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Designing A Spatial Zoning-Based Waste Supply Chain Risk Mitigation Strategy In Bandung City

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Abstract

Urban solid waste supply chain management often faces inefficiency due to conventional "spatial-blind" risk mitigation approaches. This study aims to design a precise waste supply chain risk mitigation model by integrating the House of Risk (HOR) and Geographic Information System (GIS) methods in the Tegalega Sub-City Area (SWK), Bandung City. Through HOR Phase 1, 12 risk events and 23 risk agents were identified. Evaluation using Aggregate Risk Potential (ARP) and Pareto Diagram revealed that besides external constraints from the Sarimukti Landfill, logistical bottlenecks were absolutely dominated by spatial factors, namely narrow road access, traffic congestion, and high-density slum characteristics. To overcome regional bias, occurrence probability values were calibrated using geospatial analysis into Spatially-Weighted Risk. This integration successfully transformed statistical figures into a Risk Zoning Map (Red, Yellow, and Green Zones) to provide objective spatial decision support. Furthermore, HOR Phase 2 formulated 6 preventive actions evaluated using the Effectiveness to Difficulty (ETD) ratio. The ranking results established night shift scheduling (ETD: 16,593.33) and Mobile Depo diversification exclusively assigned for the Red Zone (ETD: 15,037.33) as the top priorities. The integration of the HOR-GIS model proves that zone-based mitigation strategies are far more tactical and cost-effective compared to the conventional "one-size-fits-all" approach.

Keywords: Geographic Information System, House of Risk, risk mitigation, spatial weighting, waste supply chain

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INTRODUCTION

The problem of urban solid waste management has become one of the most pressing challenges in developing countries. Waste management today is no longer viewed as a simple linear activity of collection, transportation, and disposal, but rather as a complex supply chain system vulnerable to stochastic risks at every stage (Kurniawan et al., 2021; Tirkolaee et al., 2020). Bandung, as a metropolitan area, is currently facing a critical waste management supply chain crisis. With waste production reaching over 1,500 tons per day, the city's logistics system is under severe pressure, exacerbated by limited disposal quotas and operating hours at the Sarimukti Final Processing Site (TPA). This gap between the rate of waste generation and daily transportation capacity often leads to operational bottlenecks and waste accumulation at various Temporary Storage Sites (TPS).

In responding to these operational disruptions, a Supply Chain Risk Management (SCRM) approach is crucial. One of the most common methods used to prioritize operational risk mitigation is the House of Risk (HOR) (Pujawan & Geraldin, 2009). However, the application of conventional risk evaluation methods to urban infrastructure suffers from a fundamental weakness: spatial blindness. In the classic HOR model, the probability of occurrence and severity are assumed to be uniform across the city, regardless of geographic variability (Ardiansyah, 2023; Puji, 2024). However, the risk of fleet delays in slum areas with narrow access roads (alleys) carries a much higher probability of failure and impacts social conflict than in residential areas with arterial road access.

A review of the literature over the past 10 years reveals a methodological dichotomy. Research using Geographic Information Systems (GIS) in waste logistics tends to focus on deterministically optimizing the shortest-distance route without considering the probability of failure of logistics agents (Nguyen et al., 2023; Samah et al., 2021). In contrast, risk management-based (SCRM) research is very detailed in calculating the probability of failure but fails to visualize the exact location of the risk triggers. This lack of integrated risk visualization complicates decision-makers at the Environmental Agency, resulting in reactive and one-size-fits-all mitigation strategies, ultimately leading to inefficient budget allocation (wasting large trucks due to their inability to maneuver through narrow alleys).

This research gap is the background and uniqueness of this research. This research aims to design a Spatial Decision Support System model that integrates the risk weighting of the HOR method with the spatial analysis capabilities of GIS. Through the Spatially Weighted Risk concept, the probability value of risk events is calibrated using factual spatial data, so that mitigation is no

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longer global but allocated based on vulnerability zoning mapping (Risk Mapping). The final objective of this research is to formulate tactical mitigation strategies such as the implementation of dynamic routes and diversification of fleet dimensions that are specifically tailored (tailor-made) for the Tegalega Sub-City Region (SWK) of Bandung City. The benefits of this research are expected to provide an evidence-based policy framework for local governments in reducing the domino effect (ripple effect) of paralysis of the urban waste supply chain efficiently and on target.

METHOD

This research was designed using a Sequential Exploratory Mixed Methods Design approach, which combines qualitative data extraction based on expert perception with mathematical modeling and quantitative spatial analysis. The research took the location of the study object in the Tegalega Sub-City (SWK), Bandung City, which includes five administrative areas: Bandung Kulon, Babakan Ciparay, Bojongloa Kaler, Bojongloa Kidul, and Astana Anyar Districts. The selection of research subjects (participants) was carried out using a purposive sampling technique. The expert panel involved consisted of three key informants representing regulatory elements (Environmental Service Officials), operational executor elements (Waste Management Unit Coordinators), and academic environmental experts. This expert triangulation was applied to avoid sectoral bias in risk assessment.

Data collection techniques are divided into primary and secondary data collection. Primary data were obtained through in-depth interviews, field observations (ground truthing), and an iterative questionnaire based on the modified Delphi method for the expert judgment process on the HOR Phase 1 and 2 instruments. Secondary data were acquired from relevant agency databases, which include daily waste generation volume data, fleet inventory, and spatial data sets (shapefiles) of road networks, administrative boundaries, and TPS coordinates.

The data analysis technique is carried out through three integrated systematic stages. First, data processing using HOR Phase 1 to identify Risk Events (Ei) and Risk Sources (Aj). At this stage, the Aggregate Risk Potential (ARP) value is calculated based on the multiplication of Severity, Occurrence, and Correlation weights, then sorted using the 80/20 Pareto Diagram principle to extract the dominant risk agents. Second, spatial data analysis and validation using Quantum GIS (QGIS) software. The geospatial techniques used include Overlay of road width attributes, Buffer Analysis to measure the safe distance of facilities from sensitive areas, and Network Analysis to measure fleet travel time constraints. The output of this stage is the Spatially Weighted Risk weighting that transforms the regional classification into three Risk Mapping hierarchies using the

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Natural Breaks method (Red, Yellow, and Green Zones). Third, HOR Phase 2 processing to formulate Preventive Actions (PAk). The feasibility of mitigation strategies is evaluated using the Effectiveness to Difficulty (ETD) ratio, which is a calculation of the strategy's effectiveness in reducing risk (TEk) divided by the bureaucratic difficulty and implementation costs (Dk) to determine the final priority of policy allocation per spatial zone.

RESULTS AND DISCUSSION

1. Supply Chain Risk Identification and Quantification (HOR Phase 1)

Mapping the waste management supply chain structure in Tegalega SWK using the Supply Chain Operations Reference (SCOR) framework resulted in the determination of 12 Risk Events (Ei) and 23 Risk Sources (Aj). Through expert validation and focus group discussions, all risk variables were comprehensively defined to describe the actual conditions of waste flow from upstream to downstream.

A complete list of the 12 Risk Events (Ei) identified in the SWK Tegalega waste logistics system is presented in Table 1.

Table 1.Risk Event Identification (Ei)

No	Code	Risk Incidence (Ei)	Severity
1	**E1**	Accumulation of waste that is not collected at the source (residents' homes)	**7**
2	**E2**	Accumulation and overload of waste at TPS/TPST	**8**
3	**E3**	Waste/leachate scattered on the collection and transportation routes	**7**
4	**E4**	Odor disturbance and health impacts on communities around the source/TPS	**8**
5	**E5**	Groundwater/drainage pollution due to leachate	**6**
6	**E6**	Social conflict/residents' rejection of polling stations and transportation activities	**7**
7	**E7**	Operational disruptions due to the activities of illegal scavengers and informal parties	**8**
8	**E8**	Occupational accident incidents (K3)	**6**

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No	Code	Risk Incidence (Ei)	Severity
9	**E9**	Delays in transportation and failure to reach the TPA	**9**
10	**E10**	Fleet damage and disruption to smooth distribution	**9**
11	**E11**	Fire incidents or extreme events in garbage piles	**8**
12	**E12**	Non-conformity of infrastructure specifications and failure of data/reporting systems	**5**

The root causes that triggered the occurrence of the above risk events were identified as Risk Agents (Aj). The 23 final Risk Agents resulting from the Delphi screening were classified into five tactical categories, as presented in Table 2.

Table 2.Identifying Risk Agents (Aj)

No	Code	Risk Incidence (Ei)	Occurrence
1	**A20**	Capacity limitations and operating conditions of the Sarimukti Landfill	**9**
2	**A21**	Policy on limiting waste quotas and landfill operating hours	**9**
3	**A19**	Characteristics of risk areas: high density, slums	**9**
4	**A16**	Consistent traffic jams on loading and unloading lanes	**9**
5	**A17**	The condition/capacity of the road to the polling station is poor (narrow, damaged)	**9**
6	**A1**	Daily waste volume exceeds collection capacity	**8**
7	**A3**	Low level of sorting by the community at the source	**8**
8	**A6**	The capacity and design of the TPS are inadequate for the waste generated.	**8**

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9	**A7**	Proximity of polling stations to sensitive facilities (schools/mosques)	**8**
10	**A8**	The physical condition of the TPS is poor (floor, drainage)	**8**
11	**A13**	Transportation service schedules and patterns are not optimal	**8**
12	**A5**	Disturbing activities of illegal scavengers	**7**
13	**A14**	Loading and unloading productivity at TPS is low (manual)	**7**
14	**A15**	Practice*overloading*and lack of supervision	**7**
15	**A4**	Waste containing mixed sharp/B3 objects	**6**
16	**A9**	The land status and legality of the TPS are unclear.	**6**
17	**A10**	The number and capacity of the transport truck fleet is insufficient	**6**
18	**A11**	Condition of the truck fleet is old and lacks maintenance (breaks down)	**6**
19	**A2**	Irregularity of collection schedule at source	**5**
20	**A22**	Collection and transportation SOPs not followed	**5**
21	**A12**	The condition of the garbage cart/motorcycle is not suitable	**4**
22	**A18**	Steep/hilly road topography	**4**
23	**A23**	Lack of field human resource capacity (overwork)	**4**

The measurement of handling urgency is formulated using the Aggregate Risk Potential (ARP) value in the HOR Phase 1 framework, which integrates the assessment of the severity of the impact (severity), probability of occurrence (occurrence), and the causality correlation matrix of the expert questionnaire results.

The ARP value ranking is visualized using a Pareto Diagram to sort out dominant risk sources based on the 80/20 ratio principle. The results of the cumulative calculation summary for all 23 risk agents are presented in Table 3.

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Table 3. Results of the Aggregate Risk Potential (ARP) Pareto Calculation

Rank	Agent Code	RAP Value	Percentage (%)	Cumulative Percentage (%)
1	A21	2241	8.51%	8.51%
2	A20	2052	7.79%	16.30%
3	A1	1872	7.11%	23.41%
4	A6	1728	6.56%	29.97%
5	A8	1720	6.53%	36.50%
6	A13	1688	6.41%	42.91%
7	A7	1608	6.11%	49.01%
8	A19	1530	5.81%	54.82%
9	A17	1350	5.13%	59.95%
10	A15	1309	4.97%	64.92%
11	A11	1250	4.75%	69.66%
12	A14	1144	4.34%	74.01%
13	A10	1092	4.15%	78.15%
14	A3	1000	3.80%	81.95%
15	A16	850	3.23%	85.18%
16	A4	728	2.76%	87.94%
17	A5	612	2.32%	90.27%
18	A9	600	2.28%	92.54%
19	A2	590	2.24%	94.78%
20	A22	470	1.78%	96.57%
21	A23	444	1.69%	98.25%
22	A12	260	0.99%	99.24%
23	A18	200	0.76%	100.00%
TOTAL		26338	100.00%	

Based on Pareto's law, the 80% accumulated cut-off point is ranked 14th (A3) with an accumulated value of 81.95%. However, to formulate a tactical operational handling strategy and focus on the allocation of limited Environmental Agency resources (resource constraints), the intervention analysis was narrowed specifically to the top 10 risk agents (Top 10). These ten

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dominant risk agents represent the main triggers of operational failure of the waste logistics supply chain in the Tegalega SWK:

1. Systemic Constraints of Sarimukti Landfill (A21 & A20): Ranked first and second with extreme ARP values (2241 & 2052). As a regional landfill, strict weekly waste quota policies and the damaged muddy landfill infrastructure have created extreme downtime for trucks. These downstream issues act as hard constraints that cripple delivery continuity.
2. Volume Surge vs. Facility Design Capacity (A1, A6, & A8): The high daily volume (A1) is not commensurate with the carrying capacity of existing TPSs. Many TPSs were built without estimating future demographic trends, resulting in too small a design area (A6) and physical damage to sanitation (A8), which causes piles to overflow onto the road.
3. Urban Logistics Fleet Efficiency (A13 & A15): Suboptimal transport schedules (A13) that directly clash with peak city activity reduce daily travel. This triggers field crews to practice overloading (A15), which risks accelerating truck mechanical failures on the road.
4. Regional Spatial Morphological Barriers (A7, A19, & A17): The narrow dimensions of the access road (A17) and the characteristics of densely populated slum settlements (A19) paralyze the maneuvering of large trucks from the Department upstream. This causes the congestion at the daily polling stations to become very critical due to the full dependence on manual carts, coupled with the issue of social rejection (NIMBY Syndrome) due to the location of the polling stations being too close to sensitive public facilities for residents (A7).

The empirical evidence above demonstrates that to address the waste crisis, transportation inefficiencies can no longer be approached spatially blindly. Spatial data integration (GIS) is needed to localize these spatial variables (A7, A19, A17) so that operational mitigation interventions and fleet distribution are geographically targeted.

2. Integration of Spatial Analysis and Zoning Mapping (Risk Mapping)

To counteract the "spatially blind" weakness of the conventional HOR risk evaluation model, the probability of occurrence of risk agents was recalibrated into Spatially-Weighted Risk through projection into Quantum GIS (QGIS) software. Overlay analysis, buffer analysis, and network analysis were applied to precisely represent the vulnerability distribution in the Tegalega SWK.

The spatial mapping output (Risk Mapping) classifies service areas into three strategic zoning hierarchies using the Natural Breaks (Jenks) algorithm:

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1. Red Zone (Critical Risk): A polygon formed by the fatal intersection of high land use density (A1), access road widths below 4 meters (A17), and residential density (A19). This zone delineates the heart of dense settlements that require tactical decentralized mitigation.
2. Yellow Zone (Medium Risk): Areas with adequate arterial and collector road accessibility for heavy trucks, but are vulnerable to increased travel time due to the cost friction of traffic congestion (A16).
3. Green Zone (Low Risk): A planned urban area with a sufficient collection infrastructure ratio and measurable and optimal logistics service distances.

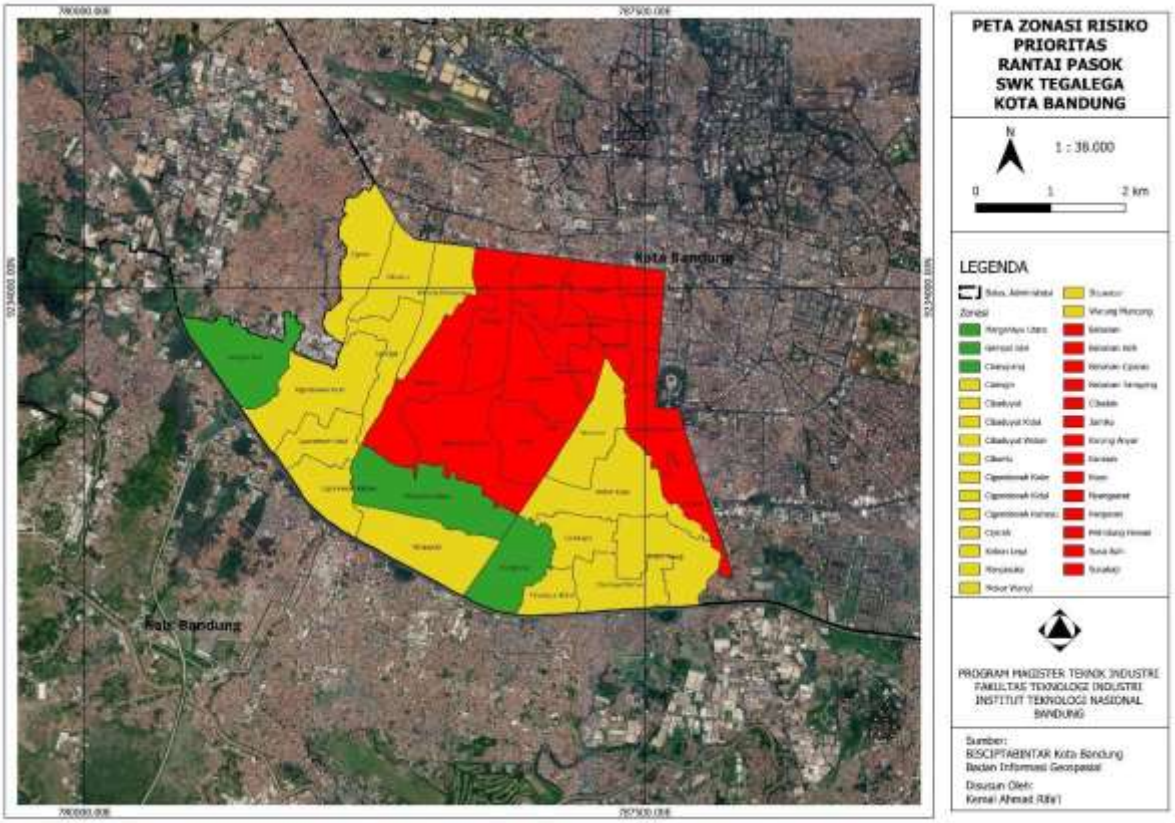


Figure 1.GIS-Based Supply Chain Risk Priority Zoning Mapping in Tegalega SWK

3. Formulation of Zoning-Based Mitigation Strategy (HOR Phase 2)

Based on the Risk Zoning Map, the Preventive Action (PAk) formulation for HOR Phase 2 was designed using a tailor-made approach (allocated based on spatial locus). Expert validation was used to calculate the Total Effectiveness (TEk) of each strategy in reducing the ARP value. This

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value was then compared with the Level of Difficulty of Bureaucratic Implementation and Cost (Dk) to obtain a strategic feasibility ratio, namely the Effectiveness to Difficulty Ratio (ETDk).

Table 4. Priority Ranking of Mitigation Strategies Based on ETD Ratio (HOR Phase 2)

Code	Preventive Action (Mitigation Strategy)	Location / Zoning Recommendations	Total Effectiveness (TEk)	Difficulty Level (Dk)	ETDk Ratio	Rank
PA 2	Trip Scheduling*Shift*Night (*Off-Peak*)	Main City Road Access	49780	3	16593.33	1
PA 3	Diversification*Mobile Depo*(Tricycle)	Red Zone Exclusive	45112	3	15037.33	3
PA 4	Relocation and Restructuring of TPS Based on*Buffer*	Intersection Polygon*Buffer*A7	62298	5	12459.6	4
PA 6	Construction of a City-Scale Independent TPST	Land*Greenfield* City	61559	5	12311.8	5
PA 1	Implementation*Dynamic Routing*Integrated WebGIS	All Arterial Routes and Yellow Zones	39450	4	9862.5	2
PA 5	Supervision*Overloading*and Operational SOPs	Internal Management of UPT	22165	3	7388.33	6

Referring to the evaluation parameters in Table 4, the execution of operational engineering through Night Shift Scheduling (ETD: 16,593.33) is the first priority as a Quick Wins strategy. This intervention is very rational to be executed in the Yellow Zone and arterial routes because it exploits off-peak time intervals. This arrangement is able to eliminate fleet contact with traffic congestion (A16) massively, avoid peak heavy equipment queues at the Sarimukti Landfill

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(A20), and does not burden the Regional Revenue and Expenditure Budget (APBD) extremely because the difficulty level is relatively low (Dk = 3).

Convergently, to overcome the accessibility paralysis concentrated in the Red Zone (narrow road A17 and slum A19), the direction of government capital expenditure must be shifted purely to the second priority, namely Diversification of micro-dimensional fleets in the form of Mobile Depots with a hydraulic system (ETD: 15,037.33). The implementation of HOR and GIS integration in this study validates the analytical postulate that urban waste logistics resilience can only be achieved if budget allocation and types of interventions are based entirely on the characteristics of spatial zoning (Spatially Targeted Intervention).

CONCLUSION

The waste logistics supply chain crisis in metropolitan cities is absolutely dominated by geospatial vulnerabilities, including limited road widths, dense/slum areas, and intersections with persistent congestion points. The combination of the House of Risk (HOR) methodology with a Geographic Information System (GIS) in this study successfully neutralizes the weaknesses of the conventional SCRM model which is "location blind". The Spatially-Weighted Risk calibration mechanism successfully represents statistical complexity into a Supply Chain Risk Zoning Map (Red, Yellow, Green Zones) as an objective instrument for decision-making. Based on the results of the Effectiveness to Difficulty Ratio (ETD) calculation in HOR Phase 2, local governments are recommended to shift from a "flat-out" logistics procurement strategy to precision mitigation. The most crucial Quick Wins strategy must be focused on night shift engineering (ETD: 16,593.33) to optimize arterial routes (Yellow Zone), as well as reallocating regional spending for the procurement of micro transport vehicles (Mobile Depot) (ETD: 15,037.33) which function exclusively to overcome the paralysis of fleet maneuvers in the Red Zone.

REFERENCES

Al Zahra, P., & Shohibuddin, M. (2022). Studi IRBA di TPA Bagendung, Cilegon: Penilaian risiko dan dampak lingkungan. Jurnal Teknik Lingkungan, 12(2), 45-58.

Ardiansyah, N. (2023). Implementasi metode house of risk (HOR) untuk manajemen risiko rantai pasok produk seat track adjuster 4L45W. Jurnal Teknik Industri, 9(1), 12-24.

Arsana, I. W. A., et al. (2022). Analisis spasial timbulan dan komposisi sampah berbasis GIS untuk perencanaan pengelolaan sampah. Jurnal Ilmu Lingkungan, 20(1), 115-125.

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Fadhil, M., Hisjam, M., & Hidayat, Y. A. (2021). Risk analysis of reverse logistics implementation in the construction industry with a supply chain perspective. Journal of Industrial Engineering and Management, 14(4), 776-793.

Kurniawan, T. A., Othman, M. H. D., Hwang, G. H., Gikas, P., & Ul-Saufie, A. Z. (2021). The circular economy of urban solid waste management: A way towards sustainable development goals. Journal of Cleaner Production, 297, 126588.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic information science and systems (4th ed.). Wiley.

Nguyen, T. T. T., et al. (2023). Pendekatan berbasis GIS untuk optimasi rute pengumpulan sampah padat perkotaan: Studi kasus di Vietnam. Environmental Science and Pollution Research, 30, 45210-45225.

Oliveira, J. C., de Lima, R. S., & Costa, S. R. R. (2019). The role of simulation and optimization methods in supply chain risk management: Performance and review standpoints. Simulation Modelling Practice and Theory, 92, 128-156.

Pujawan, I. N., & Geraldin, L. H. (2009). House of risk: A model for proactive supply chain risk management. Business Process Management Journal, 15(6), 953–967.

Samah, H. A., et al. (2021). Visualisasi spasial sistem pengelolaan sampah menggunakan GIS: Studi kasus di Putrajaya. Geografia-Malaysian Journal of Society and Space, 17(2), 1-14.

Sisay, T., et al. (2025). Analisis spasial distribusi fasilitas pengelolaan sampah menggunakan GIS: Studi kasus di Sleman. GeoJournal, 88, 1205-1220.

Subedi, S., et al. (2025). Pemilihan lokasi pengelolaan sampah berbasis GIS MCDA di Distrik Kanchanpur, Nepal. Journal of the Institute of Engineering, 16(1), 205-218.

Tirkolaee, E. B., Mahdavi, I., & Esfahani, M. M. S. (2020). A robust green location-allocation-inventory problem to design an urban waste management system under uncertainty. Waste Management, 102, 340-350.

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