Which One is Best? Household Solid Waste Collection Facility Siting in a Developing Countries' Autonomous Region

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Abstract

In many developing countries, the regencies in them have a relatively high degree of autonomy one of which is related to rights to place capacitated waste collection facilities from which the waste is conveyed to final waste clearance facilities. The rights include the management of waste generated by the waste producers at some places yet, due to limited budget, do not touch the waste management at this lowest level at other places. Given the growing importance and emergence of waste-related issues, the paper deals with the problem of siting household solid waste collection facilities within the context of an autonomous region. A waste-weighted P-median, a pure P-median, a P-centre, a P-dispersion and a "distance gap" models are proposed for the problem. By using data obtained from Karanganyar Regency, the Republic of Indonesia, as a problem context, the paper concludes that the best model for the siting problem in such regions is driven by the objective of the siting itself. Moreover, the paper suggests that collection facilities with large capacities should be given a lot more attention in terms of having anticipation to the demand of household solid waste the regions will have in the future.

1. Introduction

In many developing countries, the regencies in them have a relatively high degree of autonomy, in such a way that the authority in the regencies has a wide spectrum of rights to govern their regency. This includes the authority to place capacitated waste collection facilities from which the waste is conveyed to final waste clearance facilities. In some places, the rights include the management of waste at its lowest level: the waste generated by the waste producers. It is nonetheless empirical at other places that, due to limited budget, the rights do not touch the waste management at this lowest level. Household solid waste is not an exception. In the first case, the collection of household solid waste and its transportation to solid waste collection facilities is carried out by an agency responsible for it. In the second circumstance, it is frequently found that the household solid waste producers have to transport the waste they produce to solid waste collection facilities provided by the authority.

In general, importance and emergence of waste-related issues grow over time [1]–[7]. Waste creates a variety of risks for the people living in the surrounding area [8]–[10] or, otherwise, is seeming to be dangerous to neighboring residents [11], [12]. Landslide [13], disturbance to micro hydro power station [14] and negative impacts to land resources and environment (Wang et al. 2010), to name a few, are examples of serious problems resulted from bad waste management. More specifically, poor management of household solid waste leads to a variety of mishaps (Giusti, 2009; Laurent et al., 2014; Tai et al., 2011). The mishaps are even critical in developing countries (Al-khatib et al., 2007; Henry et al., 2006; Oteng-ababio et al., 2013; Owusu, 2010; Pasang et al., 2007; Troschinetz & Mihelcic, 2009). With regard to developing countries, it is sadly revealed that studies on waste management practices are very rare (Laurent et al., 2014).

In response to the existence of the waste, one of the options available is by presenting waste facility treatments. The establishment of household solid waste collection facilities can be seen as part of this kind of response. The establishment is even more important in the presence of a drastically growing household solid waste production, a circumstance occurring in many places around the world.

People concerned with waste-caused problems are already familiar with operations research techniques and methods as well as multi-criteria decision making approaches in aiding the management of waste (see, for instance, (Banias, Achillas, Vlachokostas, Moussiopoulos, & Tarsenis, 2010; Berglund & Kwon, 2014; Cagliano & Torino, 2014; Chauhan & Singh, 2016; Erkut, Karagiannidis, Perkoulidis, & Tjandra, 2008; Taylor, Korucu, Arslan, & Karademir, 2013; Taylor, Korucu, Karademir, Korucu, & Karademir, 2014)). In particular, the use of location models in waste operation context is abundant, including P-centre model [32], P-dispersion model [33], set covering models [34]–[36], P-median models [37], [38], and a mixture of them [39], [40].

Presenting a combination of location models applied to a given context of waste facility siting problem and contrasting the performance of the models, nonetheless, is none found. Still in waste facility siting context, the presence of autonomy of a region is indicative (see, e.g, [32], [33], [35], [37], [41]).

This paper addresses the problem of placing household solid waste collection facilities taking place in Karanganyar Regency, an autonomous region located in Central Java, the Republic of Indonesia. In doing so, a P-centre model, two P-median models, a P-dispersion model and a modified P-centre and P-dispersion model are used. The siting configuration resulted by the implementation of each of the model is subsequently presented and discussed. From the study, it is hoped that a general insight applicable for similar autonomous region in any developing countries can be obtained.

The rest of the paper is presented as follows. Section 2 presents a brief narration about the problem context. Proposed mathematical models for the problem are provided in Section 3. Results of the models' implementation to the problem context are discussed in Section 4. The paper ends with conclusion in Section 5.

2. Problem Context

Karanganyar Regency is one of the autonomous regencies in Central Java, Indonesia. Located between 70'28" and 70'46" south latitude and 110'40" and 110'70" east longitude [42], the regency consists of 17 Sub-Regencies, 162 villages, 15 kelurahan, 1,117 dusun and 2,323 dukuh (BPS Karanganyar 2018). With a total area of 773.79 km2, around half of the Greater London area, the regency was expected to be inhabited by 871,596 residents in 2017 [42]. In terms of waste management, the Ministry of Environment Agency in Karanganyar Regency is responsible for household solid waste in the regency. According to the agency [43], [44], it is is in control of household solid waste resulted by the Sub-Regencies of Tawangmangu, Karanganyar, Tasikmadu, Jaten, Colomadu, Gondangrejo, Karangpandan and Kebakkramat. The remaining sub-regencies are concluded as being able to take care of the household solid waste they produce and therefore they do not need the Agency's operation in their areas. From 2016 secondary data obtained by [43] and [44], there were 56 household waste collection facilities in the 8 sub-regencies of the regency. Among the 56 facilities, fieldworks carried out [43], [45] revealed that some of the facilities did not really exist and 10 facilities are exclusively devoted for certain communities. For these reasons, the facilities chosen as alternatives for selection in the current paper were reduced into 36 facilities and are named alternatives for household solid waste collection facilities (and from now on are being shorted as WCFs). In year 2016, the agency was in control of household solid waste produced by 39 villages and kelurahan and the aforementioned 10 community-devoted waste facilities in the 8 sub-regencies [43], [44]. These 39 villages and kelurahan and 10 community-devoted waste facilities are furthermore used as units of household solid waste producers in this paper (and are henceforth being shorted as WPs).

Table 1 provides data on the WPs in year 2016 and projected year 2026 rounded into two decimal places. Data on the WPs in year 2016 were obtained by multiplying number of inhabitants at each WP with 1.45 liters of waste produced by an individual in one day. In this case, the 1.45-liter figure was obtained from the ratio of total waste produced in July 2016 (in m3) and total population of Karanganyar Regency (in individual) in the same month.

The year 2026 data, meanwhile, were obtained by firstly making forecast on total waste produced in the year 2026 by using total waste data from year 2010 to year 2016. The approximation on waste production by each of the WPs in year 2026 comes from the estimate of waste production in year 2026 multiplied by population proportion of each WPs. In this sense, the proportion comes from the division of population in the WPs in year 2016 and the estimate of the total population in the same year. The estimates of population of which WPs are actually WCFs are made by assuming that each WCF produces 6.00 m3 of household solid waste. With this assumption, the estimate of the population is simply the 6.00 m3 figure divided by (1000/1.45) individual/ m3 = 4138 individuals.

Table 1
Data on WP alternatives

WP alternative	Location		2016 population (in individual)	2016 waste volume (in m3)	2026 waste volume (in m3)
	Sub-regency/ community	Village/ Kelurahan			
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

WP alternati-ve	Location		2016 population (in individual)	2016 waste volume (in m3)	2026 waste volume (in m3)
	Sub-regency/ community	Village/ Kelurahan			
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		Klodran	5,555	8.05	12.06
33	Gondangrejo	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		Tuban	7,077	10.26	15.37
38	Kebakkramat	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**

Table 2 provides data on the WCFs. The geographical coordinate for each of the WCFs was identified by using Google map. Along with geographical coordinate for each of the WPs, the coordinates were used to get travelling time distances (and are henceforth being shorted as “distances”) between each of the WPs and each of the SWCSs. In this circumstance, the capacity of each alternative for WCFs, the coordinates and the “distances” were from the field works carried out by [43] and [44].

Table 2
Data on WCFs

WCF	Sub-regency	Location	Coordinate	Capacity (in m3)
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

WCF	Sub-regency	Location	Coordinate	Capacity (in m3)
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**

3. Mathematical Models

In order to deal with the problem, 5 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 aiming at obtaining a minimum distance between a maximum "distance" and a minimum one (and is henceforth called a "distance gap" model). The models are defined under the light of the following sets, parameters and decision variables.

Sets:

I = set of WPs;

J = set of alternatives for WCFs;

Parameters:

P = maximum number of WCFs to establish;

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 minimized;

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

With all of the abovementioned sets, parameters and decision variables, the full model of the waste-weighted P-median can be presented as follows.

Objective function:

min $\sum_i \sum_j V_i t_{ij} Y_{ij}$ .... (0a)

Constraints:

$$\sum_j X_j \leq P$$

1

....

$Y_{ij} - X_j \leq 0$, $\forall i \epsilon I, j \epsilon J$ .... (2)

$\sum_j Y_{ij} = 1$, $\forall i \epsilon I$ .... (3)

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

$$X_j, Y_{ij} \epsilon \{0, \ 1\} , \forall i I, j \epsilon J$$

5

....

Constraint (0a) dictates that the objective of the model is to minimize total waste-weighted "distance". Constraint (1) requires the total number of WCF to open to be equal to a certain value. The need that a particular WP can only be served by an open WCF is represented by constraints (2), whereas constraints (3) state that each WP should be served by exactly one open WCF. Constraints (4) necessitate that service of a WCF cannot exceed its capacity. Decision variables should be binary, and this requirement is reflected by constraints (5).

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

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

The P-centre model, on the other hand, is defined by constraints (1)–(5) and constraints (6), with the objective function appearing in constraint (0C). What follows is the full model.

Objective function:

min W_{max} .... (0c)

Constraints:

Constraints (1)–(5)

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

The model aims to minimize a maximum “distance” – as reflected by constraint (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 maximize a minimum “distance” – as reflected by constraint (0d) -, given the existence of constraints (1)–(5) and any possible values for the minimum “distance” (see constraints (7)).

max W_{min} .... (0d)

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

Finally, the proposed “distance gap” model minimizes 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 constraint (0e). The model is defined on constraints (1)–(7).

min $W_{max} - W_{min}$ .... (0e)

4. Results And Discussion

All the 5 models are subsequently applied to the data available. In this case, maximum number of WCFs to establish is set 36. The model implementation is carried out by using Lingo 11 software. Table 3 summarizes the results of the model implementation to the data. The results of the implementation in year 2016 is available at Table 4. Table 5, in the meantime, gives summary of the results in association with year 2026.

From the output of the model implementation, it is found that waste volume produced is still manageable. This is indicated by its total value which is still less than total capacity of WCFs selected. It is also clear from the implementation that increasing volume of the household solid waste leads to increasing total capacity of WCFs selected and decreasing unused capacity of the same WCFs. Increasing volume of the household solid waste also leads to increasing total waste-weighted “distance” on one hand and, on the other hand, is not always parallel to increasing total number of WCFs selected.

The model implementation suggests that the best model is driven by the objective of the site positioning. Siting facilities with the objective of minimizing total waste-weighted “distance” can be obtained by the use of the waste-weighted P-median model. The use of the pure P-median model is best for achieving a minimum value of total pure “distance“ of waste collection facility siting. The two models are suitable in a situation where the waste is collected b a single authoritative body (such as the cases in [19], [41] and [21]) and, at the same time, the existence of such household solid waste collection facilities are welcomed or are perceived not dangerous (such as those mentioned in [46]). The waste-weighted “distance” model is suitable in a situation where the waste production quantity varies highly over the region (see, e.g.,[19], [41] and [21]), whereas the pure “distance” model is appropriate for a region where the waste production quantity is relatively the same over the region. Siting facilities with the objective of achieving a minimum largest “distance” and at the same time as fair as possible is best approached with the P-centre model, whereas the waste collection siting objective of obtaining a maximum smallest “distance” and at the same time as fair as possible is best approached with the P-dispersion model. These two models fit the circumstance where inhabitants in surrounding areas have to send household solid waste they produce to waste collection facilities (see, e.g., [27] and [47]). The P-centre model fits the situation where the presence of household solid waste collection facilities is welcomed by the communities around the facilities or the facility alternatives are far from residences. The P-dispersion model, on the other hand, is appropriate in the existence of NIMBY syndrome (such as that available in [48] or, in general, given the presence of environmental justice issue (see, for instance, [49]). Siting facilities of which main objective is achieving a relatively equal pure “distance” is best achieved with the employment of the “distance gap” model. This model is a mixture of the P-centre model and the P-dispersion model.

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 m3	1,322.00 m3	1,008.00 m3	1,293.00 m3	1,436.00 m3
	2026	1,358.00 m3	1,388.00 m3	1,234.00 m3	1,364.00 m3	1,360.00 m3
Unused capacity of the selected WCFs	2016	866.11 m3	860.11 m3	546.11 m3	831.11 m3	974.11 m3
	2026	666.23 m3	696.23 m3	542.23 m3	672.23 m3	668.23 m3
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

Indicator	Year	Waste-weighted *P*-median	Pure *P*-median	*P*-centre	*P*-dispersion	“Distance gap”
	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

For whatever situation, the site positioning policy should take into account the impact of the positioning to the residents [50]. The site positioning should be put in a broader context of waste management in such a way that every stakeholder is in acceptance position.

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, 34	19, 34, 46	17, 19, 32	5, 8, 16, 38	9, 13, 21, 42
2	40, 46	40	3, 10, 46	36, 47	11
3	23	23	5, 14	22	28, 32
4	2	2	13, 27		18, 46
5			2, 15, 31, 43	1, 6, 49	6, 12
6	27, 42	27, 42	16, 23, 33, 42, 47	9, 10, 12, 20, 35, 37, 39	24, 37
7	6, 16, 31	6, 16, 31	11, 35		1, 22, 38, 41
8				24, 30, 32	30
9	3, 43	3, 43	21, 36	25, 48	36
10	7, 10, 11, 15, 20	7, 10, 11, 15, 20		2, 28, 34, 42	14, 34
11	47	47	41		
12	24	24	24	13, 26	29
13	14	14	22, 39	19	17
14	35	35		17, 23, 40	39
15			12		
16				46	3
17			40		
18	8	8	25, 44	21	23
19	18	18	48		43, 47
20	4	4			25
21	17, 28, 37	17, 28, 37	8, 29, 38	11, 31	7
22	44	44		41	33
23	26, 33	26, 33	4, 30, 34	27, 29	31
24	38, 39	38, 39	28, 37	15	5

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"
25	48		26		45
26	21, 32	12, 21, 32		7, 14	8, 16, 19, 20, 35, 40
27	12	48			27
28	9, 25, 30, 36	9, 25, 30, 36	7	18, 33, 44, 45	2, 10
29			1	3	
30					
31	1	1			4
32	41	41			44
33	13	13			49
34	49	49	49		15
35	5, 22, 29, 45	5, 22, 29, 45	6, 9, 18, 20, 45	4, 43	48
36					26

With respect to year 2016 solely (see Table 4), the results of the model implementation show the following findings. Firstly, the alternatives selected in waste-weighted P-median (28 facilities) and pure P-median (27 facilities) are relatively the same. The only difference is alternative 25. The allocation of WP to the selected alternatives are also relatively indifferent. Secondly, alternatives 1, 2, 3, 6, 9, 12, 13, 18, 21, 23, 24, 26, 28, 35 are always selected by each of the model: Out of these, alternatives 1 and 6 seem to be the favorites for the models. Thirdly, alternative 30 is not selected by all the 5 models. In other words, the alternative is the least favorite for all the 5 models. Fourthly, alternatives with big capacities (1, 6, 10, 21, 26, 28, 35) serve more waste producers in most of the models. Alternative 10 is not selected in P-centre, possibly due to the fact that its "distances" to WPs are far. Alternative 1 is always selected by each of the models despite its relatively small capacity. It might be because of its relatively close "distance" to 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

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"
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 in year 2026 (see Table 5), in the meantime, several insights can be provided. Firstly, the alternatives selected in waste-weighted P-median (25 facilities) and pure P-median (27 facilities) are relatively the same. The only difference is alternative 3 and alternative 5. The allocation of WP to the selected alternatives are also relatively indifferent. Secondly, 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 model. Out of these, alternatives 1, 6, 7, 21, 35 seem to be the favorites in all models. Thirdly, it is appearing that alternatives 17, 20, 25, 29, 30, 31, 33, 36 are never selected by the models. Fourthly, alternatives with big capacities (1, 6, 7, 10, 21, 26, 28, 35) serve more waste producers in most of the models. Total number of WPs allocated to alternative 10 is not as high as that allocated to alternative 21, possibly due to the fact that its "distances" to WPs are far. Alternative 1 is always selected by each of the models despite its relatively small capacity. 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 m3, possibly due to the fact that the alternative, Klegen, is relatively "distant" to WPs compared to alternative 1, i.e. Fajar Indah Timur.

By contrasting the performance of each model within the 2016 and 2026 data, it is indicative that more than 40% (i.e. at least 15 out of 36) of WCF alternatives are selected in both data. Moreover, the siting configuration gives indication of shifting that the more the waste volume is, the more the alternatives with larger capacity is favored.

5. Conclusions

Following the analysis and discussion, it is found that the best model for the site positioning problem in an autonomous region is driven by the objective of the site positioning. The conclusion implies that any autonomous regions with autonomy similar to Karanganyar Regency, the Republic of Indonesia, or those with autonomy including the authority to take care of the waste management at its lowest level, should be firstly clear about what main objective they have when they want to locate their household solid waste facilities. Above all, the site positioning should be put in a broader context of waste management, such a way every stakeholder is in acceptance position.

By contrasting the performance of each model for the problem with the 2016 and the 2026 data, it is suggestive that more than 40% (i.e., at least 15 out of 36) of WCF alternatives are selected in both data. Moreover, the siting configuration gives indication of shifting that the more the waste volume is, the more alternatives with larger capacity is preferred. With this regard, it seems logical for any regions with similar household solid waste management to focus more on their waste facilities with large capacities in order to be anticipative to the future demand of household solid waste they will have.

Statements & Declarations

Declarations

Ethical Approval

Not applicable.

Competing Interests

The authors declare no conflict of interest.

Authors' Contributions

Eko Setiawan, Juang Victorio Kusuma and Ganang Adi Sulistyawan contributed to the study conception and design. Material preparation and data collection were carried out by Juang Victorio Kusuma and Ganang Adi Sulistyawan. Analysis was performed by Eko Setiawan and Septin Puji Astuti. The first draft of the manuscript was written by Eko Setiawan. Septin Puji Astuti commented on previous versions of the manuscript. All authors read and agreed on the final manuscript.

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Availability of data and materials

The data underlying this article are available in Table 1 (line 108) and Table 2 (line 116) in the article.

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