FORUM GEOGRAFI
ISSN: 0852-0682 | E-ISSN: 2460-3945
HTTPS://JOURNALS.UMS.AC.ID/INDEX.PHP/FG/

Optimising Household Solid Waste Collection Facility in Autonomous Regions of Developing Countries: A Case Study on Karanganyar Regency, Indonesia

Eko Setiawan[1,2*], Juang Victorio Kusuma[2], Ganang Adi Sulistyawan[2], Septin Puji Astuti[3]

[1] Department of Industrial Engineering, Faculty of Engineering, Muhammadiyah University of Surakarta, Sukoharjo 57162, Indonesia
[2] Pusat Studi Logistik dan Optimisasi Industri (Puslogin), Muhammadiyah University of Surakarta, Sukoharjo 57162 Indonesia
[3] Department of Environmental Sciences, Universitas Islam Negeri RM Said Surakarta, Sukoharjo 57168, Indonesia

*) Correspondence: eko.setiawan@ums.ac.id

Citation:
Setiawan, E., Kusuma, J. V., Sulistyawan, G. A., & Astuti, S. P. (2024). Optimising Household Solid Waste Collection Facility in Autonomous Re-gions of Developing Countries: A Case Study on Karanganyar Regency, Indonesia. Forum Geografi. 38(3), 317-328.

Article history:
Received: 12 February 2024
Revised: 30 Agust 2024
Accepted: 31 Agust 2024
Published: 26 September 2024

Abstract
In many developing countries, autonomous regencies have significant rights to establish and manage waste collection facilities that are critical in conveying waste to final disposal sites. However, limited budgets often restrict these rights, particularly at the community level, where waste management needs are more acute. Given the growing importance and emergence of waste-related issues over the years, this study addresses the urgent challenge of siting household solid-waste collection facilities within the context of an autonomous region. We propose several location-allocation models namely a waste-weighted P-median, a pure P-median, a P-centre, a P-dispersion, and a "distance gap" model- to optimise the siting of these facilities. Utilising data from Karanganyar Regency in Indonesia, we demonstrate that the optimal model for facility siting is contingent on the specific objectives of the initiative, such as minimising transportation costs or maximising service coverage. Our findings underscore the need for enhanced planning around high-capacity waste collection facilities, emphasising their pivotal role in addressing the future demand for household waste management in autonomous regions. This study provides a framework for policymakers to make informed decisions about siting waste facilities and promote sustainable waste management practices in resource-constrained environments. Including more autonomous regions, a variety of scenarios on population growth and waste generation, additional perspectives on waste management, environmental and social considerations, and the investigation of emerging technologies in waste management are suggested as areas for future research.

Keywords: Autonomous region; Facility siting; Household solid waste; Location-allocation model.

1. Introduction

In many developing countries, regencies have a relatively high degree of autonomy, allowing a wide spectrum of rights to govern their jurisdictions. This includes the authority to establish waste collection facilities from which waste is conveyed to the final disposal sites. In some areas, rights include the management of waste at the most basic level, that is, waste generated by individual producers (Banerjee & Sarkhel, 2020). However, in other areas, limited budgets mean that waste management at this level has not yet been addressed (Yukalang *et al.,* 2017).

Household solid wastes are no exception. In the first scenario, household solid waste is collected and transported to waste collection facilities by a designated agency (Arantes *et al.,* 2020; Brotosusilo *et al.,* 2020; Dan *et al.,* 2021). In the second scenario, household waste producers must transport their waste to the collection facilities provided by the authorities (Blanchard *et al.,* 2023).

The importance and emergence of waste-related issues have grown over time (Kennes & Thalasso, 1998; Krook *et al.,* 2012; McCunney, 1986; Wang *et al.,* 2016; Yu & Solvang, 2017; Yuan & Shen, 2011; Zaman, 2015). Waste creates a variety of risks for people living in surrounding areas (Finkelman, 2004; Owusu, 2010; Ziraba *et al.,* 2016) or; otherwise, it is often perceived as dangerous to neighbouring residents (Litmanen, 1999; Murdock *et al.,* 1998).

Landslide (Defu *et al.,* 2013), disturbance to micro hydropower stations (Mateos *et al.,* 2013), and negative impacts on land resources and environment (Lestari & Trihadiningrum, 2019; Manzoor & Sharma, 2019; Vaverková, 2019), to name a few, are examples of serious problems resulting from poor waste management. Poor management of household solid waste leads to a variety of mishaps (Giusti, 2009; Laurent *et al.,* 2014). These issues are critical in developing countries (Abalansa *et al.,* 2021; Agamuthu, 2013; Chisholm *et al.,* 2021; Mantzaras *et al.,* 2019). Unfortunately, studies on waste management practices in developing countries are rare (Laurent *et al.,* 2014).

In response to the presence of waste, one available option is the implementation of waste treatment facilities (Treacy, 2022). The establishment of household solid waste collection facilities can be seen as part of this response. This is especially important considering the drastically growing production of household solid waste, a situation that occurs in many places worldwide (UNEP, 2024).

People concerned with waste-related problems are already familiar with operations research techniques and methods, as well as multi-criteria decision-making approaches to aid waste management (Banias *et al.,* 2010; Berglund & Kwon, 2014; Cagliano *et al.,* 2014; Chauhan & Singh, 2016; Erkut *et al.,* 2008; Karak *et al.,* 2012).

In particular, the use of location models in the context of waste management is abundant, including P-centre model (Maharani, 2018), P-dispersion model (Brylian, 2018), set covering models (Ghiani *et al.,* 2012; Setiawan *et al.,* 2018; Susy Susanty, Yuni Triani, 2012), P-median models (Aremu *et al.,* 2012; Putra, 2017), and a combination of these (Setiawan, 2016; Setiawan *et al.,* 2019).

Presenting a combination of location models applied to a given context of the waste facility siting problem and contrasting the performance of the models has not been found in the literature. However, regional autonomy is indicative of waste facility siting (Al-Khatib *et al.,* 2010; Brylian, 2018; Maharani, 2018; Putra, 2017; Setiawan *et al.,* 2018).

This study addresses the problem of placing household solid waste collection facilities in the Karanganyar Regency, an autonomous region located in Central Java, Republic of Indonesia. A P-centre model, two P-median models, a P-dispersion model, and a modified P-centre and P-dispersion model were used in this study. The siting configurations resulting from each model are subsequently presented and discussed. We hope that this study provides general insights applicable to similar autonomous regions in any developing country.

The remainder of the paper is organised as follows: Section 2 presents the research methods, consisting of a brief overview of the problem context and the proposed mathematical models for the problem. The results of the model implementation in the problem context are discussed in Section 3. The paper concludes with the findings presented in Section 4.

2. Research Methods

2.1. Problem context

The Karanganyar Regency is autonomous in Central Java, Indonesia. Located between 70°28' and 70°46' south latitude and 110°40' and 110°70' east longitude (BPS Karanganyar, 2018), the regency consists of 17 sub-regencies, 162 villages, 15 urban-villages, 1,117 sub-village and 2,323 hamlet (BPS Karanganyar 2018). With a total area of 773.79 km^2, about half the size of Greater London, the regency was expected to be inhabited by 871,596 residents in 2017 (BPS Karanganyar, 2018).

In terms of waste management, the Ministry of the Environment Agency in the Karanganyar Regency is responsible for household solid waste. According to the agency (Kusuma, 2017; Sulistyawan, 2017), it manages household solid waste generated by the sub-regencies of Tawangmangu, Karanganyar, Tasikmadu, Jaten, Colomadu, Gondangrejo, Karangpandan and Kebakkramat. The remaining subregencies are considered capable of handling the household solid waste they produce; therefore, they require agency operations in their areas.

From the 2016 secondary data obtained by Sulistyawan (2017) and Kusuma (2017), 56 household waste collection facilities existed in the eight sub-regencies of the regency. Among these 56 facilities, fieldwork carried out by Ifan *et al.* (2004) and Sulistyawan (2017) revealed that some facilities did not exist, and 10 facilities were exclusively devoted to certain communities.

Therefore, the facilities chosen as alternatives in the current study were reduced to 36 and referred to as alternatives for household solid waste collection facilities (WCFs). In 2016, the agency managed household solid waste produced by 39 villages and urban villages, as well as the aforementioned 10 community-devoted waste facilities in eight sub-regencies (Kusuma, 2017; Sulistyawan, 2017). These 39 villages and villages, and 10 community-devoted waste facilities were used as units of household solid waste producers (WPs) in this study.

Table 1 provides data on the WPs for 2016 and the projected year 2026, rounded to two decimal places, while Figure 1 shows a map of the waste volume estimate in 2016 and its projection in 2026. Data for the WPs in 2016 were obtained by multiplying the number of inhabitants at each WP by 1.45 litres of waste produced per person per day.

The 1.45-liter figure was derived from the ratio of the total waste produced in July 2016 (measured in m^3) to the total population of Karanganyar Regency (in individuals) for the same month.

The data for 2026 were obtained by first forecasting the total waste production for 2026 using the total waste data from 2010 to 2016. The estimated waste production for each WP in 2026 is calculated by multiplying the total projected waste production for 2026 by the population proportion of each WP.

The proportion was determined by dividing the population of each WP in 2016 by the total estimated population for the same year. For WPs that are WCFs, the population estimates assume that each WCF produces 6.00 m^3 of solid household waste.

Under this assumption, the estimated population was calculated as 6.00 m^3 divided by (1000/1.45) individuals per m^3, which equals 4,138 individuals.

Table 1. Waste Volume Estimate in 2016 and Its Projection in 2026.

WP Alternative	Location		2016 Population	2016 Waste Volume (in m^3)	2026 Waste Volume (in m^3)
	Sub-regency/ Community	Village/ Urban Village			
1	Tawangmangu	Sepanjang	3,684	5.34	8.00
2		Tawangmangu	8,675	12.58	18.84
3		Kalisoro	4,056	5.88	8.81
4		Blumbang	3,767	5.46	8.18
5		Nglebak	4,883	7.08	10.6
6	Karanganyar	Lalung	8,014	11.62	17.4
7		Tegalgede	9,392	13.62	20.4
8		Jungke	5,789	8.39	12.57
9		Cangakan	6,447	9.35	14.00
10		Karanganyar	4,458	6.46	9.68
11		Bejen	10,282	14.91	22.33
12		Popongan	7,514	10.90	16.32
13	Tasikmadu	Buran	4,989	7.23	10.83
14		Papahan	7,161	10.38	15.55
15		Ngijo	6,969	10.11	15.13
16		Gaum	5,822	8.44	12.64
17		Pandeyan	4,957	7.19	10.76
18	Jaten	Jati	6,915	10.03	15.02
19		Jaten	15,329	22.23	33.29
20		Sroyo	9,780	14.18	21.24
21		Brujul	5,963	8.65	12.95
22	Colomadu	Ngasem	5,567	8.07	12.09
23		Bolon	6,709	9.73	14.57
24		Malangjiwan	11,755	17.04	25.53
25		Paulan	3,221	4.67	6.99
26		Gajahan	2,149	3.12	4.67
27		Blulukan	7,282	10.56	15.81
28		Gawanan	6,185	8.97	13.43
29		Gedongan	8,711	12.63	18.92
30		Tohudan	5,877	8.52	12.76
31		Baturan	10,442	15.14	22.68
32	Gondangrejo	Klodran	5,555	8.05	12.06
33		Wonorejo	14,314	20.76	31.08
34		Plesungan	9,783	14.19	21.24
35		Selokaton	9,085	13.17	19.73
36		Dayu	3,073	4.46	6.67
37	Kebakkramat	Tuban	7,077	10.26	15.37
38		Kemiri	9,214	13.36	20.01
39		Nangsri	6,318	9.16	13.72
40	Community in Karangpandan	AURI	4,138	6.00	8.99
41		RSUD	4,138	6.00	8.99
42		Garmindo	4,138	6.00	8.99
43		RSU Jati Husada	4,138	6.00	8.99
44		Pondok Bukhori	4,138	6.00	8.99
45		Bukit Hermon	4,138	6.00	8.99
46		Putri Duyung	4,138	6.00	8.99
47		El Bethel	4,138	6.00	8.99
48		Rusunawa	4,138	6.00	8.99
49		Palur Plasa	4,138	6.00	8.99
		Total	318,543	461.89	691.77

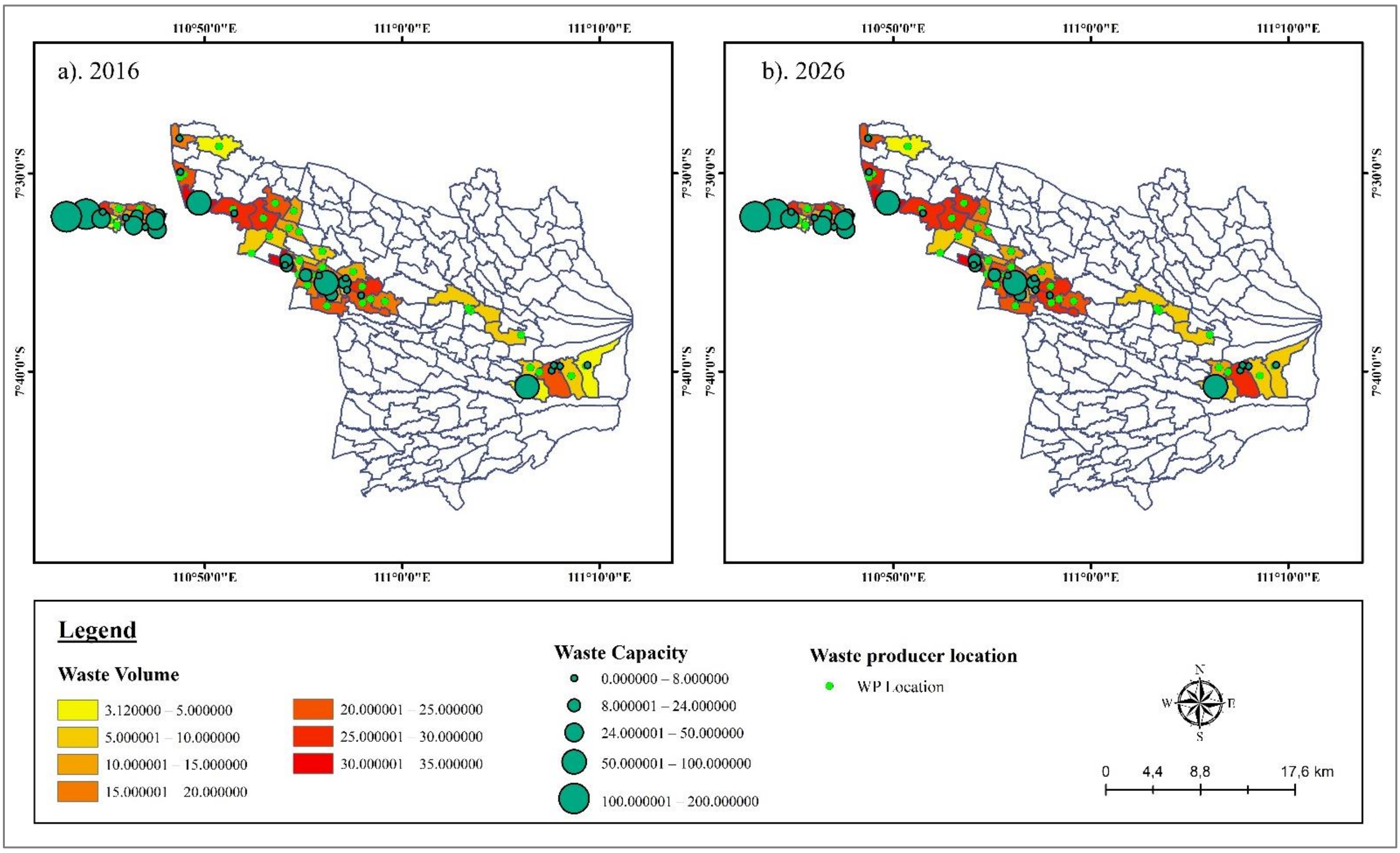

Figure 1. The Waste Volume Estimate (m^3) in 2016 (a) and the Waste Volume Projection (m^3) in 2026 (b) in WP alternatives.

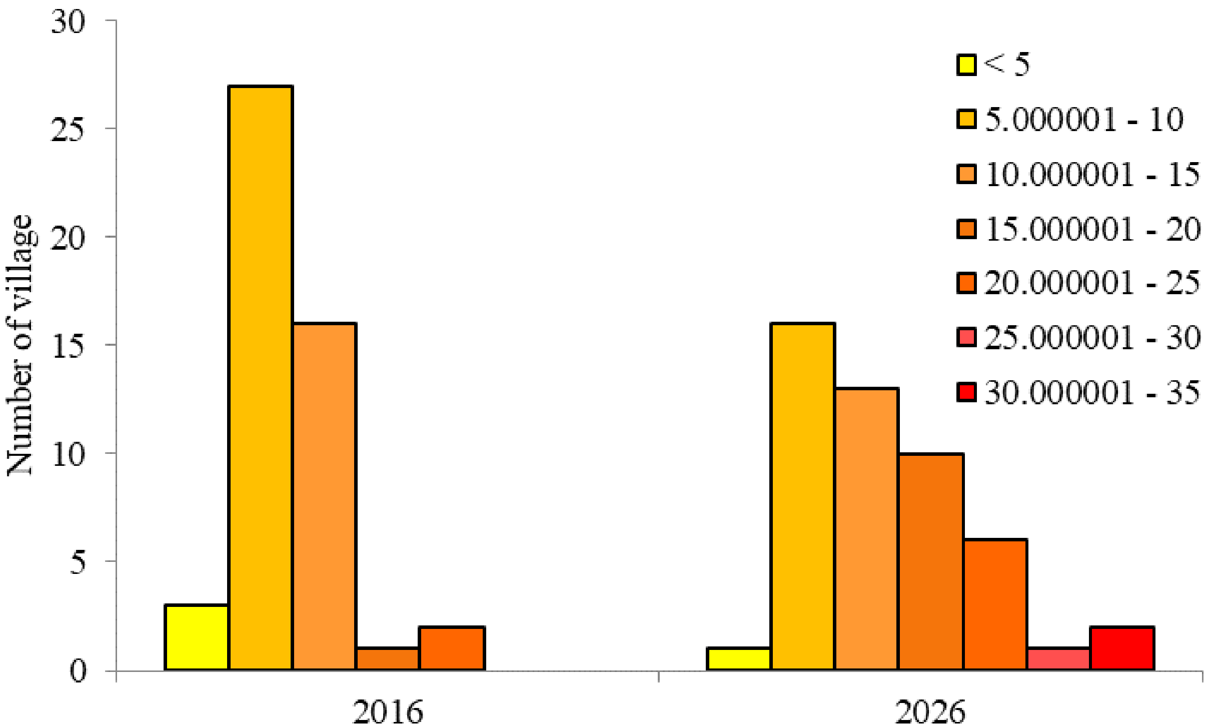

Figure 2. Number of Villages based on Waste Capacity.

Figure 2 summarises the number of villages based on waste volume. As the population increases, waste volume increases correspondingly, leading to an increase in the number of villages with high waste volumes.

Table 2 presents the data for the WCFs. The geographical coordinates of each WCFs are identified using Google Maps. Along with the geographical coordinates for each WP, these coordinates were used to calculate travel time distances (henceforth referred to as "distances") between each WP and each solid waste collection facility (WCF). The capacity of each alternative WCF, along with the coordinates and "distances", were obtained from fieldwork carried out by Sulistyawan (2017) and Kusuma (2017).

Table 2. Data on WCFs.

WCF	Sub-regency	Location	Coordinate	Capacity (in m^3)
1	Colomadu	Fajar Indah Timur	(-7.549698,110.793086)	50.00
2		Klodran Utara	(-7.536847,110.795372)	20.00
3		Klodran Selatan	(-7.540157,110.797997)	20.00
4		Tohudan	(-7.532492,110.773903)	20.00
5		Pilangan	(-7.538419,110.792174)	50.00
6		Bolon	(-7.537489,110.736016)	200.00
7		Klegen	(-7.539610,110.741798)	50.00
8		Blulukan	(-7.538641,110.770424)	50.00
9		Fajar Indah Barat	(-7.546547,110.784470)	15.00
10		Ngasem	(-7.531412,110.722548)	200.00
11		Sub-district Office of Colomadu	(-7.531246,110.749929)	6.00
12	Karanganyar	Jungke	(-7.601020,110.948252)	24.00
13		Jengglong	(-7.592744,110.949890)	24.00
14		Pandes	(-7.590650,110.936507)	24.00
15		Tegalwinangun	(-7.602244,110.964256)	12.00
16		Perum WU	(-7.598950,110.967198)	8.00
17		J. Siwaluh	(-7.598606,110.953377)	6.00
18		Perum MA	(-7.606175,110.954090)	12.00
19		Perum RSS	(-7.600323,110.982689)	12.00
20		Edu Park	(-7.588570,110.952612)	6.00
21	Jaten	Bulu	(-7.571835,110.898979)	200.00
22		Perum BGI	(-7.572403,110.902994)	30.00
23		Jumok	(-7.587793,110.913336)	30.00
24		Perum DA	(-7.573431,110.889954)	30.00
25		Getas	(-7.576311,110.901215)	6.00
26	Tasikmadu	GPI Papahan	(-7.573595,110.930367)	100.00
27		Papahan	(-7.582809,110.922865)	12.00
28	Gondangrejo	Wonorejo	(-7.526267,110.838135)	100.00
29		Plesungan	(-7.527589,110.852446)	6.00
30		Tuban	(-7.472977,110.806114)	6.00
31	Tawangmangu	Grojogan Sewu	(-7.663518,111.132321)	6.00
32		Balaikambang	(-7.662031,111.133080)	8.00
33		BPTO	(-7.663247,111.132021)	8.00
34		Beji	(-7.661876,111.127060)	15.00
35		Sepanjang	(-7.673762,111.099571)	100.00
36		Blumbang	(-7.664157,111.156224)	6.00
Total				1472.00

2.2. Mathematical Models

To address the problem, five mathematical models are proposed: a waste-weighted P-median model, a pure P-median model, a P-centre model, a P-dispersion model and a model aimed at minimising the difference between the maximum and minimum "distances" (referred as a "distance gap" model).

The full waste-weighted P-median model is expressed as follows:

Objective function:

$$nin \sum_i \sum_j V_i t_{ij} Y_{ij} \tag{0a}$$

Constraints:

$$\sum_j X_j \leq P \tag{1}$$

$$Y_{ij} - X_j \leq 0, \forall i \in I, j \in J \tag{2}$$

$$\sum_j Y_{ij} = 1, \forall i \in I \tag{3}$$

$$\sum_i \left(V_i Y_{ij} - C_j X_j\right) \leq 0, \forall j \in J \quad (4)$$

$$X_j, Y_{ij} \in \{0,\ 1\}, \forall i\ I, j \in J \quad (5)$$

Objective function (0a) dictates that the objective of the model is to minimise the total waste-weighted "distance". Constraint (1) requires that the total number of WCFs to be opened is equal to a certain value. Constraint (2) represents the requirement that a particular WP be served only by an open WCF, whereas constraint (3) ensures that exactly one open WCF serves each WP. Constraint (4) requires that the service provided by WCF does not exceed its capacity. Finally, the decision variables must be binary, as reflected in constraint (5).

In the meantime, the objective of the pure P-median (see constraint (0b)) is to minimise the total "distance" given the existence of constraints (1) – (5).

$$\min \sum_i \sum_j t_{ij} Y_{ij} \quad (0b)$$

The P-centre model, in contrast, is defined by constraints (1) – (5) and constraints (6), with the objective function appearing in constraint (0c). The complete model is as follows:

Objective function:

$$\min W_{max} \quad (0c)$$

Constraints (1) – (5)

$$\sum_j t_{ij} Y_{ij} - W_{max} \leq 0, \forall i \in I \quad (6)$$

The model aims to minimise a maximum "distance" – as reflected by objective function (0c) -, given the existence of constraints (1) – (5) and any possible values for the maximum "distance" (see constraints (6)).

In contrast to the abovementioned P-centre model, the proposed P-dispersion model aims to maximise a minimum "distance" – as reflected by objective function (0d) -, given the existence of constraints (1) – (5) and any possible values for the minimum "distance" (see constraints (7)).

$$\min W_{min} \quad (0d)$$

$$W_{min} - \sum_j t_{ij} Y_{ij} \leq 0, \forall i \in I \quad (7)$$

Finally, the proposed "distance gap" model minimises the gap between the maximum "distance" (see the *P*-centre model) and the minimum "distance" (see the *P*-dispersion model), as it is represented by objective function (0e). The model is defined by constraints Equation (1) – (7).

$$\min W_{max} - W_{min} \quad (0e)$$

Sets:

I = set of WPs;

J = set of alternatives for WCFs

Parameters:

P = maximum number of WCFs required for establishment

t_{ij} = "distance" from WP i, i = i, 2, ..., I to alternative site for WCFs j, j = 1, 2, ..., J;

V_i = waste volume of WP i;

C_j = capacity of WCF alternative j, j = 1, 2, ..., J

Decision variables:

$$X_j = \begin{cases} 1, & \text{if alternative j is selected as WCF} \\ 0, & \text{otherwise} \end{cases};$$

$$Y_{ij} = \begin{cases} 1, & \text{if WP i is served by WCF alternative j} \\ 0, & \text{otherwise} \end{cases};$$

W_{min} = total "distances" to be minimised;

W_{max} = total "distances" to be maximised;

3. Results and Discussion

Subsequently, all five models were applied to the available data. In this case, the maximum number of established WCFs is set to 36. Model implementation was carried out using the Lingo 11 software. Table 3 summarises the results of model implementation of the data. The results of the 2016 implementation are presented in Table 4. Table 5 summarises the results in association with 2026.

Table 3. Summary of the Results

Indicator	Year	Waste-weighted P-median	Pure P-median	P-centre	P-dispersion	"Distance gap"
Selected WCFs	2016	1, 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 14, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 31, 32, 33, 34, 35	1, 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 14, 18, 19, 20, 21, 22, 23, 24, 26, 27, 28, 31, 32, 33, 34, 35	1, 2, 3, 4, 5, 6, 7, 9, 11, 12, 13, 15, 17, 18, 19, 21, 23, 24, 25, 28, 29, 34, 35	1, 2, 3, 5, 6, 8, 9, 10, 12, 13, 14, 16, 18, 21, 22, 23, 24, 26, 28, 29, 35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 31, 32, 33, 34, 35, 36
	2026	1, 2. 3, 4, 6, 7, 8, 9, 10, 12, 13, 14, 15, 18, 19, 21, 22, 23, 24, 26, 27, 32, 34, 35	1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 18, 19, 21, 22, 23, 24, 26, 27, 28, 32, 34, 35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 18, 21, 22, 23, 26, 34, 35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 19, 21, 22, 24, 26, 27, 28, 34, 35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16, 21, 22, 23, 24, 26, 27, 28, 34, 35
Total # of WCF alternatives selected	2016	28 facilities	27 facilities	23 facilities	21 facilities	31 facilities
	2026	25 facilities	25 facilities	20 facilities	24 facilities	23 facilities
Total capacity of the selected WCFs	2016	1,328.00 m^3	1,322.00 m^3	1,008.00 m^3	1,293.00 m^3	1,436.00 m^3
	2026	1,358.00 m^3	1,388.00 m^3	1,234.00 m^3	1,364.00 m^3	1,360.00 m^3
Unused capacity of the selected WCFs	2016	866.11 m^3	860.11 m^3	546.11 m^3	831.11 m^3	974.11 m^3
	2026	666.23 m^3	696.23 m^3	542.23 m^3	672.23 m^3	668.23 m^3
Largest "distance"	2016	33.00 min	33.00 min	33.00 min	102.00 min	40.00 min
	2026	33.00 min	33.00 min	33.00 min	99.00 min	47.00 min
Smallest "distance"	2016	1.00 min	1.00 min	4.00 min	39.00 min	31.00 min
	2026	1.00 min	1.00 min	4.00 min	39.00 min	36.00 min
Gap of "distance"	2016	32.00 min	32.00 min	29.00 min	63.00 min	9.00 min
	2026	32.00 min	32.00 min	29.00 min	60.00 min	11.00 min
Total waste-weighted "distance"	2016	3,028.61 min	3,032.41 min	8,475.06 min	22,546.90 min	17,065.80 min
	2026	5,110.58 min	5,127.57 min	11,627.00 min	34,302.20 min	28,508.80 min
Total pure "distance"	2016	326.00 min	325.00 min	907.00 min	2,456.00 min	1,798.00 min
	2026	366.00 min	362.00 min	850.00 min	2,520.00 min	2,019.00 min
Total iteration	2016	176	243	648	562	558,002
	2026	275	243	476	420	8,225

The output of the model implementation (Table 3) shows that the volume of waste produced is still manageable. This was indicated by the total waste volume being less than the total capacity of the selected WCFs. The implementation also shows that an increasing volume of household solid waste leads to an increase in the total capacity of the selected WCFs and a decrease in their unused capacity. Additionally, while an increase in household solid waste volume leads to an increase in the total waste-weighted "distance", it does not necessarily correlate with an increase in the total number of WCFs selected.

Model implementation suggests that the objective of site positioning drives the best model. Siting facilities to minimise the total waste-weighted "distance" can be achieved by using the waste-weighted P-median model. The pure P-median model is ideal for achieving a minimum total pure "distance" in waste collection facility siting. These two models are suitable in situations where waste is collected by a single authoritative body (Al-khatib *et al.,* 2007; Al-Khatib *et al.,* 2010; Henry *et al.,* 2006) and, simultaneously, the existence of household solid waste collection facilities is welcomed or perceived as not threatening (Johnson & Scicchitano, 2012). The waste-weighted "distance" model is appropriate when waste production quantity varies significantly across the region (Al-khatib *et al.,* 2007; Al-Khatib *et al.,* 2010; Henry *et al.,* 2006), whereas the pure "distance" model suits regions where waste production quantity is relatively uniform. Sitting facilities to achieve the minimum largest "distance" and fairness are best approached using the P-centre model. In contrast, the P-dispersion model best addresses the objective of obtaining a maximum smallest “distance” with fairness. These two models fit the circumstances in which inhabitants in surrounding areas must transport their household solid waste to collection facilities (Aliu *et al.,* 2014; Djunaidi *et al.,* 2018). The P-centre model is suitable when the presence of household solid waste collection facilities is welcomed by communities or when facility alternatives are distant from residences. In contrast, the P-dispersion model is appropriate in the presence of NIMBY syndrome (such as that described in Johnson *et al.,* 2018) or, more generally, when an environmental justice issue exists (Kubanza *et al.,* 2017). Siting facilities with the main objective of achieving a relatively equal pure “distance” is best accomplished with the “distance gap” model, a combination of the P-centre and P-dispersion models. In any situation, the site positioning policy should consider the impact of positioning on residents (Zhang & Chen, 2018). Site positioning should be placed within the broader context of waste management to ensure that every stakeholder is in a position of acceptance.

Table 4. The WPs Served by the WCFs in Each Model – Year 2016.

Alternatives for WCF	The WPs served by each of the WCF alternatives resulted from each model				
	Waste-weighted *P*-median	Pure *P*-median	*P*-centre	*P*-dispersion	“Distance gap”
1	19, 23	23, 34	14, 26, 27, 32	4, 8, 38	9, 25, 38, 43
2	40, 46	40, 46	13, 46	48	35
3	39		5, 25	22	46
4	2	2	3, 36	1, 25	4, 10
5		19	19, 21	6, 20, 36	6, 22, 36, 42
6	27, 34, 42	27, 42	7, 11, 16, 17, 28, 29, 30, 31, 34, 38, 41, 42	12, 21, 35, 37, 39, 46	12, 20, 21, 24, 37
7	3, 6, 31	3, 6, 31	20, 23, 47	14, 24	14, 30, 32
8	16	16	43	10, 30	29
9	43	43	4	47	13
10	10, 11, 15, 20	10, 11, 15, 20	10, 40	9, 28, 34	34
11				26	
12	7	7	37	45	5, 44
13	14	14	2	5, 32	28, 40
14	35	35	12	23	
15	47	47		44	3
16					1
17					
18	41	41	44		
19	4	4		49	
20					
21	8, 17, 28, 37	8, 17, 24, 28, 37	8, 15, 24, 48	2, 7, 31	11, 23, 31
22	44	44	35	29	7
23	24	26, 39	39		47
24	38	38		15, 42	41
25					
26	12, 21, 32	12, 21, 32	1, 22	19, 40	19, 33, 39
27	48	48		13	45
28	5, 9, 25, 26, 30, 36	5, 9, 25, 30, 36		3, 16, 18, 33, 41	2, 18, 28
29					
30					
31					
32	1	1			
33					
34	49	49	49	17	26
35	13, 18, 22, 29, 33, 45	13, 18, 22, 29, 33, 45	6, 9, 18, 33, 45	11, 27, 43	8, 15, 16, 17, 27, 48
36					

For 2016 (see Table 4), the model implementation results revealed the following findings. First, the alternatives selected in the waste-weighted P-median (28 facilities) and pure P-median (27 facilities) models were relatively similar, with the only difference being alternative 25. The allocation of WPs to the selected alternatives was also relatively unchanged. Second, alternatives 1, 2, 3, 6, 9, 12, 13, 18, 21, 23, 24, 26, 28, 35 are always selected by each model. Among these, alternatives 1 and 6 seem to be favoured by the models. Third, alternative 30 was not selected by any of the five models, making it the least preferred option. Fourth, alternatives with large capacities (1, 6, 10, 21, 26, 28, and 35) served more waste producers in most models. Alternative 10 is not selected in the P-centre model, possibly due to its "distances" to WPs being too great. Alternative 1 is always selected by each model despite its relatively small capacity, likely because of its proximity to the WPs.

Table 5. The WPs Served by the WCFs in Each Model – Year 2026.

Alternatives for WCF	The WPs served by each of the WCF alternatives resulted from each model				
	Waste-weighted *P*-median	**Pure *P*-median**	***P*-centre**	***P*-dispersion**	**"Distance gap"**
1	19, 23	23, 34	14, 26, 27, 32	4, 8, 38	9, 25, 38, 43
2	40, 46	40, 46	13, 46	48	35
3	39		5, 25	22	46
4	2	2	3, 36	1, 25	4, 10
5		19	19, 21	6, 20, 36	6, 22, 36, 42
6	27, 34, 42	27, 42	7, 11, 16, 17, 28, 29, 30, 31, 34, 38, 41, 42	12, 21, 35, 37, 39, 46	12, 20, 21, 24, 37
7	3, 6, 31	3, 6, 31	20, 23, 47	14, 24	14, 30, 32
8	16	16	43	10, 30	29
9	43	43	4	47	13
10	10, 11, 15, 20	10, 11, 15, 20	10, 40	9, 28, 34	34
11				26	
12	7	7	37	45	5, 44
13	14	14	2	5, 32	28, 40
14	35	35	12	23	
15	47	47		44	3
16					1
17					
18	41	41	44		
19	4	4		49	
20					
21	8, 17, 28, 37	8, 17, 24, 28, 37	8, 15, 24, 48	2, 7, 31	11, 23, 31
22	44	44	35	29	7
23	24	26, 39	39		47
24	38	38		15, 42	41
25					
26	12, 21, 32	12, 21, 32	1, 22	19, 40	19, 33, 39
27	48	48		13	45
28	5, 9, 25, 26, 30, 36	5, 9, 25, 30, 36		3, 16, 18, 33, 41	2, 18, 28
29					
30					
31					
32	1	1			
33					
34	49	49	49	17	26
35	13, 18, 22, 29, 33, 45	13, 18, 22, 29, 33, 45	6, 9, 18, 33, 45	11, 27, 43	8, 15, 16, 17, 27, 48
36					

Considering the results of the model implementation for 2026 (see Table 5), several insights can be provided. First, the alternatives selected for the waste-weighted P-median (25 facilities) and pure P-median (27 facilities) were relatively the same. The only difference was between Alternatives 3 and 5. The allocation of WP to selected alternatives was relatively indifferent. Second, from all the alternatives, alternatives 1, 2, 4, 6, 7, 8, 9, 10, 12, 13, 21, 22, 24, 26, 34, 35 are always selected by each of the models. Of these, alternatives 1, 6, 7, 21, and 35 appear to be the favourites in all models. Third, alternatives 17, 20, 25, 29, 30, 31, 33 and 36 were not selected for the models. Fourth, alternatives with large capacities (1, 6, 7, 10, 21, 26, 28, and 35) served more waste producers in most models. The total number of WPs allocated to alternative 10 is not as high as that allocated to alternative 21, possibly because its "distances" to WPs are far. Alternative 1 was always selected by each model despite its relatively small capacity. The total number of WPs allocated to alternative 7 is not as high as that allocated to alternative 21 even though both of them have the capacity of 50 m^3, possibly because the alternative, Klegen, is relatively "distant" to WPs compared to alternative 1, i.e. Fajar Indah Timur.

By contrasting the performance of each model using the 2016 and 2026 data, it is evident that more than 40% (i.e. at least 15 out of 36) of the WCF alternatives were selected for both datasets. Moreover, the siting configuration indicated that alternatives with larger capacities were favoured as the waste volume increased.

4. Conclusion

The analysis highlighted that the optimal model for site positioning in autonomous regions was fundamentally determined by clear waste management objectives. Regions with autonomy similar to the Karanganyar Regency should prioritise defining their main goals when establishing household solid waste facilities. Site positioning must be integrated into a broader waste management strategy to ensure stakeholder acceptance and effective implementation.

A comparison of model performance using 2016 and 2026 data suggests that over 40% of waste collection facility (WCF) alternatives are consistently selected across both timeframes. This trend indicates a preference for larger-capacity facilities as waste volumes increase, underscoring the importance of anticipating future waste management needs. Thus, regions with similar challenges should focus on developing large-capacity facilities to address future demands efficiently.

This study relies on assumptions about population growth and waste generation, which may not accurately reflect real conditions. Future research could explore various scenarios to assess their impact on outcomes. The analysis was specific to Karanganyar Regency and may not be applicable to other regions. The inclusion of diverse areas can improve the generalisability of the findings.

While stakeholder acceptance is emphasised, this study does not fully consider all perspectives of waste management. Future studies should use interviews or surveys to examine these views. Current models focus on logistic factors and overlook both environmental and social factors. Integrating these factors can offer a more comprehensive approach to siting. Finally, this study did not consider the technological advancements in waste management. The investigation of emerging technologies can inform future planning.

Acknowledgements

This paper is financially supported by the Applied Research Program No. 211.25/A.3-III/LPPM/V/2017) from Directorate General of Research and Development Strengthening, Ministry of Research, Technology and Higher Education, Republic of Indonesia.

Author Contributions

Conceptualisation: Setiawan, E.; **methodology**: Setiawan, E.; **investigation**: Kusuma, J. V., Sulistyawan, G. A.; **writing—original draft preparation**: Setiawan, E.; **writing—review and editing**: Setiawan, E., Astuti, S. P.; **visualisation**: Astuti, S. P. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.Data availability.

Data is available

upon Request.

Funding

This research received no external funding.

References

Abalansa, S., El Mahrad, B., Icely, J., & Newton, A. (2021). Electronic waste, an environmental problem exported to developing countries: The good, the bad and the ugly. *Sustainability (Switzerland)*, 13(9), 1–24. doi: 10.3390/su13095302

Agamuthu, P. (2013). Landfilling in developing countries. *Waste Management and Research*, 31(1), 1–2. doi: 10.1177/0734242X12469169

Al-khatib, I. A., Arafat, H. A., Basheer, T., & Shawahneh, H. (2007). Trends and problems of solid waste management in developing countries : A case study in seven Palestinian districts. *Waste Management*, 27(12), 1910–1919. doi: 10.1016/j.wasman.2006.11.006

Al-Khatib, I. A., Monou, M., Abu Zahra, A. S. F., Shaheen, H. Q., & Kassinos, D. (2010). Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district - Palestine. *Journal of Environmental Management*, 91(5), 1131–1138. doi: 10.1016/j.jenvman.2010.01.003

Aliu, I. R., Adeyemi, O. E., & Adebayo, A. (2014). Municipal household solid waste collection strategies in an African megacity: Analysis of public private partnership performance in Lagos. *Waste Management and Research*, 32(9), 67–78. doi: 10.1177/0734242X14544354

Arantes, V., Zou, C., & Che, Y. (2020). Coping with waste : A government-NGO collaborative governance approach in Shanghai. *Journal of Environmental Management*, 259, 109653. doi: 10.1016/j.jenvman.2019.109653

Aremu, A. S., Sule, B. F., Downs, J., & Mihelcic, J. R. (2012). Framework to Determine the Optimal Spatial Location and Number of Municipal Solid Waste Bins in a Developing World Urban Neighborhood. *Journal of Environmental Engineering*, 138, 645–653. doi: 10.1061/(ASCE)EE.1943-7870

Banerjee, S., & Sarkhel, P. (2020). Municipal solid waste management , household and local government participation : a cross country analysis. *Journal of Environmental Planning and Management*, 63(2), 210–235. doi: 10.1080/09640568.2019.1576512

Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N., & Tarsenis, S. (2010). Assessing multiple criteria for the optimal location of a construction and demolition waste management facility. Building and Environment, 45(10), 2317–2326. https://doi.org/10.1016/j.buildenv.2010.04.016

Berglund, P. G., & Kwon, C. (2014). Robust Facility Location Problem for Hazardous Waste Transportation. *Networks and Spatial Economics*, 14(1), 91–116. doi: 10.1007/s11067-013-9208-4

Blanchard, C., Harris, P., Pocock, C., & Mccabe, B. K. (2023). Food and Garden Organic Waste Management in Australia : Co-Benefits for Regional Communities and Local Government by Comm Processes. *Sustainability*, 15, 9901. doi: 10.3390/su15139901

BPS Karanganyar. (2018). *Kabupaten Karanganyar dalam Angka*. BPS Karanganyar.

Brotosusilo, A., Nabila, S. H., Negoro, H. A., & Utari, D. (2020). The level of individual participation of community in implementing effective solid waste management policies. *Global Journal of Environmental Science and Management,* 6(3), 341–354. doi: 10.22034/gjesm.2020.03.05

Brylian, B. (2018). *Analisis Penentuan Lokasi Tempat Pembuangan Sementara (TPS) Sampah di Kabupaten Klaten dengan Metode P-Dispersion*. Universitas Muhammadiyah Surakarta.

Cagliano, A. C., Pilloni, M. T., & Rafele, C. (2014). A multi-criteria fuzzy method for selecting the location of a solid waste disposal facility. *International Journal of Management and Decision Making*, 13(3), 221–249. doi: 10.1504/IJMDM.2014.063568

Chauhan, A., & Singh, A. (2016). A hybrid multi-criteria decision making method approach for selecting a sustainable location of healthcare waste disposal facility. *Journal of Cleaner Production*, 139, 1001–1010. doi: 10.1016/j.jclepro.2016.08.098

Chisholm, J. M., Zamani, R., Negm, A. M., Said, N., Abdel daiem, M. M., Dibaj, M., & Akrami, M. (2021). Sustainable waste management of medical waste in African developing countries: A narrative review. *Waste Management and Research*, 39(9), 1149–1163. doi: 10.1177/0734242X211029175

Dan, Y., Dan, T., Huynh, X., & Dung, T. (2021). Understanding the role of informal sector for sustainable development of municipal solid waste management system : A case study in Vietnam. *Waste Management*, 124, 118–127. doi: 10.1016/j.wasman.2021.01.033

Defu, L., Huajun, L., Guilin, L., Hongda, S., & Fengqing, W. (2013). *Typhoon/ Hurricane/ Tropical Cyclone Disasters: Prediction, Prevention and Mitigation. In B. Raskovic & S. Mrdja (Eds.), Natural Disasters: Prevention, Risk Factors and Management*. Nova Science Publishers, Inc.

Djunaidi, M., Angga, & Setiawan, E. (2018). Disposal Site Selection Using TOPSIS in Wonogiri District Central Java. *Jurnal Ilmiah Teknik Industri*, 17(1), 62–70. doi: 10.23917/jiti.v17i1.5389

Erkut, E., Karagiannidis, A., Perkoulidis, G., & Tjandra, S. A. (2008). A multicriteria facility location model for municipal solid waste management in North Greece. *European Journal of Operational Research*, 187(3), 1402–1421. doi: 10.1016/j.ejor.2006.09.021

Finkelman, R. B. (2004). Potential health impacts of burning coal beds and waste banks. *International Journal of Coal Geology*, 59(1–2), 19–24. doi: 10.1016/j.coal.2003.11.002

Ghiani, G., Laganà, D., Manni, E., & Triki, C. (2012). Capacitated location of collection sites in an urban waste management system. *Waste Management*, 32(7), 1291–1296. doi: 10.1016/j.wasman.2012.02.009

Giusti, L. (2009). A review of waste management practices and their impact on human health. *Waste Management*, 29(8), 2227–2239. doi: 10.1016/j.wasman.2009.03.028

Henry, R. K., Yongsheng, Z., & Jun, D. (2006). Municipal solid waste management challenges in developing countries - Kenyan case study. *Waste Management*, 26(1), 92–100. doi: 10.1016/j.wasman.2005.03.007

Ifan, H. K., Dou, J. M., Manullang, S., & Dou, H. (2004). Developing competitive technical intelligence in Indonesia. *Technovation*, 24(12), 995–999. doi: 10.1016/S0166-4972(03)00069-5

Johnson, R. J., & Scicchitano, M. J. (2012). Don't Call Me NIMBY. *Environment and Behavior*, 44(3), 410–426. doi: 10.1177/0013916511435354

Johnson, T., Lora, A., & Jixia, W. (2018). The quest for environmental justice in China : citizen participation and the rural – urban network against Panguanying ' s waste incinerator. *Sustainability Science*, 13(3), 733–746. doi: 10.1007/s11625-018-0545-6

Karak, T., Bhagat, R. M., & Bhattacharyya, P. (2012). Waste Generation , Composition , and Management : The World Scenario Municipal Solid Waste Generation , Composition , and Management : Critical Reviews in Environmental Science and Technology. *Critical Reviews in Environmental Science and Technology*, 42(15), 1509–1630. doi: 10.1080/10643389.2011.569871

Kennes, C., & Thalasso, F. (1998). Review: Waste gas biotreatment technology. *Journal of Chemical Technology and Biotechnology*, 72(4), 303–319. doi: 10.1002/(SICI)1097-4660(199808)72:4<303::AID-JCTB903>3.0.CO;2-Y

Krook, J., Svensson, N., & Eklund, M. (2012). Landfill mining : A critical review of two decades of research. *Waste Management*, 32(3), 513–520. doi: 10.1016/j.wasman.2011.10.015

Kubanza, N. S., Das, D. K., & Simatele, D. (2017). Some happy, others sad: exploring environmental justice in solid waste management in Kinshasa, The Democratic Republic of Congo. *Local Environment*, 22(5), 595–620. doi: 10.1080/13549839.2016.1242120

Kusuma, J. V. (2017). *Penentuan Lokasi Ideal Tempat Penampungan Sementara (TPS) Sampah dengan Metode P Median di Wilayah Karanganyar.* Universitas Muhammadiyah Surakarta.

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M. Z., & Christensen, T. H. (2014). Review of LCA studies of solid waste management systems – Part I : Lessons learned and perspectives. *Waste Management*, 34(3), 573–588. doi: 10.1016/j.wasman.2013.10.045

Lestari, P., & Trihadiningrum, Y. (2019). The impact of improper solid waste management to plastic pollution in Indonesian coast and marine environment. *Marine Pollution Bulletin*, 149, 110505. doi: 10.1016/j.marpolbul.2019.110505

Litmanen, T. (1999). Cultural approach to the perception of risk: analysing concern about the siting of a high-level nuclear waste facility in Finland. *Waste Management & Research*, 17(3), 212–219. doi: 10.1177/0734242X990170030

Maharani, E. A. (2018). *Penentuan Alternatif Lokasi Tempat Penampungan Sementara (TPS) di Kabupaten Klaten Menggunakan Metode P-Center*. Universitas Muhammadiyah Surakarta.

Mantzaras, G., Voudrias, E. A., Aamer Khalil, M., Suliman, S. M., Agamuthu, P., Al-Anbari, M. A., Thameer, M. Y., Al-Ansari, N., Argoubi, M., Jammeli, H., Masri, H., Aydemir-Karadag, A., Bid, S., Siddique, G., Bundhoo, Z. M. A., Chisholm, J. M., Zamani, R., Negm, A. M., Said, N., … Hogland, W. (2019). The intellectual structure of the waste management field. *Journal of Material Cycles and Waste Management*, 23(1), 2051–2064. doi: 10.1007/s10163-018-0728-3

Manzoor, J., & Sharma, M. (2019). Impact of biomedical waste on environment and human health. *Environmental Claims Journal,* 31(4), 311–334. doi: 10.1080/10406026.2019.1619265

Mateos, R. M., Garcia-Moreno, I., Herrera, G., & Mulas, J. (2013). Losses Caused by Recent Mass-Movements in Majorca (Spain). In C. Margottini, P. Canuti, & K. Sassa (Eds.), Landslide Science and Practice Volume 7: Social and Economic Impact and Policies. *Springer*, 7(333).

McCunney, R. J. (1986). Health Effects of Work at Waste Water Treatment Plants : A Review of the Literature With Guidelines for Medical Surveillance. *Am J Ind Med*., 279, 271–279. doi: 10.1002/ajim.4700090310

Murdock, S. H., Spies, S., Effah, K., White, S., Krannich, R., Wulfhorst, J. D., Wrigley, K., Leistritz, F. L., & Sell, R. (1998). Waste Facility Siting in Rural Communities in the United States: An Assessment of Impacts and Their Effects on Residents ' Levels Of Support/ Opposition. *Journal of the Community Development Society*, 29(1), 90–118. doi: 10.1080/15575339809489775

Owusu, G. (2010). Social effects of poor sanitation and waste management on poor urban communities : a neighborhood-specific study of Sabon Zongo , Accra. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 3(2), 145–160. doi: 10.1080/17549175.2010.502001

Putra, A. N. H. (2017). *Penerapan Metode P-Median dalam Penentuan Lokasi Optimal Tempat Penampungan Sementara (TPS) Sampah di Kabupaten Klaten*. Universitas Muhammadiyah Surakarta.

Setiawan, E. (2016). *Can resource sharing improve disaster response effectiveness? Evidence from west sumatra earthquake*. Proceedings of the International Conference on Industrial Engineering and Operations Management, 8-10 March, 1104–1113.

Setiawan, E., Liu, J., & French, A. (2019). Resource location for relief distribution and victim evacuation after a sudden-onset disaster. *IISE Transactions*, 51(8), 830–846. doi: 10.1080/24725854.2018.1517284

Setiawan, E., Nugrahadi, B., Widiyastuti, Y., & Djunaidi, M. (2018). Positioning household waste transfer points: A municipality government - organized waste perspective. *Sustinere: Journal of Environment and Sustainability*, 2(2), 76–85. doi: 10.22515/sustinere.jes.v2i2.41

Sulistyawan, G. A. (2017). *Penerapan Metode Set Covering dalam Site Positioning Tempat Penampungan Sementara (TPS) Sampah di Wilayah Karanganyar*. Universitas Muhammadiyah Surakarta.

Susy Susanty, Yuni Triani, H. P. (2012). *Usulan Perbaikan Penentuan Lokasi Tempat Pembuangan Sementara (TPS) Sampah Menggunakan Metode Set Covering Problem (SCP) (Studi Kasus di PD . Kebersihan Wilayah Operasional Bandung Barat)*. Prosiding Seminar Nasional Teknoin 2012 ISBN No . 978-979-96964-3-9, 978, 195–202.

Treacy, J. (2022). Policy Implementation on Waste Management and Achievement of Related SDGs BT - SDGs in the European Region. In W. Leal Filho, M. A. P. Dinis, S. Moggi, E. Price, & A. Hope (Eds.), Implementing the UN Sustainable Development Goals – Regional Perspectives (1–29). *Springer International Publishing*. doi: 10.1007/978-3-030-91261-1_35-1

UNEP. (2024). Beyond an age. Turning rubbish into a resource. United Nations Environment Programme. Retrieved from https://wedocs.unep.org/handle/20.500.11822/44939

Vaverková, M. D. (2019). Landfill impacts on the environment— review. *Geosciences (Switzerland),* 9(10), 1–16. doi: 10.3390/geosciences9100431

Wang, Y., Lai, N., Zuo, J., Chen, G., & Du, H. (2016). Characteristics and trends of research on waste-to-energy incineration : A bibliometric analysis , 1999 – 2015. *Renewable and Sustainable Energy Reviews*, 66, 95–104. doi: 10.1016/j.rser.2016.07.006

Yu, H., & Solvang, W. D. (2017). A multi-objective location-allocation optimization for sustainable management of municipal solid waste. *Environment Systems and Decisions*, 37(3), 289–308. doi: 10.1007/s10669-017-9632-y

Yuan, H., & Shen, L. (2011). Trend of the research on construction and demolition waste management. *Waste Management*, 31(4), 670–679. doi: 10.1016/j.wasman.2010.10.030

Yukalang, N., Clarke, B., & Ross, K. (2017). Barriers to Effective Municipal Solid Waste Management in a Rapidly Urbanizing Area in Thailand. *International Journal of Environmental Research and Public Health*, 14, 1013. doi: 10.3390/ijerph14091013

Zaman, A. U. (2015). A comprehensive review of the development of zero waste management: Lessons learned and guidelines. *Journal of Cleaner Production*, 91, 12–25. doi: 10.1016/j.jclepro.2014.12.013

Zhang, L., & Chen, J. (2018). Measuring the NIMBY effect in urban China: the case of waste transfer stations in metropolis Shanghai. *Journal of Housing and the Built Environment*, 33(1), 1–18. Doi : 10.1007/s10901-017-9565-2

Ziraba, A. K., Haregu, T. N., & Mberu, B. (2016). A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. *Archives of Public Health*, 74(55), 1–11. doi: 10.1186/s13690-016-0166-4