Jurnal Serambi Engineering JSE
Volume XI, No.3, Juli 2026 Hal 20785 - 20793
p-ISSN : 2528-3561
e-ISSN : 2541-1934

Analysis of Technical Operational Failures Risk in TPS 3R Using Failure Mode and Effects Analysis (FMEA)

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Received: July 13, 2026 Approved: July 29, 2026

Abstract
Waste management in Indonesia continues to face operational challenges due to the predominance of the collect–transport–dispose approach, which limits waste reduction efforts at the source. This study aims to identify and prioritize technical operational failure risks in community-based waste management facilities (TPS 3R) located at TPS 3R Mutiara Bogor Raya, TPS 3R Ciparigi 2, and TPS 3R Jalan Jawa, Bogor City, Indonesia. Data were collected through field observations, semi-structured interviews with facility managers, and community questionnaires regarding waste storage and source segregation practices. Risk assessment was conducted using the Failure Modes and Effects Analysis (FMEA) method by evaluating Severity, Occurrence, and Detection parameters to obtain Risk Priority Number (RPN) values. The results indicate that operational failure risks are primarily associated with managerial capacity, waste storage and segregation systems, collection operations, and waste processing activities. The highest priority risks include failure of operational management systems (RPN 64) and unreliable waste processing chains (RPN 60) at TPS 3R Mutiara Bogor Raya, inadequate collection route planning (RPN 48) at TPS 3R Ciparigi 2, and unequal fleet distribution (RPN 48) at TPS 3R Jalan Jawa. Overall, low source segregation participation and operational system limitations were identified as dominant factors influencing TPS 3R performance. Strengthening management systems, operational planning, and community participation is therefore essential to improve facility sustainability.
Keywords: *TPS 3R, FMEA, failure risk, waste management, operation*

Abstrak
Pengelolaan sampah di Indonesia masih menghadapi berbagai kendala operasional akibat dominannya paradigma kumpul–angkut–buang yang membatasi upaya pengurangan sampah dari sumber. Penelitian ini bertujuan mengidentifikasi dan menentukan prioritas risiko kegagalan aspek teknis operasional pada fasilitas Tempat Pengolahan Sampah *Reduce-Reuse-Recycle* (TPS 3R) di TPS 3R Mutiara Bogor Raya, TPS 3R Ciparigi 2, dan TPS 3R Jalan Jawa, Kota Bogor. Data diperoleh melalui observasi lapangan, wawancara semi-terstruktur dengan pengelola TPS 3R, serta penyebaran kuesioner kepada masyarakat terkait kondisi pewadahan dan praktik pemilahan sampah di sumber. Analisis risiko dilakukan menggunakan metode *Failure Modes and Effects Analysis* (FMEA) dengan menilai parameter Severity, Occurrence, dan Detection untuk menghasilkan nilai *Risk Priority Number* (RPN). Hasil penelitian menunjukkan bahwa risiko kegagalan operasional terutama berasal dari aspek manajerial, sistem pewadahan dan pemilahan, pengumpulan, serta pengolahan sampah. Risiko prioritas tertinggi meliputi kegagalan sistem manajemen operasional (RPN 64) dan ketidakandalan rantai pengolahan sampah (RPN 60) pada TPS 3R Mutiara Bogor Raya, tidak adanya perencanaan rute pengumpulan (RPN 48) pada TPS 3R Ciparigi 2, serta ketimpangan distribusi armada pengangkutan (RPN 48) pada TPS 3R Jalan Jawa. Secara umum, rendahnya partisipasi pemilahan sampah di sumber dan keterbatasan sistem operasional menjadi faktor dominan yang memengaruhi kinerja TPS 3R.
Kata Kunci: *TPS 3R, FMEA, risiko kegagalan, pengelolaan sampah, operasional*

1. Introduction
Municipal solid waste pollution has become a major challenge worldwide, particularly in developing countries where waste management systems often face financial, technical, and institutional limitations. As a result, inadequate waste management can lead to adverse impacts on public health and the environment. Medina (2011) highlighted that conventional waste management approaches in developing countries frequently rely on centralized and capital-intensive solutions that are often incompatible with local conditions, leading to suboptimal performance [1].

In Indonesia, waste management is regulated under Law No. 18 of 2008, which emphasizes waste reduction and waste handling. However, waste management practices remain largely dependent on the collect–transport–dispose approach, causing most waste to be transported directly to landfills [2]. According to the Ministry of Environment, only 61.97% of the national waste generation was properly managed in 2024. This dependence on landfills became evident during the waste emergencies experienced in several Indonesian cities, where landfill disruptions resulted in waste accumulation throughout the collection and processing system.

To reduce landfill dependency, community-based waste management facilities known as TPS 3R (Reduce, Reuse, Recycle) have been promoted. TPS 3R facilities have been reported to reduce waste transported to landfills by approximately 35–63% through on-site processing of organic and recyclable waste [3]. Nevertheless, the effectiveness of TPS 3R depends on several factors, including operational performance, financing, community participation, and institutional capacity as outlined in SNI 3242:2008.

Previous studies have identified institutional and technical-operational aspects as key determinants of TPS 3R sustainability [4]. However, improving all operational components simultaneously often requires substantial resources. Therefore, a systematic risk-based approach is needed to identify critical operational vulnerabilities and prioritize improvement efforts. This study aims to identify and prioritize technical operational failure risks in TPS 3R facilities using the Failure Modes and Effects Analysis (FMEA) method as a basis for improving operational performance and supporting sustainable waste management [5].

2. Research Methodology

Data Collection Methodology

This study employed a combination of qualitative and quantitative approaches. Data was obtained through:

1. Semi-structured interviews with TPS 3R managers to identify the main operational risks.

Structured and semi-structured interviews were conducted to identify potential risks associated with the technical and operational aspects of TPS 3R facilities based on the experiences and perceptions of facility managers. According to ISO 31010:2019 [6], structured interviews employ predefined questions, whereas semi-structured interviews allow additional exploration of issues that emerge during the discussion. This approach was selected because it enables the collection of detailed information regarding potential failure modes, their causes, and operational impacts. Furthermore, semi-structured interviews are particularly suitable for exploration studies aimed at obtaining a comprehensive understanding of participants' experiences and perspectives. The risks were categorized into:

- Risks in the Containerization Sub-Aspect
- Risks in the Waste Sorting Behavior at Source Sub-Aspect
- Risks in the Collection Sub-Aspect
- Risks in the Waste Processing Sub-Aspect

2. Questionnaires distributed to the community to determine containerization conditions and waste sorting habits using a Likert scale.

Questionnaires were distributed to households served by each TPS 3R facility to capture community perspectives regarding waste storage conditions and source-segregation practices. The survey aimed to identify potential failure risks associated with these aspects from the users' perspective. The collected information was subsequently used to support the risk identification process and complement the findings obtained from interviews and field observations [7]. The number of respondents at each study site was determined using the Yamane sampling formula to ensure adequate representation of the target population.

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Where:

- n = sample size;
- N = Total population size, and
- E = Margin of error (10%)

Prior to data collection, the questionnaire instrument was subjected to validity and reliability testing using IBM SPSS Statistics version 29.0.2.0. The pilot test involved 30 respondents to evaluate the consistency and suitability of the instrument. This number of respondents was considered adequate for preliminary testing, as it is commonly assumed to provide a data distribution that reasonably approximates normality [8].

The dimensions and attributes included in the questionnaire were established through a review of relevant literature and previous studies. These variables were selected to represent the key factors associated with the technical and operational aspects of TPS 3R facilities. The dimensions, attributes, and supporting references are presented in **Table 1**.

Table 1. The Dimensions, Attributes, and Supporting Reference Included in Questionnaire

Dimensions	Attributes	Reference
Waste Storage (Technical Aspect)	Availability of Physical Condition of Waste Containers	[9]
	Waste Container Labeling and Color Coding	[9]
	Location and Accessibility of Waste Containers	[9]
	Cleanliness and Maintenance of Waste Containers	[9]
Waste Segregation (Behavioral Aspect)	Knowledge of Waste Categories	[10]
	Organic and Inorganic Waste Segregation Practices	[10]
	Waste Segregation According to the 3R Concept	[10]
Transportation Frequency	Perceived Ease of Waste Segregation	[10]
	Consistency of Waste Segregation Behavior (Habit)	[10]
Perceived Technical Impacts	Impact of Mixed Waste on TPS 3R Operations	[11]
	Impact on the Quality of Processed Products	[11]
	Impact of Poor Waste Storage Practices on TPS 3R Performance	[11]

3. Field observations to examine the actual conditions of the waste management system.

Direct field observations were carried out to assess waste storage, collection, processing, and operational management activities at each TPS 3R facility[12]. The observations were used to identify potential technical-operational failure risks and to validate information obtained from semi-structured interviews and questionnaire surveys.

Risk Analysis Method

Risk analysis was conducted using the Failure Modes and Effects Analysis (FMEA) method. This method was used to:

- Identify failure modes

Failure mode identification was conducted through semi-structured interviews with the managers of TPS 3R Mutiara Bogor Raya, TPS 3R Ciparigi 2, and TPS 3R Jalan Jawa. The findings were supplemented by questionnaire data collected from households served by each facility to capture community perspectives on potential operational failures[6].

- Determine causes and Effect

Potential causes and effect of each failure mode were identified through a second-stage structured interview with TPS 3R managers. This process aimed to investigate the underlying conditions and contributing factors that could trigger operational failures within the waste management system [6].

- Determine risk priorities

Risk values were calculated using the Risk Priority Number (RPN), which is the product of three parameters, namely Severity (S), Occurrence (O), and Detection (D). The Risk Priority Number (RPN) was calculated for each identified operational failure mode to determine its level of priority. The RPN value was obtained using the following equation [6].

$$Risk\ Priority\ Number\ (RPN) = \text{Severity (S)} \times \text{Occurrence (O)} \times \text{Detection (D)} \qquad (2)$$

The calculated RPN values were subsequently used to prioritize the identified failure modes. Failure modes with the highest RPN values were considered the most critical, as they represent the greatest potential impact on operational performance and therefore warrant priority consideration in risk mitigation planning [6].

3. Results and Discussion

Existing Waste Management Conditions at the Study Location

Data on waste generation, composition, and characteristics at TPS 3R Mutiara Bogor Raya, TPS 3R Ciparigi 2, and TPS 3R Jalan Jawa were secondary data obtained from the Plastic Smart City Endline Assessment project and Direct Observation. The data were collected through measurements and field observations using standardized methods, thereby ensuring accountable validity. These data were used to describe the actual conditions of waste management as the basis for risk analysis of the technical operational aspects of TPS 3R in accordance with ISO/IEC 31010:2019[6]. The following is a summary of the existing waste management conditions at TPS 3R Mutiara Bogor Raya.

1. TPS 3R Mutiara Bogor Raya

The existing conditions of waste management at TPS 3R Mutiara Bogor Raya facility were evaluated using secondary data and field observation results. The findings, along with the corresponding analysis, are summarized in **Table 2**.

Table 2. Existing Waste Management Conditions at TPS 3R Mutiara Bogor Raya

Existing Waste Management Conditions	Magnitude/Condition/Documentation	Analysis
Waste Generation	The average waste obtained was 0.80134 kg/person/day.	The amount of waste generated by the community is very high.
Composition	Most of the organic waste fraction consisted of food waste at 40.35%, including leftover rice, vegetable residues, fruit residues, and other food waste.	Organic waste is dominant. It has the potential to cause odors and leachate if handling is delayed for more than 3 days.
Characteristics	Moisture content: 63.73%; Calorific value: 2049.11 kcal/kg	The waste contains high moisture content; therefore, pre-drying is required.
Waste Storage and Sorting Habits	Mixed, uncovered, and non-uniform	Makes it difficult for residents to begin waste sorting practices.
Waste Collection	1 pickup truck and 2 waste collection motorcycles	Able to cover a wider service area and operate efficiently.
Waste Processing	Organic waste: Compost and BSF Non-Organic waste : sell to the recycle plan	

Source: Evorise (2025) and Direct Observation

2. TPS 3R Ciparigi 2

The existing waste management conditions at TPS 3R Ciparigi 2 were assessed using secondary data from the Plastic Smart City Endline Assessment project and field observations. The data were used to characterize waste generation, composition, and operational conditions, which served as the basis for the technical-operational risk assessment. The results are summarized in **Table 3**.

Table 3. Existing Waste Management Conditions at TPS 3R Ciparigi 2

Existing Waste Management Conditions	Magnitude/Condition/Documentation	Analysis
Waste Generation	The cumulative average waste generation rate was 0.32 kg/person/day.	The amount of waste entering TPS 3R Ciparigi is relatively fluctuating and depends on service conditions and community participation. There is no

Existing Waste Management Conditions	Magnitude/Condition/Documentation	Analysis
		structured recording system, making volume control difficult.
Composition	The majority of the organic waste fraction consisted of food waste at 42.85%, including leftover rice, vegetable residues, fruit residues, and other food waste.	The waste composition is dominated by mixed household waste. Source segregation has not been consistently implemented; therefore, the composition is not well defined from the outset.
Characteristics	Moisture content: 63.73%; Calorific value: 2049.11 kcal/kg	The characteristics of the incoming waste tend to be heterogeneous, with high moisture content and low calorific value.
Waste Storage and Sorting Habits	Mixed and non-uniform	Makes it difficult for the community to initiate waste sorting practices.
Waste Collection	1 waste collection motorcycle and 3 waste carts	This process is highly dependent on human resources conditions and the social relationship between managers and the community.
Waste Processing	Organic waste: Anaerobic digester	

3. TPS 3R Jalan Jawa

The existing waste management conditions at TPS 3R Jalan Jawa were evaluated based on secondary data from the Plastic Smart City Endline Assessment project, complemented by field observations and discussions with facility managers. The collected information described the quantity and characteristics of incoming waste, as well as the operational practices implemented at the facility. This assessment served as a foundation for understanding the current performance of the system and for conducting the subsequent technical-operational risk analysis. The results are summarized in **Table 4**.

Table 4. Existing Waste Management Conditions at TPS 3R Jalan Jawa

Existing Waste Management Conditions	Magnitude/Condition/Documentation	Analysis
Waste Generation	The cumulative average waste generation rate was 0,344 kg/person/day.	The amount of waste entering TPS 3R Jalan Jawa is relatively fluctuating and depends on service conditions and community participation. There is no structured recording system, making volume control difficult.
Composition	The majority of the organic waste fraction consisted of food waste at 48,12%, including leftover rice, vegetable residues, fruit residues, and other food waste.	The waste composition is dominated by mixed household waste. Source segregation has not been consistently implemented; therefore, the composition is not well defined from the outset.
Characteristics	Moisture content: 73.30%; Calorific value: 1771,34 kcal/kg	The relatively high moisture content of the waste increases the likelihood of odor emissions and leachate generation during the collection process. In addition, excessive moisture may negatively affect the effectiveness of waste treatment operations. Consequently, pre-drying is required before composting or thermal processing to achieve more efficient and stable treatment performance.
Waste Storage and Sorting Habits	Mixed and non-uniform	Makes it difficult for the community to initiate waste sorting practices.
Waste Collection	By waste cart from each sub-quarter	The waste collection system relies on handcarts operated by individual RT

Existing Waste Management Conditions	Magnitude/Condition/Documentation	Analysis
		leaders, resulting in a decentralized collection process. This condition may hinder coordination and monitoring efforts, thereby increasing the risk of inconsistencies in the quantity and composition of waste received by the facility.
Waste Processing	Organic waste: shredder and making compost non-organic waste : shredder and sell to the recycle plan nearby that facility	

Risk Analysis with Failure Modes and Effect Analysis (FMEA)

The Failure Modes and Effects Analysis (FMEA) method was employed to assess operational risks within the TPS 3R facilities. Input data for the analysis were collected through a second round of structured interviews with facility managers to identify potential failure modes, their causes, and associated impacts. The results were then subjected to expert validation involving academic researchers and waste management practitioners to ensure the relevance and credibility of the risk assessment.

1. TPS 3R Mutiara Bogor Raya

Information obtained from the structured interviews with TPS 3R Mutiara Bogor Raya managers was used to identify potential operational failure modes within the waste management system. The identified risks and their corresponding FMEA assessment results are presented in **Table 5**.

Table 5. Results of Failure Modes and Effects Analysis at TPS 3R Mutiara Bogor Raya

Code	Failure Risk	Severity	Frequency	Detection	RPN
P1	Failure of the operational management system	4,5	3,25	2	29,25
P2	Financial management instability	4,25	4	2,25	38,25
Code	Waste Storage and Sorting				
W1	Unplanned waste storage at the source	4,25	4,25	2,25	40,641
W2	Low level of community participation in waste sorting	4,25	4,25	2	36,125
W3	Waste containers are not labeled and not differentiated between organic and non-organic waste bins	2	4,75	3,5	33,25
Code	Waste Collection				
K1	Inefficiency in collection scheduling	3,5	4,25	2,5	37,188
K2	Insufficient waste collection fleet	4,25	4	2,25	38,25
K3	Frequent overload of collection vehicles	4,25	3,5	1,75	26,04
Code	Waste Processing				
O1	Overloading of the waste sorting process at the TPS	4,5	4,25	2	38,25
O2	Damage and suboptimal performance of machinery	4,75	3,25	3,25	50,17
O3	Unreliability of the waste processing system chain	4,75	3,25	3,25	50,172
O4	Processed products that do not meet the demands of the surrounding market	3,5	3,25	2,25	25,6

High RPN values indicate that the potential failure risks possess a high level of hazard when assessed in terms of severity, frequency, and detection. Therefore, these potential risks require special attention in the planning of strategies to avoid or minimize the impacts that may arise if the risks materialize.

Jurnal Serambi Engineering JSE Volume XI, No.3, Juli 2026 Hal 20785 - 20793 p-ISSN : 2528-3561 e-ISSN : 2541-1934

These risks were identified as priority concerns due to their greater potential to disrupt operational performance compared with other identified failure modes [13].

2. TPS 3R Ciparigi 2

Based on the results of structured interviews with TPS 3R managers and the Expert Adjustment process conducted with professionals and academic practitioners in the field of waste management, risk calculations and identification were carried out using the Failure Modes and Effects Analysis (FMEA) method. Results of Failure Modes and Effects Analysis at TPS 3R Ciparigi 2, details on the **Table 5**.

Table 5. Results of Failure Modes and Effects Analysis at TPS 3R Ciparigi 2

Code	Failure Risk	Severity	Frequency	Detection	RPN
P1	Operational dependence on the individual capacity of managers	4,75	3,25	2	30,875
P2	Instability in operational human resource performance	4	4	2,25	36
Code	Waste Storage and Sorting				
W1	Absence of a source segregation control system	4,5	4,75	2	42,75
W2	Ineffectiveness of waste sorting socialization	2	3	2	12
W3	Failure of the community assistance system	4,25	4,25	2	36,125
W4	Failure in the provision and management of waste storage facilities supporting segregation	4,5	4,75	2	42,75
W5	Majority of the community are unaware and unwilling to sort waste at the source	4,25	4,25	2	36,125
Code	Waste Collection				
K1	Absence of collection route system planning	3,5	4	2,75	38,5
K2	Lack of number collection vehicle	4	4	2,25	36
K3	Operational disruptions due to equipment damage	4,25	3,75	2,5	39,84
Code	Waste Processing				
O1	High dependence on the number of human resources	3,5	4	2,5	35
O2	Inconsistency in the processing flow	4,75	3,25	3,25	50,17
O3	Environmental disturbances from organic waste processing	4	2,25	3	27
O4	Failure of processed products to be sold or utilized	3,5	3,25	2,25	25,59

Based on these results, the failure modes with the highest Risk Priority Number (RPN) in each operational aspect namely P2, W1 and W4, K3, and O2 were identified as priority risks for further analysis. High RPN values indicate that the potential failure risks possess a high level of hazard when assessed in terms of severity, occurrence, and detection[5]. Therefore, these potential risks require special attention in the planning of strategies to avoid or minimize the impacts that may arise if the risks materialize[14].

3. TPS 3R Jalan Jawa

Based on the results of structured interviews with TPS 3R managers and the Expert Adjustment process conducted with professionals and academic practitioners in the field of waste management, risk calculations and identification were carried out using the Failure Modes and Effects Analysis (FMEA) method. Results of Failure Modes and Effects Analysis at TPS 3R Jalan Jawa on **Table 6**.

Table 6. Results of Failure Modes and Effects Analysis at TPS 3R Jalan Jawa

Code	Failure Risk	Severity	Frequency	Detection	RPN
P1	Inadequate competency of operational personnel	4,25	3,5	2	29,75
P2	Inability of the system to accommodate waste volume	4	4,25	1,75	29,75
Code	Waste Storage and Sorting				
W1	Non-uniform waste storage containers at the source	4,5	4,25	2,25	43,03125
W2	Failure to provide and manage waste storage facilities that support source separation	4,5	4,75	2	42,75
W3	Most residents are unwilling to separate waste at the source	4,25	4,25	2	36,125
Code	Waste Collection				
K1	Waste in the service area cannot be fully collected	3	4	3	36
K2	Uneven distribution of collection vehicles among neighborhood units (RTs)	4	4	2,5	40
Code	Waste Processing				
O1	Processed waste products lack a clear off-taker	3	3,75	2,75	30,9375
O2	Extreme processing overcapacity	4,75	3,25	3,25	50,17188
O3	Entry of non-household waste into the TPS 3R system	2,5	2,25	2,25	12,65625
O4	Absence of a proper maintenance plan for machinery and processing technology	4,25	3	2,75	35,0625

Based on the analysis results, the failure modes with the highest Risk Priority Number (RPN) in each operational aspect namely P1 and P2, W1, K2, and O2. Were identified as priority risks for further analysis. High RPN values indicate that the potential failure risks possess a high level of hazard when assessed in terms of severity, occurrence, and detection [5]. Therefore, these potential risks require special attention in the planning of strategies to avoid or minimize the impacts that may arise if the risks materialize. Failures in technical and operational aspects may be attributed to inadequate managerial support and insufficient government involvement [15]

4. Conclusion

This study demonstrates that the risk of failure in the technical operational aspects of TPS 3R is influenced by management factors, operational capacity, and community behavior, particularly the low level of waste segregation at the source. TPS 3R Mutiara Bogor Raya is dominated by managerial issues, TPS 3R Ciparigi 2 by unstructured operational systems and dependence on individuals, while TPS 3R Jalan Jawa is characterized by an imbalance between waste volume and processing capacity.

The results of the FMEA analysis indicate several risks with high RPN values, particularly in the sub-aspects of waste storage, segregation, and processing, thereby requiring priority handling. Therefore, integrated improvements are needed through strengthening operational systems, increasing capacity, and encouraging source segregation to improve the performance of TPS 3R.

5. Acknowledgment

With utmost respect and gratitude, the author would like to express sincere thanks to Almighty God for the blessings of health, time, knowledge, and sustenance granted to the author, enabling the completion of this Thesis successfully.

The author would also like to express profound gratitude to Bandi Subandi and Diah Rodiah as the author's parents. Furthermore, the completion of this research was also supported by dedicated and supportive lecturers and professionals. Therefore, the author would like to convey sincere thanks to Opy Kurniasari, Wahyu Dewi Yantini, and Adha Nur Kholif Pratama.

6. References

[1] M. Medina, “Solid Wastes, Poverty, and the Environment in Developing Country Cities: Challenges and Opportunities,” *Urban. Dev. Multidiscip. Perspect.*, 2011, doi: 10.1093/acprof:oso/9780199590148.003.0015.

[2] Pemerintah Republik Indonesia, Undang Undang Republik Indonesia, No. 18, 2008.

[3] Sakti, Rahmad Dwiky Satria. "Peran tempat pengolahan sampah 3R (reduce, reuse, recycle) dalam mengurangi pengangkutan sampah TPA di kawasan Kabupaten Sleman." *Environmental Engineering Journal ITATS* 2.2 (2022): 1-10.

[4] I. M. W. Widyarsana, Khairunisa, N. S. Dewi, Qurratu, A. Meilita, and R. H. Nurulloh, “Analisis Aspek Pengelolaan Sampah di TPS 3R Sauyunan,” *J. Serambi Eng.*, vol. IX, no. 3, pp. 9269–9281, 2024.

[5] Project Management Institute, *PMBOK® Guide Sixth Edition (PMI, 2017)*, 6th ed., vol. 6. 2017. Project Management Institute. Available: http://www.citeulike.org/group/14887/article/9008974

[6] ISO/IEC, IEC 31010:2019, Risk Management, Risk Assessment Techniques, 2nd ed. Geneva, Switzerland: International Organization for Standardization and International Electrotechnical Commission, 2019.

[7] Sugiyono, *Metode Penelitian Kuantitatif, Kualitatif, dan R&D*. Bandung, Indonesia: Alfabeta, 2017.

[8] M. Rahardjo, Antara Konsep, Proposisi, Teori, Variabel dan Hipotesis dalam Penelitian. Malang, Indonesia: Universitas Islam Negeri Maulana Malik Ibrahim Malang, 2018. [Online]. Available: http://repository.uin-malang.ac.id/2410/2/2410.pdf.

[9] J. Pan and P. Liu, “Exploring waste separation using an extended theory of planned behavior: A comparison between adults and children,” *Frontiers in Psychology*, vol. 15, pp. 1–13, 2024, doi: 10.3389/fpsyg.2024.1337969.

[10] Hafsah, Akmali Khansa, and A. M. Asih. "Household behavior on plastic waste separation in Indonesia." *IEOM Society International* 9 (2021): 2493.

[11] Badan Standardisasi Nasional, *SNI 19-2454-2002: Tata Cara Teknik Operasional Pengelolaan Sampah Perkotaan*. Jakarta, Indonesia: Badan Standardisasi Nasional, 2002.

[12] Hadi, Sumasno. "Pemeriksaan Keabsahan data penelitian kualitatif pada skripsi." *Jurnal Ilmu Pendidikan* 22.1 (2016): 74-79.

[13] M. N. H. R. Abd Samad, M. I. H. Mohammad Nasir, N. Mohamad Arif, and M. A. A. Zakaria, “Risk Assessment for Municipal Waste Collection at Majlis Bandaraya Kuala Terengganu, Terengganu,” MAEH Journal of Environmental Health, vol. 3, no. 2, pp. 41–46, 2021.

[14] Institute for Water Resources, U.S. Army Corps of Engineers, Corps Risk Analysis Gateway Training Module: Risk Assessment – Qualitative Methods. Alexandria, VA, USA: U.S. Army Corps of Engineers, 2025.

[15] K. A. S. Dipayani, C. Meidiana, and S. A. Mustaniroh, “Strategy to Improve Community-Based Waste Reduction Potential (Case Study at TPS 3R Pudak Mesari, Darmasaba Village, Badung Regency),” *Journal of Information Systems Engineering and Management*, vol. 10, no. 43s, pp. 672–683, 2025, doi: 10.52783/jisem.v10i43s.8466.