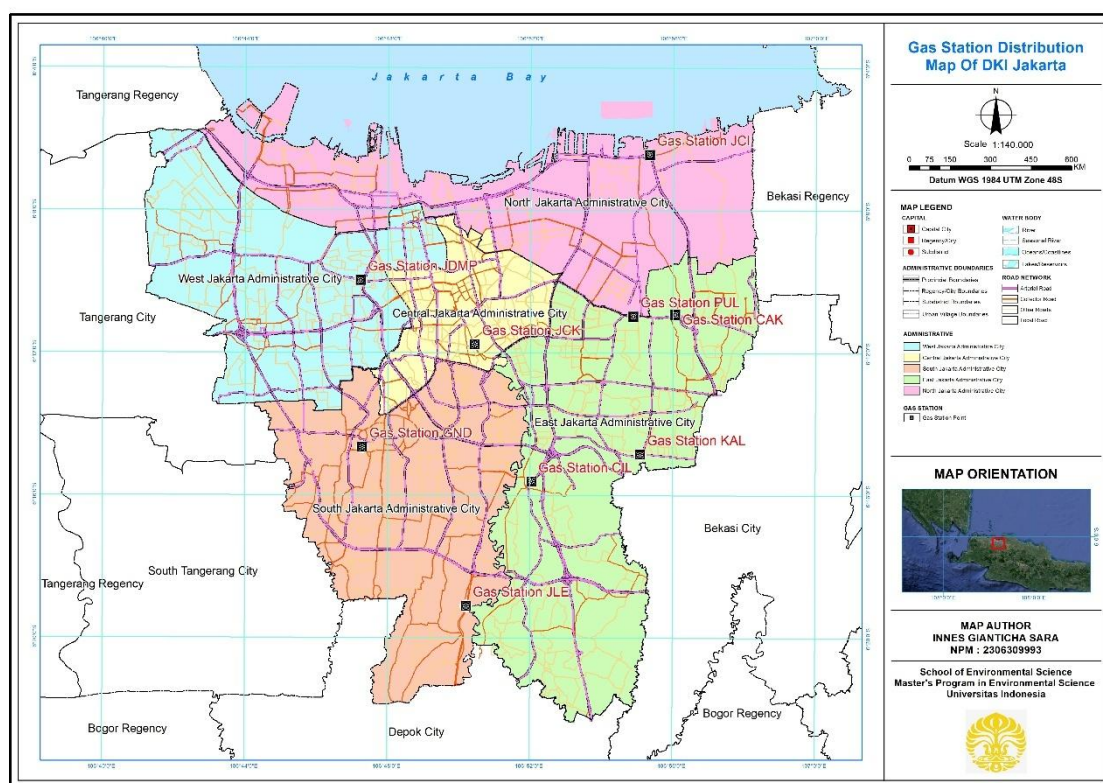


Fig. 1. Location of the study area in the Jakarta Province

The study population comprised all gas stations under the management of PT XPR in Jakarta. The study sample was selected using the purposive sampling techniques based on four inclusion criteria; (1) the gas station is directly managed by PT XPR, (2) located within Jakarta, (3) it is indicated as having incompletely implemented hazardous waste temporary storage facility management, and (4) it has annual fuel sales volumes of 13,000-19,000 kiloliters per year as a proxy for operational intensity that correlates with the volume of hazardous waste generated.

Based on these criteria, nine gas stations were selected as the study sample, distributed across the five administrative regions of Jakarta, gas station JCI North Jakarta—Cilincing; gas station JLE and gas station GND (South Jakarta—Lenteng Agung and Gandaria); gas

station JDMF (West Jakarta—Daan Mogot); gas station JCK (Central Jakarta—Cikini); gas station JCAK, gas station CIL, gas station KAL and gas station PUL (East Jakarta—Cakung, Cililitan, Kalimalang and Pulogadung). This distribution ensured representation across administrative zone and different urban contexts, including industrial, urban and commercial areas, which may affect the availability and capacity of hazardous waste temporary storage facilities.

Data collection was conducted using two primary instruments that were specifically developed to address the focus of the study. The first instrument was a structured observation checklist containing 19 technical criteria for the hazardous waste temporary storage facility, which has been developed based on the requirements stipulated in Article 9 of PermenLHK No. 6 of 2021. The criteria are categorized into an three evaluation categories covering facility and structure, hazardous waste packaging, and documentation and recording. Before completing the checklist, the first level assessment used a questionnaire to obtain a statement regarding the availability of hazardous waste temporary storage facility. Compliance evaluation in this study was based on three hierarchical regulatory instruments. First, Government Regulation No. 22 of 2021, Article 285-297, stated the general obligation to generate of hazardous waste to implement systematic management in accordance with the polluter pays principle. Second, the PermenLHK No. 6 of 2021, Article 9 regarding the construction requirements for hazardous waste temporary storage facilities, Article 15 regarding storage time limits, and Article 17 regarding logbook recording obligations. The combination of these three regulations forms a comprehensive normative framework for assessing the gaps between the actual condition of hazardous waste temporary storage facilities in the field and the mandated standard. The data analysis was carried out in two sequential levels. The first level was the binary analysis of the availability of hazardous waste temporary storage facilities, followed by a separate gap analysis of the technical criteria stipulated in PermenLHK No. 6 of 2021. The results of the analysis were subsequently categorized into two levels: “Compliant” and “Non-Compliant”. The categorisation threshold was set at 66.7% (equivalent to fulfilment in at least six of the nine sampled gas stations): a criterion or category with a fulfilment level of $\geq 66.7\%$ was classified as “Compliant”, and one below 66.7% as “Non-Compliant”. This threshold follows the two-thirds majority rule commonly used in descriptive regulatory compliance assessments and is applied consistently at the criterion level, the category level, and the station level. It should be noted that PermenLHK No. 6 of 2021 itself does not define a quantitative compliance threshold; the 66.7% cut-off is therefore an analytical convention adopted in this study and not a regulatory standard. The instrument comprises 19 technical criteria in total, grouped into three categories that are used consistently throughout the analysis, facility and structure (9 criteria, Articles 52, 56, and 57), hazardous waste packaging (7 criteria, Article 52), and documentation and recording (3 criteria, Article 54). Each criterion is scored across the nine sampled stations, giving 171 criterion–station assessments in total (81 for facility and structure, 63 for packaging, and 27 for documentation and recording); every category, aggregate, and per-station percentage reported in this article is computed from this same denominator. This categorization enables the identification of which item represents the most critical points across all samples, as well as comparison of compliance profiles (Zhao & Huang, 2019). An additional analysis was conducted per criterion to identify which management dimension deviated most from the regulatory standards. All results were presented in the form of frequency distribution table, percentage graphs, and interpretative narratives linking the findings to the relevant regulatory provisions, thereby every gap can be directly linked with the law obligations that have not been fulfilled. Checklist instrument validation was conducted using triangulation of three data sources; written questionnaire response, the results of direct field observation, and semi-structured interview with the gas station operator. The validity of the 19-item observation checklist was established through direct content derivation from the technical provisions of Article 9 of PermenLHK No. 6 of 2021, whereby each checklist item corresponds to a specific regulatory clause, and was further reinforced through triangulation of three data sources to ensure consistency of measurement. The

purposive sampling strategy was applied to a population of 36 gas stations under PT X's management in Jakarta, based on four selection criteria, (1) direct management by PT X; (2) location within Jakarta's dense urban area with limited land availability; (3) incomplete implementation of hazardous waste storage management; and (4) an annual fuel sales volume of 13,000-19,000 kiloliters, indicating a higher intensity of hazardous waste generation. Application of these criteria yielded nine gas stations, proportionally distributed across all five administrative regions of Jakarta (with a minimum of one unit per region) to ensure representativeness across varying urban contexts.

3. Results and Discussion

3.1 Analysis of hazardous waste management at fuel filling stations

In accordance with Article 285 of Government Regulation No. 22 of 2021 regarding the Implementation of Environmental Protection and Management, every generator of hazardous waste is obligated to be fully responsible (strict liability) for the entire waste management chain arising from its activities. This management cycle is characterized by interconnectivity and must be implemented systematically, beginning with the identification of the operational activities, quantification of waste volumes, packaging that is appropriate to the waste characteristics, accountable manifest recording, and temporary storage in facilities that comply with applicable technical standards prior to transfer to the licensed third parties. The regulation explicitly prohibits any form of disposal, release, or placement of hazardous waste outside designated Temporary Storage Facilities (TPS LB3) unless permitted under applicable requirements.

At the operational level of gas station examined in this study, the analysis focused on two main dimensions: a qualitative identification of the types of hazardous waste generated by fuel filling stations and a quantitative evaluation on the technical compliance of internal hazardous waste temporary storage facilities at the gas stations. The performance of the management at the generation and temporary storage serves as an important indicator for compliance of gas station operators with applicable regulatory requirement, particularly PermenLHK No. 6 of 2021 regarding Procedures and Requirements for Hazardous Waste Management. Through the fulfillment of the facilities and infrastructure of the standardised hazardous waste temporary storage facility, gas station operators/ managers not only ensure compliance with legal requirements, but also undertake the risk mitigation in a reduced environment before the waste is integrated into the sustainable management chain with formal legality (Table 1 and Fig. 2) .

Table 1. Identification of hazardous waste generated at fuel filling station

Types of Hazardous Waste (Waste Code)	N (Frequency)	% of Responses	% of Cases
Used lubricating oil - B105d	8	25.8	88.9
Used contaminated rags - B110d	9	29.0	100.0
Used batteries/accumulators - B344-2	4	12.9	44.4
Hazardous-waste-contaminated packaging - B104d	3	9.7	33.3
Electronic waste and used lamps - B107d	3	9.7	33.3
Paint waste - B355-1	4	12.9	44.4
Total Responses	31	100.0	-

The results presented in Table 1 identify the pattern of hazardous waste generation across the nine selected gas stations sampled in Jakarta. Out of the six types of hazardous waste observed, used contaminated rags (B110d) were generated at all location of gas station (100%), while used lubricating oil (B105d) was generated by eight stations, making these the two most commonly generated hazardous waste from the operation of the gas stations. Used batteries (B344-2) were generated in four stations, whereas contaminated hazardous waste contaminated packaging (B104d) was generated by three

stations. Electronic waste and used lamps (B107d) and paint waste (B355-1) were generated by three and four stations, respectively.

Used lubricating oil waste (B105d) is generated from vehicle oil-change activities conducted at workshop facilities operating in the gas station area. In addition, used lubricating oil also be generated from the operation of generator sets used as backup power sources during emergencies. Based on its characteristics, this waste is classified as Category 2 hazardous waste due to its flammable properties and its potential to contain toxic substance, including heavy metals such as (lead, cadmium, barium, as well as Polycyclic Aromatic Hydrocarbons (PAH), which are known to be carcinogenic. The high viscosity and low water solubility of used lubricating oil make it a potential source of soil and groundwater contamination if it is not managed in an impermeable storage facility. Used contaminated rags (B110d) were the most frequently generated type of hazardous waste identified in this study. This finding reflects the routine use of used rags in the daily operations of gas stations. The waste is generated from activities such as cleaning fuel and lubricant spills in dispenser areas, station driveways, mechanicals equipment, and during vehicle maintenance or the maintenance of gas station facilities and infrastructure. Used contaminated rags are classified as hazardous waste because they contain residual contamination from substances that have been wiped or cleaned, particularly fuel and oil.

The characteristics of its hazardous waste include flammability due to residual hydrocarbons in the fabric fiber, as well as potential toxicity from the presence of volatile organic compounds (VOCs). If not properly managed, used contaminated rags may become a source of ignition in fuel filling station environments where hydrocarbon vapors are commonly present. Used batteries are generated from the replacement of backup batteries or during the maintenance of generator sets processes. Used batteries have characteristics hazardous characteristic, including corrosivity due to concentrated sulfuric acid (H_2SO_4), toxicity due their lead and other heavy metal contents, and potential reactivity when battery cells are physically damaged. Lead contained in battery electrode plates is a persistent heavy metal that can accumulate within the food chain and cause adverse effects on the nervous systems of humans and other organisms. Contaminated hazardous waste packaging (B104d) originates from the use of primary containers for hazardous materials utilized in fuel filling station operations, such as jerrycans or bottles previously used for fuel sample storage, as well as container for chemical cleaning products used in maintenance activities and product quality monitoring during pre-operational inspections before the gas station opens. These used containers are classified as hazardous waste because they still contain residues of dangerous substances from their previous contents. Their hazardous characteristics are derived from the original products that may include flammable, corrosive, or toxic properties depending on the type of material previously stored. Improper management, such as reuse for food-related purposes or open burning, may result in hazardous chemical exposure to workers and contamination of the surrounding environment.

Electronic waste and used lamps (B107d) are generated from the replacement of lighting equipment in fuel filling station facilities (particularly neon lamps that contain mercury), electronic components of fuel dispensers, point-of-sale (POS) modules, and electrical components within operational control panels. The hazardous characteristics of electronic waste and used lamps are primarily related to toxicity, mainly due to the mercury (Hg) content in fluorescent lamp tubes and the lead content in the solder components of electronic devices. Mercury is a strong neurotoxin that can spread into the environment in vapor form when lamps are broken and can potentially contaminate aquatic ecosystems through methylation processes that convert mercury into methylmercury, a highly toxic substance for aquatic organisms and humans. Paint waste originates from the physical maintenance activities of fuel filling station buildings and facilities, including the periodic repair of canopies, walls, pillars, signage, and pavement markings in accordance with company standards. Paint waste includes unused paint residues, used paint containers, contaminated brushes and rollers, as well as thinners or organic solvents used during the painting processes. Paint waste is classified as hazardous waste due to its flammable

characteristics resulting from hydrocarbon-based organic compounds and its toxic properties associated with the content of volatile organic compounds (VOCs) such as benzene, toluene, and xylene. It may also potentially pose environmental hazards because these compounds are persistent and can contaminate soil and groundwater if not properly managed. All waste codes refer to Appendix XIV of Government Regulations No. 22 of 2021. Hazardous waste characteristics are defined under Article 1 (3) and include explosive, flammable, reactive, infectious, corrosive, and/ or toxic properties.

From an environmental risk perspective, the compliance gaps identified in this study are not merely administrative issues, but also reflect potential environmental hazards in Jakarta. The absence of impermeable flooring and adequate spill drainage systems at the majority of the locations may result in the infiltration of used lubricating oil (B105d), which contains carcinogenic Polycyclic Aromatic Hydrocarbon (PAH) compounds, into soil and groundwater aquifer in the populated residential areas. Meanwhile, the storage of used rags (B110d) in open areas or multifunctional rooms without adequate protection from heat and humidity may increase fire risk due to the presence of residual flammable hydrocarbons. These findings underscore that compliance with the technical requirements for hazardous waste temporary storage facilities is not merely a matter of legal compliance but also constitutes a critical component of environmental risk management and operational safety system at gas station.

The potential exposure pathways of hazardous waste from fuel filling station operations to the environmental and human receptors can be identified conceptually identified through four main mechanisms. None of which was measured empirically in this study, which are: (1) infiltration into soil and groundwater where the spills or leakages of liquid hazardous waste (such as used lubricating oil, battery electrolyte, and solvents) that are not adequately contained by hazardous waste temporary storage facilities may infiltrate through the soil surface, migrate vertically along hydraulic gradients, and potentially affect the surface of groundwater aquifers that are used by some residents of Jakarta as their sources of clean water. This potential risk may be exacerbated by the fact that most gas stations do not have impermeable flooring or spill drainage systems that meet the required technical standards; (2) surface runoff into urban drainage systems, where rainfall flowing through the unprotected hazardous waste temporary storage facility areas– whether open metal-cage structures or outdoor storage locations– carries hazardous waste contamination into open drainage channels, which discharge into receiving water bodies in Jakarta, including rivers that pass through densely populated residential areas; (3) volatilization and inhalation, where volatile organic compounds (VOCs) from paint waste and vapors from used lubricating oil may volatilize under elevated temperatures in open storage areas and be inhaled by fuel filling station workers who work in these areas, potentially resulting in chronic exposure to carcinogenic and neurotoxic compounds; and (4) direct dermal contact, where workers handling hazardous waste without wearing adequate personal protective equipment (PPE) may be exposed through direct dermal contact. The PAH compounds in the used lubricating oil may be absorbed through the skin and accumulate in fatty tissues, potentially contributing to long-term carcinogenic effects.

The identification of types and characteristics of hazardous waste presented in this study provides a basis for understanding why the availability and compliance of hazardous waste temporary storage facilities constitute a critical component within the hazardous waste management system of a gas station. It should be emphasised that no soil, groundwater, or ambient air sampling was carried out in this study. The exposure pathways described above are therefore presented as potential, conceptually derived mechanisms based on the observed physical deficiencies and on the characteristics of the waste types identified, and should not be read as evidence that contamination has actually occurred at the sampled locations. Verification would require environmental sampling and laboratory analysis, which is recommended for further research.

3.2 Hazardous waste storage facilities and infrastructure

The hazardous waste temporary storage facility, as the primary infrastructure component of hazardous waste management in the waste-generator level, must comply with several technical requirements. These include the provision of a permanent structure building, a flood-free location, a designated loading and unloading area, impermeable flooring, drainage systems for spills and leaks, spill-response equipment, emergency response facilities, protection from rain exposure, and identification markers consisting of coordinate point and hazardous waste symbols. In addition, the packaging of hazardous waste stored within the facility must comply with applicable regulatory requirements. PermenLHK No. 6 of 2021 was enacted to implement the provisions of Article 449 paragraphs (a) to (q) of Government regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management, and also integrates technical approvals and/or operational feasibility letters for hazardous waste management into the environmental approval processes. In the hierarchical regulatory framework, PermenLHK No. 6 of 2021 serves as a technical implementing regulation that operationalizes the hazardous waste management obligations established in principle under the Government regulation. Gas stations, as generator of hazardous waste from non-specific sources, are directly bound by the technical requirements stipulated in this regulation, particularly the obligation cluster related to the storage, packaging, recording and transfer of hazardous waste.



Fig. 2. (a) Without a hazardous waste storage facility; (b) non-permanent hazardous waste storage facility

The results from this study show that, out of a total of nine gas stations included in the sample, only 3 gas stations (33.3%) reported having hazardous waste temporary storage facilities, while the remaining six stations (66.7%) reported not having hazardous waste temporary storage facilities. The three units that have hazardous waste temporary storage facilities are gas station JCK (Central Jakarta–Cikini), gas station KAL (East Jakarta – Kalimalang), and gas station JLE (South Jakarta—Lenteng Agung). These findings indicate that the majority of gas stations examined in this study have not fulfilled their fundamental obligation to manage hazardous waste by providing hazardous waste temporary storage facilities that comply with the applicable requirements. This condition potentially causes environmental risk and contamination due to the absence of structured waste management systems, furthermore it serves as an initial indicator of the low level of compliance with hazardous waste management regulations among gas stations included in this study (Table 2). To further substantiate this descriptive comparison, a supplementary statistical test was conducted at the checklist item level between the two groups. Of the 19 technical criteria evaluated among gas stations with hazardous waste storage facilities, 15 items achieved a high level of implementation ($\geq 66.7\%$), compared with none of the 19 criteria evaluated among gas stations without a hazardous waste storage facility. Given the small number of sampled gas stations and the fact that the checklist items were measured repeatedly within the same stations rather than as fully independent observations, the comparison is reported descriptively and no inferential statistical test was applied.

Table 2. Compliance of hazardous waste temporary storage facilities with the technical criteria of PermenLHK No. 6 of 2021

Criteria (Questionnaire Items)	Reference to PermenLHK No. 6 of 2021	Yes	Percentage (%)	Compliance Gap	Level of Compliance
Hazardous waste storage facility is a permanent structure	Article 56(b)	0	0.0%	100.0%	Non-Compliant
Hazardous waste storage facility is located in a flood-free area	Article 57(1)(a)	4	44.4%	55.6%	Non-Compliant
Equipped with a loading and unloading area	Article 56(b)	3	33.3%	66.7%	Non-Compliant
Equipped with spill response equipment	Article 56(c)	3	33.3%	66.7%	Non-Compliant
Equipped with emergency response equipment (sand, fire extinguisher, and first-aid kit)	Article 56(c)	3	33.3%	66.7%	Non-Compliant
Has an impermeable floor	Article 52(b)	3	33.3%	66.7%	Non-Compliant
Has a drainage system for spills and leakages	Article 56(b) & (c)	2	22.2%	77.8%	Non-Compliant
Hazardous waste is protected from rain and stored in a covered area	Article 52(a)	4	44.4%	55.6%	Non-Compliant
Equipped with identification information, including coordinates and symbols	Article 52(c) & Article 53	3	33.3%	66.7%	Non-Compliant
Packaging containers are appropriate for the characteristics of the hazardous waste	Article 52(d)	4	44.4%	55.6%	Non-Compliant
Not mixed with domestic waste container	Article 56	4	44.4%	55.6%	Non-Compliant
Packaging is made of metal or plastic materials	Article 52(d)	7	77.8%	22.2%	Compliant
Packaging is capable of securely containing hazardous waste	Article 52(e)	7	77.8%	22.2%	Compliant
Equipped with a secure lid to prevent spills	Article 52(f)	5	55.6%	44.4%	Non-Compliant
Packaging is leak-free, rust-free, and undamaged	Article 52(g)	6	66.7%	33.3%	Compliant
Equipped with the required symbols and labels	Article 52(c)	5	55.6%	44.4%	Non-Compliant
Monitoring: Incoming waste logbook	Article 54(b)	3	33.3%	66.7%	Non-Compliant
Monitoring: Outgoing waste logbook	Article 54(b)	2	22.2%	77.8%	Non-Compliant
Has a documented hazardous waste management standard operating procedure (SOP)	Article 54(a)	2	22.2%	77.8%	Non-Compliant

The category of hazardous waste temporary storage facility recorded the lowest level of compliance, at only 30.9% (25 of the 81 assessments across 9 criteria × 9 stations). Of the

9 infrastructure-related criteria evaluated, all were classified as Non-Compliant. The criterion with the most critical condition is the permanent building, which was not fulfilled by any of the gas stations (0%), based on the provisions of Article 56(b) of PermenLHK No. 6 of 2021, which requires that hazardous waste storage facilities to be established as buildings that comply with the prescribed technical requirements. Field verification directly explains this result: three gas stations that claimed to have hazardous waste temporary storage facility- which are gas station JCK, KAL, and JLE- used metal cage structures as hazardous storage facilities, rather than permanent buildings. These structures were moveable and not fixed in place that does not meet the characteristics of a “building that complies with the technical requirements” as stipulated by the regulation. For the six gas stations that reported not having the hazardous waste temporary storage facility- which are gas station JDMP, GND, CIL, JCAK, JCI, and PUL- field observation and in-depth interview with gas station managers indicated that their technical and regulatory condition were far from the minimum requirements stipulated by the regulation. The absence of a dedicated hazardous waste temporary storage facility does not mean that the hazardous waste generated from operational activities is not stored at all, rather, the waste is stored in existing rooms and buildings that are used for other functions, without clear physical separation. These rooms generally do not have impermeable flooring, not equipped with spill containment systems, and do not provide adequate emergency response equipment. The drainage system criterion was fulfilled by only 2 out of 9 fuel filling stations (22.2%), referring to Article 56(b) and (c) which require the provision of drainage systems and spill containment facilities. The other criteria, including flood-free location, protection from rain exposure, enclosed storage conditions, suitability of packing containers, and segregation from other waste, were each fulfilled by only 4 out of 9 fuel filling stations (44.4%).

In contrast to the facility category, hazardous waste packaging recorded the strongest performance, with a compliance level of 60.3% (38 of the 63 assessments across 7 criteria × 9 stations); although this is the highest of the three categories, it still falls below the 66.7% threshold and is therefore also classified as non-compliant. Two packaging criteria recorded the highest level of fulfilment: the use of metal packaging materials and the ability of the packaging to securely hold the waste of B3 within the container, each of which was fulfilled by 7 out of 9 fuel filling stations (77.8%), referring to Article 52 paragraph(d) and (e). The criterion requiring packaging to be free from leakage, corrosion, and physical damage was fulfilled by six gas stations (66.7%), while the criteria requiring secure closures to prevent spills and the provision of appropriate symbols and labels were each fulfilled by five gas stations (55.6%); both fall below the 66.7% threshold and are therefore classified as non-compliant, meaning that that only three of the seven packaging criteria reach compliant status.

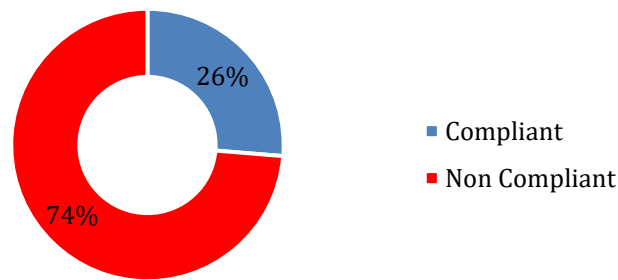
The documentation and recording category, comprising three criteria (incoming logbook, outgoing logbook, and hazardous waste management SOP), recorded a compliance level of 25.9% (7 of 27 assessments), and was categorized as non-compliant. The incoming waste logbook was maintained by 3 of the 9 gas stations (33.3%) and the outgoing waste logbook by 2 of 9 (22.2%), in accordance with Article 54(b), which requires monitoring and recording of hazardous waste entering and leaving the storage facility, while a documented hazardous waste management SOP was held by 2 of 9 stations (22.2%) under Article 54(a).

The sentence introduces an expectation before presenting the actual comparison and contains an incomplete comparison. These three gas stations formed an analytical group that conceptually, would be expected to demonstrate a higher level of compliance than gas stations hazardous waste temporary storage facilities, considering that the existence of a hazardous waste temporary storage facility constitutes an infrastructural prerequisite for fulfilling most of the technical facility criteria required under PermenLHK No. 6 of 2021. However, field verification revealed facts that substantially altered the compliance picture presented by the declared implementation of the hazardous waste temporary storage facility; the facilities referred to as hazardous waste temporary storage facilities at these three gas stations took the form of open-design metal cage structures without solid walls. Gas station KAL had the largest land area among all study locations, covering 5,813 m². Its

compliance level reached 84.2%. Within the overall context of this study, gas station KAL represents a case where hazardous waste temporary storage facility management was implemented relatively well. The three criteria that were not fulfilled have considerable structural significance, as all three are building-related technical requirements stipulated under PermenLHK No. 6 of 2021, which are, (1) Permanent building– the hazardous waste temporary storage facility only consisted of a metal cage structure that did not meet the definition of a permanent building; (2) an impermeable floor with a slope directing spills toward a containment area; and (3) a drainage system for hazardous waste leaks and spills. The most notable aspect of gas station KAL's compliance profile was its full compliance with all hazardous waste packaging criteria (100%) and documentation and recording (100%). The consistent maintenance of inbound logbooks, the ownership of Standard Operating Procedures (SOPs), and packaging practices that were appropriate to the characteristics of the waste indicate that the hazardous waste management system at the operational level of gas station KAL had been established and was functioning effectively. Gas station JCK recorded a level of compliance of 63.2%. The distribution of compliance patterns across the assessed criteria indicates full compliance with all hazardous waste packaging requirements, but failed in the majority of documentation-related criteria. Of the 9 facility criteria evaluated, only five were fulfilled, while the four unmet criteria comprised: (1) permanent building; (2) an adequate loading and unloading area; (3) hazardous waste spill response equipment; and (4) a drainage system for hazardous waste leaks and spills. The pattern of non-compliance concentrated in construction-related and technical requirements, is consistent with the inherent limitations of the metal cage structure used as the hazardous waste temporary storage facility. The most critical condition in the gas station JCK compliance profile was the complete failure to meet all three documentation and recording criteria, the incoming hazardous waste logbook, outgoing hazardous waste logbook and SOP of hazardous waste management which did not fulfill the criteria. The lack of a documentation and recording system has dual implications: internally, the operator/manager does not have the sufficient/ required data to monitor the accumulation of hazardous waste volume and ensure that maximum storage period is not exceeded, as stipulated under Article 58-60 of PermenLHK No. 6 of 2021; externally, the absence of logbook hinders verification by the Jakarta Environmental Agency regarding the proper transfer of hazardous waste to licensed transporters and treatment facilities. Gas station JLE recorded a compliance level of 63.2% identical to that of gas station JCK, but with a different distribution of weaknesses. Gas station JLE did not transfer hazardous waste to licensed parties, indicating one of two equally problematic possibilities: either hazardous waste accumulated in the storage area beyond the permitted storage period without further management, or the hazardous waste was transferred to parties without official licenses for hazardous waste management.

The comparative analysis of the three gas stations revealed two dominant patterns that extend beyond individual locations and appear to be systemic within the group of gas stations that have hazardous waste temporary storage facilities. The first pattern is the common failure to meet the permanent-building and drainage-related criteria across all three locations, which is a direct consequence of the use of metal cage structures as hazardous waste temporary storage facilities. This suggests that the root causes of many facility-related compliance gaps tend to be structural and cannot be addressed solely through the operational compliance without physical modifications to the facility design. The second pattern is the dualism of gas station KAL, which fulfills all documentation requirements, and gas station JCK and gas station JLE, which failed to meet any of the documentation criteria. This condition cannot be explained by variations in infrastructure, as the recording obligations do not depend on the quality of TPS construction. Rather, it is more reflected on the managerial capacity and the culture of administrative compliance at the management level.

a)



b)

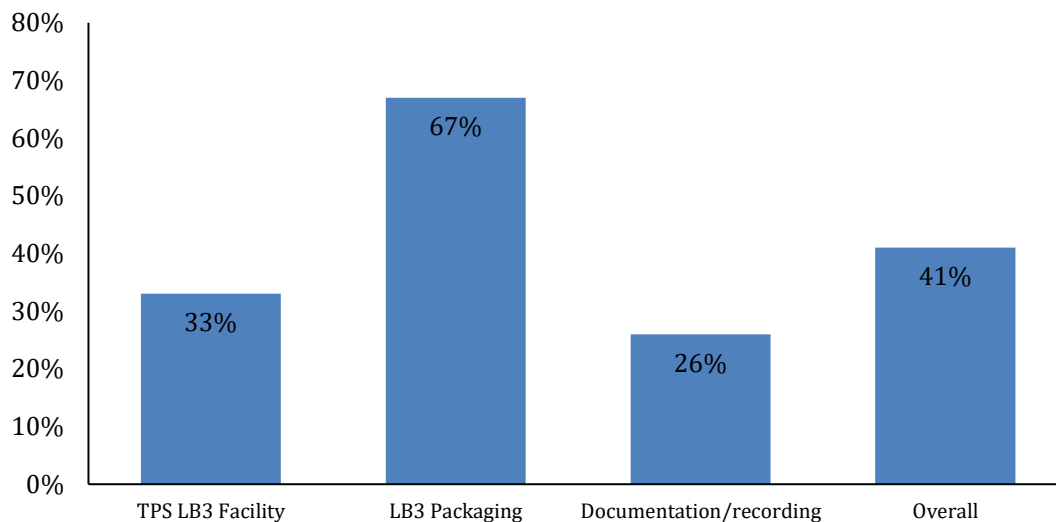


Fig. 3. (a) Hazardous waste packaging practice at the sampled gas stations; (b) Documentation and recording practice at the sampled gas stations

The compliance assessment was conducted based in the actual condition on the field, which consisted of three assessment categories: (1) hazardous waste temporary storage facilities; (2) hazardous waste packaging; and (3) documenting/ recording. Overall, the nine locations recorded an aggregate compliance level of 40.9% (70 of 171 assessments), with the following breakdown: hazardous waste temporary storage facilities, comprising 9 criteria, 30.9% (non-compliant); hazardous waste packaging, comprising 7 criteria, 60.3% (non-compliant); and documentation and recording, comprising 3 criteria, 25.9% (non-compliant). This condition illustrates that the hazardous waste temporary storage facilities available at the fuel filling stations are in the form of metal cage structures and are therefore not considered permanent buildings, This provides an empirical explanation for the universal non-fulfillment of the permanent building criterion. This condition confirms that the required policy intervention is not merely limited to awareness raising or capacity-building efforts. The evaluation of compliance with the criteria stipulated under PermenLHK No. 6 of 2021 found that only three regulatory criteria achieved compliant status– all of which originated from hazardous waste packaging activities– while sixteen criteria (84.2%) were categorized as non-compliant, covering hazardous waste temporary storage facility requirements and documentation/recording. The analysis results of the condition of hazardous waste temporary storage infrastructure across nine gas stations in the Jakarta indicates a level of compliance that is generally far from fulfilling all technical requirements stipulated under PermenLHK No. 6 of 2021. Of the total 19 selected criteria, the aggregate compliance level achieved by all gas stations was only 40.9% (70 of 171 criterion–station assessments). When the analysis is examined from a regulatory scope perspective– by assessing how many of the 19 mandatory technical criteria that were successfully and systematically fulfilled by gas stations– 84.2% of all applicable regulatory

requirements were categorized as non-compliant. The fact that more than four-fifths of all applicable technical obligations failed to be fulfilled by the majority of gas stations simultaneously suggests that the compliance gap tends to be widespread and systemic rather than partial or localised. The difference between these two percentages reflects two fundamentally different analytical statements. The 40.9% result measures the degree of compliance and is sensitive to variations among fuel filling stations, whereas the 84.2% result measures the breadth of the regulatory gap and is sensitive to the distribution of regulatory criteria across all gas stations.

The uneven pattern of compliance distribution has the important implication for the regulatory monitoring strategy. In a distribution where six gas stations recorded compliance levels below 35%, while one station recorded a compliance level above 80% , the average figure loses its representativeness as a measure of typical condition. This condition indicates that the level of compliance is not a function of the intrinsic characteristics of fuel filling station facilities, but is strongly influenced by location-specific factors such as managerial leadership, commitment to environmental investment, and the history of regulatory monitoring. The three fuel filling stations that reported having TPS LB3 facilities and were verified to use non-standardized metal cage structures– gas station JCK, gas station KAL, and gas station JLE– recorded an average compliance level of 70.2%, higher than the average compliance level of 26.9% recorded by the six gas stations without hazardous waste temporary storage facilities. This difference suggests that, although the metal cage structures do not fulfil the permanent building requirement, the presence of a dedicated storage area tends to be associated with higher fulfilment of other criteria, although with only nine sampled stations this association should be interpreted as indicative rather than statistically established, particularly in terms of segregation from domestic waste, suitability of storage containers, and completeness of location identification.

The comparative compliance profile across fuel filling stations reveals an interesting pattern regarding the relationship between the availability of supporting facilities and the level of compliance with hazardous waste management. The gas stations that have active mechanics workshops, which routinely generate used lubricating oil and used rags in higher volume, generally demonstrate higher awareness of hazardous waste management compared with stations without workshop facilities. This can be explained by the fact that the supporting facilities such as active workshops generate more visibility and are an operational accumulation of hazardous waste, thereby encouraging workers/ operators/ managers to develop more structured handling systems. This finding suggests that the intensity of hazardous waste generation acts as the push factor for managerial awareness, although it does not automatically ensure compliance with all applicable technical requirements.

The identified compliance patterns indicate three main phenomena. First, there is a wide gap between regulatory knowledge (which is well understood among managers) and actual implementation in the field, which indicates that the main barriers are not lack of awareness, but rather limited infrastructure investment and weak internal and external monitoring systems. Second, the comparatively stronger performance of the packaging category (60.3%, the highest of the three categories although still below the 66.7% threshold) indicates that intervention through the standardization of internal operational procedures– such as technical guidelines are able to generate positive impacts on aspects that are relatively easy to operationalize in the field. Third, the absence of a dedicated hazardous waste temporary storage facility constitutes the structural root cause of non-compliance, as the lack of this basic infrastructure directly disables the ability of the gas station to fulfill nearly all of the technical facility criteria evaluated in this study. These findings are consistent with similar studies conducted at other hazardous waste generating facilities in Indonesia, such as evaluations of hazardous waste storage facility compliance at a PT Pertamina Gas operational facility (Hidayat & Jawwad, 2023) and at other PT X facilities (Hidayatullah, 2023), both of which likewise reported persistent gaps in permanent storage infrastructure despite adequate managerial awareness of regulatory obligations. At the

international level, comparable patterns of inadequate hazardous waste storage infrastructure at fuel-related facilities have been documented in Ghana (Fei-Baffoe et al., 2024), where the absence of impermeable, properly contained storage areas was similarly linked to elevated risks of soil and groundwater contamination by petroleum hydrocarbons. The convergence of these findings across different regulatory and geographic contexts suggests that the infrastructure gap identified in this study is not unique to the Indonesian fuel retail sector, but reflects a broader, cross national challenge in translating hazardous waste regulations into operational practice at fuel dispensing facilities.

4. Conclusions

This study indicates that non-compliance in the hazardous waste temporary storage facilities at the sampled gas stations in Jakarta tends to be structural and systemic rather than merely a set of isolated technical deficiencies. The most significant finding that distinguishes this study from similar studies is the identification of a gap between the formal recognition of the availability of hazardous waste storage facilities and the actual physical conditions observed in the field. Facilities claimed by three gas stations to serve as TPS LB3 were found to consist of open metal cage structures that inherently failed to meet the requirements for permanent buildings as mandated under PermenLHK No. 6 of 2021. Meanwhile, gas stations without dedicated TPS used rooms or open areas for waste storage. This situation indicates that non-compliance with the permanent building construction requirements is widespread, as none of the sampled fuel filling stations met these criteria. Consequently, this deficiency constitutes a fundamental factor underlying the simultaneous failure to comply with most of the technical facility requirements.

The original contribution of this study lies in a two-tier evaluation approach that combines a binary assessment of the availability of TPS with a multi-criteria compliance analysis based on the provisions of PermenLHK No. 6 of 2021, generating two complementary measures that complement each other; a compliance level of 40.9%, reflecting the overall degree of regulatory adherence, and a non-compliance rate of 84.2%, reflecting the breadth of the systemic regulatory gap. The conceptual distinction between these two measures provides a richer analytical basis for policymakers than using a single index. Scientifically, this study fills an empirical gap in the literature on hazardous waste management compliance within fuel distribution facilities, a segment of compliance studies that has generally focused on the manufacturing or healthcare sectors, while also demonstrating that gas stations, as operational facilities that generate hazardous waste and interact directly with surrounding communities, warrant specific regulatory attention.

From a policy perspective, these findings imply that regulatory agencies should move beyond administrative licensing checks toward routine, criteria-based technical audits of hazardous waste storage facility infrastructure, complemented by tiered compliance incentives, such as phased deadlines or cost-sharing schemes, to support gas station operators, particularly smaller units, in financing permanent storage construction. For gas station operators and management, the findings recommend prioritizing capital investment in permanent, code-compliant storage structures as the primary corrective action, given that this single deficiency underlies the failure to meet nearly all other technical criteria; in parallel, operators are encouraged to formalize logbook recording and standard operating procedures through simple digital or paper-based systems and to reinforce periodic staff training that translates existing regulatory knowledge into consistent field practice.

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Author Contribution

I.G.S. contributed to the conceptualization, methodology, formal analysis, investigation, visualization, and project administration of this study. S.U. and F. were responsible for the validation and writing – review & editing. Resources were provided by I.G.S. and F. Data curation was carried out by S.U. The original draft of the manuscript was written by I.G.S., S.U., and F. Supervision was conducted by S.U. Funding acquisition was handled by I.G.S. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not available.

Data Availability Statement

The primary data supporting the findings of this study were collected directly through structured questionnaires, field observations, and semi-structured interviews conducted at nine purposive gas station units under the management of PT Pertamina Patra Niaga across the five administrative regions of Jakarta. Due to operational confidentiality and administrative agreements with the participating facilities, the raw evaluation checklists and specific station-level compliance logs are not publicly archived. However, the compiled datasets and aggregate statistical analyses used in this article are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Biographies of Authors

Innes Gianticha Sara, is a Master's degree candidate at the Master's Program in Environmental Science, Graduate School of Sustainable Development, Universitas Indonesia, Central Jakarta, Special Capital Region of Jakarta 10430, Indonesia.

- Email: innes.gianticha@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Suyud Warno Utomo, is a senior academic and lecturer at the Master's Program in Environmental Science, Graduate School of Sustainable Development, Universitas Indonesia. He holds a doctoral degree specializing in environmental impact assessment and management.

- Email: suyud.si@ui.ac.id
- ORCID: 0009-0000-1424-0433
- Web of Science ResearcherID: N/A
- Scopus Author ID: 57201691938
- Homepage: <https://scholar.ui.ac.id/en/persons/suyud-warno-utomo/>

Fatmah, is an is a lecturer at the School of Environmental Science, Graduate School of Sustainable Development, Universitas Indonesia, who has conducted 5 Community Service and Empowerment (PPM) programs from 2019 to 2024. She holds a doctoral degree with extensive expertise in environmental impact assessment, public health risk methodologies, and institutional policy implementation.

- Email: ffatmah@yahoo.com
- ORCID: 0000-0002-2763-0219
- Web of Science ResearcherID: N/A
- Scopus Author ID: 57217831885
- Homepage: <https://dara.ui.ac.id/researcher/77603>