An Equity-based Positioning of Solid Waste Collection Sites for an Equitable Waste-induced Disaster Risk

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Abstract

This paper deals with the problem of having a service by solid waste collection sites for surrounding solid waste producers, in such a way that waste-induced disaster risk faced by the waste producers is relatively equal. To cope with the problem, a location mathematical model of which objective is minimizing the gap between maximum and minimum value of waste-induced disaster risk experienced by the waste producers is proposed in the paper. The model applicability is subsequently demonstrated by using a problem of having such a relatively fair service taking place in the autonomous Regency of Klaten, Central Java, Indonesia. From the application to 2015 problem context in the regency, it is concluded that Klaten Regency should build 32 solid waste collection sites in order to minimize the gap between maximum and minimum value of waste-induced disaster risk experienced by its 101 solid waste producers. The application of the same model to projected 2022 problem context in the same region, in the meantime, shows that having a minimum gap between maximum and minimum value of waste-induced disaster risk for the 101 solid waste producers can be obtained by establishing 33 solid waste collection sites. In general, it is conclusive that an equity-based positioning of solid waste collection sites for an equitable waste-induced disaster risk is possible to achieve.

Keywords
Equity, Location-allocation model, Site positioning, Solid waste, Waste-induced disaster risk.

1. Motivation

Equality is an issue of which importance grows over time. This includes equality on being exposed to disasters. This is especially crucial for people living in disaster-prone areas. It is generally accepted that waste is capable of becoming disastrous once it is not maintained well. Bad waste management results in severe problems such as landslide (Defu et al., 2013), disturbance to microhydro power station (Parlan, 2013) and harmful impacts to land resources and environment (Wang et al., 2010), to name a few.

In many countries, the existence of solid waste collection sites – to which residents in surrounding areas have to send solid waste they produce and from which the waste is subsequently transported to final waste disposal sites – is not new. It is also well known that people do not want to reside close to waste sites, a phenomenon known as NIMBY (not in my backyard) syndrome (see, for instance, Crozier and Hajzler, 2010; Feldman and Turner, 2010; Feldman and Turner, 2014; Wu et al., 2014). All of these facts lead to the need of positioning shared waste facilities relatively equally. This is even more important in the presence of a drastically growing 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 in aiding the management of waste. In particular, the use of location models in waste operation context is abundant (see, for instance, Erkut et al., 2008; Ghiani et al., 2012; Ojha et al., 2007; Korucu et al., 2013; Korucu and Karademir, 2014). It is clear from previous paragraphs that having waste facilities with relatively equal services to their users is of importance. Location models of p-center or p-dispersion, in the meantime, particularly aims at getting solutions with fairness for all parties. The search by the authors, however, found that the use of p-center models as well as p-dispersion ones on the positioning of waste facilities is not many (see, for instance, Maharani, 2018, and Brylian, 2018). This paper proposes a combination of p-center and p-dispersion models which is expected to give a configuration of solid waste collection sites in a region with relatively equal waste-induced disaster risk for all solid waste producers in the region.

The rest of the paper is presented as follows. Following the Introduction is a brief narration about the problem context. This is followed by a proposal of a mathematical model for the problem. The model applicability is subsequently tested by using a case study taking place in Klaten Regency, Central Java, Indonesia. The paper ends with Conclusion.

2. Problem Context

Usually a country consists of many regencies. In some countries, the regencies have a relatively high degree of autonomy, in such a way that the authorithy in the regencies has rights to govern their regency. This include the authority to place capacitated waste collection sites from which the waste is conveyed to final waste disposal facilities. At the same time, it is empirical that, due to limited budget, the rights does not touch the management of waste at its lowest level: the waste generated by the waste producers. Solid waste is not an exception. In this circumstance, it is frequently found that the solid waste producers have to transport the waste they produce to solid waste collection sites provided by the authority. Waste in general, at the same time, raises a variety of risks for the people living in the surrounding area (Finkelman, 2004; Owusu, 2010; Ziraba et al., 2016). Having this context and taking NIMBY syndrome into consideration, positioning intermediate facilities for solid waste by taking equality issue for the waste facility users becomes vital.

3. Mathematical Model

Having the problem context, a mathematical model is subsequently developed. In this regard, a total travelling distance between a solid waste producer in a region and all solid waste collection sites in the region weighted by the volume of solid waste produced by the waste producer is calculated. Among all total travelling distances, a maximum value and a minimum one for all the solid waste producers is considered. The gap between the two values is used as the equality measure.

What follows are sets, parameters, and decision variables defined for the mathematical model building.

Sets:
I: set of solid waste producers;
J: set of alternatives for solid waste collection sites;
Parameters:
P = total number of alternatives for solid waste collection sites;
V_{tot} = total volume of solid waste produced by all solid waste producers;
C_j = capacity of j^{th} alternative for solid waste collection sites;
V_i = waste volume of i^{th} solid waste producers.
Decision variables:
WW_{max} = maximum value of waste-weighted disaster risk;
WW_{min} = minimum value of waste-weighted disaster risk;

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

$$Y_{ij} = \begin{cases} 1, & \text{if solid waste producer } i \text{ is served by solid waste collection site } j \\ 0, & \text{otherwise} \end{cases};$$

$$Z_{ij} = \begin{cases} 1, & \text{if solid waste producer } i \text{ is connected to solid waste collection site } j \\ 0, & \text{otherwise} \end{cases}.$$

With all the above mentioned sets, parameters, and decision variables, the complete mathematical model is as follows.

Objective function:

$$\text{Min } WW_{max} - WW_{min}, \quad \ldots (0)$$

Constraints:

$$\sum_{j \in J} X_j \leq P, \quad \ldots (1)$$

$$\sum_{j \in J} C_j X_j \geq V_{tot}, \quad \ldots (2)$$

$$Z_{ij} - X_j = 0, \forall i \in I, j \in J, \quad \ldots (3)$$

$$\sum_{j \in J} V_i T_{ij} Z_{ij} - WW_{max} \leq 0, \forall i \in I, \quad \ldots (4)$$

$$WW_{min} - \sum_{j \in J} V_i T_{ij} Z_{ij} \leq 0, \forall i \in I, \quad \ldots (5)$$

$$X_j \in \{0, 1\}, \forall j \in J, \quad \ldots (6)$$

$$Y_{ij} \in \{0, 1\}, \forall i \in I, j \in J, \quad \ldots (7)$$

$$Z_{ij} \in \{0, 1\}, \forall i \in I, j \in J, \quad \ldots (8)$$

The objective of the model is to minimize the gap between maximum value and minimum one of waste-weighted disaster risk imposed to solid waste producers. This is reflected by Constraint (0).

The model ensures that the total number of solid waste collection sites to build does not surpass the total number of alternatives for the sites. Constraint (1) represents this necessity.

It is also necessary that the sites selected should give indication of having ability to handle the total volume of solid waste produced. This requirement is reflected by Constraint (2).

In order to be able to get the total travelling distance between a solid waste producer in a region and all solid waste collection sites in the region, Constraints (3) requires that each of the solid waste producers are connected to all selected solid waste facilities.

The gap as presented by the objective function is defined by a maximum value and a minimum one of waste-weighted disaster risk. Constraints (4) and Constraints (5) represent the values.

Finally, it is necessary that the decision to select an alternative for solid waste facilities or not, to allocate a solid waste producer to a selected solid waste facility, and to connect each of solid waste producers to all selected solid waste facilities is a “yes or no” decision. Constraints (6), Constraints (7) and Constraints (8) reflect this requirement.

4. Testing the Model Applicability

To test the model applicability, the model is implemented to the location problem within the context of Klaten Regency, Central Java, Indonesia. Klaten Regency is one of the autonomous regency in Indonesia consisting of 26 Sub-Regencies, 391 villages and 10 kelurahan (BPS Klaten, 2018). The regency is located between $7^0$32’19’’ into $7^0$48’33’’ south latitude and $110^0$26’14’’ into $110^0$47’51” east longitude (BPS Klaten, 2018). With a total area of 66,556 m^2, the regency was populatated by 1,167,401 inhabitants in 2016 (BPS Klaten, 2018). In year 2017, it was found that there were 101 waste-producing places, including villages, kelurahans, and market places in the centre of the regency (Putra, 2017). Based on data obtained from the same fieldwork in year 2017 (Putra, 2017), the regency had 161 solid waste collection sites spreading over its 26 Sub-Regencies. Among the sites, 54 ones are devoted to specific waste producers and are removed from further consideration. With all these regards, the 101 solid-waste producing places are used as units of solid waste producers in this test (and are being named SWPs from now on), whereas the remaining 107solid waste collection sites are used as alternatives for solid waste collection sites (and are henceforth being shorted as SWCSs).

Table 1 provides data on SWPs. Data on SWPs in year 2015 was obtained by multiplying number of population at each SWP with 2.5 liters of waste produced by an individual in one day. In this case, the 2.5-liter figure was obtained from the Ministry of Public Works at Klaten Regency and the Ministry of Energy and Mineral Resources at the same regency. The year 2022 data, on the other hand, was obtained by firstly making forecast on population growth by using population growth data from year 2001 to year 2015. The estimate of population growth in year 2022 was subsequently used to make approximation on waste production by each SWP in the same year.

Data on SWCSs is available in Table 2. In this case, the capacity of each alternative for solid waste collection sites was collected from a final year project carried out in year 2017 by Putra (2017).

In order to get a travelling distance between each of the SWPs and each of the SWCSs, a geographical coordinate for each of the SWPs and of the SWCSs was identified by using Google map. Due to limited space, nonetheless, these two kinds of data are not provided in this paper.

Table 1. Data on SWPs

No.	SWP	Waste (in m^3)		No.	SWP	Waste (in m^3)	
		2015	2022			2015	2022
1	Pasar Taji	3.9	4.1	52	Ds. Gatak	6.2	6.4
2	Pasar Menggah	3.0	3.1	53	Ds. Ciran	6.2	6.4
3	Pasar Wedi	6.0	6.2	54	Dk. Ceraken	2.7	2.8
4	Pasar Gempol	3.5	3.6	55	Perum. Karanganom 1	2.2	2.3
5	Desa Gadungan	6.3	6.5	56	Perum. Karanganom 2	2.2	2.3
6	Irobangsan	0.7	0.8	57	Pasar Jeblog	3.2	3.3
7	desa pandes	6.3	6.5	58	Pasar Jurangjero	3.0	3.1
8	Pasar Bayat	5.5	5.7	59	Pasar Ngendo	3.8	4.0
9	Pasar Cawas	9.8	10.1	60	Dk. Gringging	0.8	0.9
10	Dk. Kradenan	1.1	1.2	61	Pasar Sapi	2.5	2.6
11	Pasar Temuwangi	2.5	2.6	62	Pasar Gabus	2.5	2.6
12	Pasar Babad	2.5	2.6	63	Pasar Mranggen	2.5	2.6
13	desa jatipuro	9.9	10.2	64	Pasar Kembang	2.5	2.6
14	Pasar Gentongan	7.5	7.8	65	Pasar Surowono	2.5	2.6
15	Perum Kalikotes Baru	0.9	1.0	66	Dk.Jetis	1.0	1.1
16	Perum. Tambak Sari	0.9	1.0	67	Pasar Gayamprit	2.3	2.4
17	Genengan	0.9	1.0	68	Perum. Kota Baru	1.0	1.1
18	Dk. Gatak 1	0.9	1.0	69	Dk. Kaloran	1.0	1.1
19	Dk. Tambaksari	0.9	1.0	70	Dk. Sumberejo 1	1.0	1.1
20	Dk. Jagalan	0.9	1.0	71	Ds. Merbung 1	1.0	1.1
21	Dk. Tebon Gede	0.9	1.0	72	Perum. Danguran	1.0	1.1
22	Perum. Giya Cipta	0.9	1.0	73	Desa Danguran	9.9	10.2
23	Dk. Prigi Wetan	0.9	1.0	74	Gudang Sumberejo	1.0	1.1
24	Ds. Ngrundul	9.0	9.3	75	Ds. Trunuh	9.9	10.2
25	Ds. Basin	9.0	9.3	76	Dk. Tegalyoso	1.0	1.1
26	Dk. Balang	1.0	1.1	77	Ds. Tonggalan/Kali Golok	9.9	10.2
27	Desa Plawikan	9.6	9.9	78	Perum Glodogan	1.0	1.1
28	Pasar Kraguman	7.9	8.2	79	Ds. Glodogan	9.9	10.2
29	Pasar Srowot	5.0	5.2	80	Dk. Bendo	1.0	1.1
30	Desa Srowot	7.6	7.9	81	Dk. Padangan	1.0	1.1
31	Pasar Manisrenggo	5.0	5.2	82	Ds. Gumulan	33.4	34.4
32	Pasar Puluhwatu	4.8	5.0	83	Sungkur	1.5	1.6
33	Pasar Totogan	4.1	4.3	84	Pasar Srago	12.5	12.9
34	Dk. Drono	3.5	3.6	85	Pasar Klaten	15.0	15.5
35	Dk. Besole	3.5	3.6	86	Srago Gede	1.5	1.6
36	Pasar Klepu	1.5	1.6	87	Sendangan Mojayan 1	1.5	1.6
37	Desa Mondakan	8.2	8.5	88	Sekarsuli	1.5	1.6
38	Dk. Ngeseng	3.5	3.6	89	Dk. Plembon 1	1.0	1.1
39	Perum Kurung 1	3.5	3.6	90	Pasar Gergunung	2.5	2.6
40	jombor	8.2	8.5	91	Dk. Gergunung	1.0	1.1
41	Dk. Karwingan	3.5	3.6	92	Griya Prima	1.0	1.1
42	Perum PNS	8.2	8.5	93	Gading 1	1.0	1.1
43	Pasar Pedan	18	18.5	94	Perum. RSI	1.0	1.1
44	Pasar Karangdowo	3.6	3.7	95	Perumda Belangwetan 1	1.0	1.1
45	Pugeran	5.1	5.3	96	Perumda Belangwetan 2	1.0	1.1
46	Pasar Tanjung	6.0	6.2	97	Perumda Belangwetan 3	1.0	1.1
47	Desa Tanjung	7.1	7.3	98	Dk. Belangwetan	1.0	1.1
48	Pasar Serenan	6.0	6.2	99	Rusunawa	19.4	20
49	Desa Serenan	7.1	7.3	100	Pasar Plembon	1.8	1.9
50	Pasar Tegalgondo	5.5	5.7	101	Perum. Klaten Kencana	1.0	1.1
51	Perumahan Citra	2.7	2.8				

Table 2. Data on SWCSs

No.	Location	Capacity (in m^3)	No.	Location	Capacity (in m^3)
1	Pasar Taji	3.0	55	Pasar Serenan	12.0
2	Pasar Menggah	6.0	56	Pasar Tegalgondo	6.0
3	Pasar Wedi	20.0	57	Perumahan Citra	6.0
4	Pasar Gempol	6.0	58	Ds. Gatak	12.0
5	Desa Gadungan	24.0	59	Dk. Ceraken	6.0
6	Desa Pandes	9.0	60	Perum. Karanganom 1	6.5
7	Pasar Bayat	6.0	61	Perum. Karanganom 2	6.5
8	Pasar Cawas	8.0	62	Pasar Jeblog	9.0
9	Dk. Kradenan	3.0	63	Pasar Jurangjero	4.5
10	Pasar Temuwangi	5.0	64	Pasar Ngendo	15.0
11	Pasar Babad	6.0	65	Dk. Gringging	6.0
12	Desa Jatipuro 1	4.0	66	Pasar Sapi	4.5
13	Desa Jatipuro 2	4.0	67	Pasar Gabus	7.5
14	Desa Jatipuro 3	3.0	68	Pasar Mranggen	4.5
15	Pasar Gentongan	5.0	69	Pasar Kembang	6.0
16	Perum. Kalikotes Baru	6.0	70	Pasar Surowono	6.0
17	Perum. Tambak Sari	4.0	71	Dk. Jetis	5.0
18	Genengan 1	6.0	72	Pasar Gayamprit	9.0
19	Genengan 2	4.5	73	Perum. Kota Baru	6.0
20	Dk. Gatak 1	4.5	74	Dk. Kaloran	15.0
21	Dk. Tambaksari	3.0	75	Dk. Sumberejo 1	4.0
22	Dk. Jagalan	3.0	76	Ds. Merbung 1	60.0
23	Dk. Tebon Gede	4.0	77	Perum. Danguran	12.0
24	Perum. Giya Cipta	8.0	78	Desa Danguran	6.0
25	Dk. Prigi Wetan	3.0	79	Gudang Sumberejo	6.0
26	Ds. Ngrundul	3.0	80	Ds. Trunuh	16.0
27	Ds. Basin	20.0	81	Dk. Tegalyoso	6.0
28	Dk. Balang	2.0	82	Ds. Tonggalan/Kali Golok	20.0
29	Desa Plawikan	6.0	83	Perum Glodogan	6.0
30	Pasar Kraguman	12.0	84	Ds. Glodogan	5.0
31	Pasar Srowot	9.0	85	Dk. Bendo	2.0
32	Pasar Manisrenggo	9.0	86	Dk. Padangan	4.0
33	Pasar Puluhwatu	6.0	87	Ds. Gumulan	6.0
34	Pasar Totogan	6.0	88	Sungkur	6.0
35	Dk. Drono	5.0	89	Pasar Srago	16.0
36	Dk. Besole	4.5	90	Pasar Klaten	16.0
37	PUSPETA	12.0	91	Srago Gede	6.0
38	Dk. Mondakan	5.0	92	Sendangan Mojayan 1	7.5
39	Dk. Ngeseng	6.0	93	Sekarsuli	6.0
40	Perum Kurung 1	3.0	94	Dk. Plembon 1	6.0
41	Perum Kurung 2	3.0	95	Dk. Plembon 2	4.0
42	Jombor 1	4.0	96	Pasar Gergunung	28.0
43	Jombor 2	3.0	97	Griya Prima	12.0
44	Jombor 3	4.0	98	Gading 1	12.0
45	Jombor 4	5.0	99	Perum. RSI	4.0
46	Jombor 5	4.0	100	Perumda Belangwetan 1	3.0
47	Jombor 6	4.0	101	Perumda Belangwetan 2	4.0
48	Jombor 7	6.0	102	Perumda Belangwetan 3	4.0
49	Dk. Karwingan	2.0	103	Dk. Belangwetan	6.0
50	Perum PNS	6.0	104	Rusunawa	16.0
51	Pasar Pedan	20.0	105	Pasar Plembon	6.0
52	Ds. Sobayan	15.0	106	Perum. Klaten Kencana 1	6.0
53	Pasar Karangdowo 1	8.0	107	Perum. Klaten Kencana 2	4.0
54	Pasar Tanjung	8.0			

The mathematical model in Section 3 was finally tested by using the data already obtained. A programming code by using Lingo version 11.0 was developed in order to do the computational experiment.

From the experiment, it is revealed that, in year 2015, Klaten Regency should provide 32 solid waste collection sites with a total capacity of 441 m^3 in order to be able to serve its 101 solid waste producers with a total waste volume of 440.6 m^3, resulting in a minimum gap of 12073.8 m^3-minutes. The application of the same model to projected 2022 problem context in the same region, in the meantime, shows that having a gap of 13398.5 m^3-minutes for the 101 solid waste producers with a total waste volume of 458 m^3 can be obtained by establishing 33 solid waste collection sites with a total capacity of 458 m^3.

6. Conclusion

The paper deals with proposing an equity-based positioning of solid waste collection sites for the purpose of having such positioning with an equitable waste-induced disaster risk taken as the main consideration. It is shown in the paper that such site positioning is possible to achieve.

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