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 or justice (see, for instance, Pliefke 2008 and Zhang 2014) is an issue of which importance grows significantly over time. This includes equality on being exposed to disasters (see, for example, Tafti and Tomlinson 2018). 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, Afullo 2015; Crozier and Hajzler 2010; Feldman and Turner 2010; Feldman and Turner 2014; Flynn 201; Hsu 2006; Johnson and Scicchitano 2012; Sakai 2012; Wong 2016; Wu et al. 2014) or LULU (locally unwanted land use) (see, for example, Kim and Kim 2014; Nakazawa 2017, 2018; and Schively 2007). 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; Korucu et al. 2013; Korucu and Karademir 2014; Ojha et al. 2007). 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 authority 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 do 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) or, otherwise, is perceived to be risky to nearby inhabitants (Litmanen 1999; Murdock et al. 1998). In doing the facility placement, the authority should therefore take into account the issues of environmental justice (see, for example, Bevc et al. 2007; Gamper-Rabindran and Timmins 2011; Kubanza 2016; Lejano and Iseki 2001; Moreno-Jimenez 2016) as well as of spatial equity or spatial justice (see, for instance, Kim and Kim 2014 about spatial equity, or Soja 2010 and Pirie 1983 about spatial justice) for the society, two of the reasons are environmental criteria being found to be given priority in waste site selection (Moghaddas and Namaghi 2011; Zakaria et al. 2013) and spatial consideration is revealed as one of determining aspects in positioning waste facilities (Aremu et al. 2012; Kumar and Hassan 2013; Sener et al. 2011).

In a broader context, many research works gave a call for an environmentally and spatially just development and policy planning. The calls for an environmentally just development and policy planning came, for example, from the works of Akese and Little (2018), Johnson et al. (2018), Sicotte (2010), Dillon (2014), Huang et al. (2013), Cotton (2018), Pearce et al. (2010), Allen (2007) and Krutli et al. (2015). Research works by Roberts (2003) and Huang (2018), in the meantime, are examples of calls for a spatially equitable policy planning and development.

Having all of these issues and taking NIMBY syndrome as well as LULU phenomena into consideration, positioning collection sites for solid waste by taking equality issue for the waste facility users becomes vital and imperative.

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:

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

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

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

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

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

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

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

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

Overall, the paper proposes a way of dealing with solid waste positioning giving environmental justice as well as spatial equity in terms of the waste-induced disaster risk experienced by the waste producers. In this regard, the waste-induced disaster risk experienced by a waste producer is expressed as its total travelling distance to all solid waste collection sites multiplied by waste volume it produces. In addressing the just and equitable positioning, the paper follows this principle: "those who produce the solid waste should bear any negative effects caused by the waste; the larger the waste they produce, the more do the negative effects they should take". Additionally, the paper also avoid gap of waste-induced disaster risk experienced by the waste producers. The objective of the model is, therefore, a consolidation of these two principles, as reflected by Constraint (0). In this respect, travelling distance between two places is reflected by their travelling time.

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

The model applicability is tested by implementing it 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 655.56 km^2, nearly half of the Greater London area, the regency was populated 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 center 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 in this paper. 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 107 solid waste collection sites are used as alternatives for solid waste collection sites (and are henceforth being shorted as SWCSs).

Table 1 provides data on the SWPs. Data on the SWPs in year 2015 were 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.

Table 1. Data on SWPs

SWP	Location	Waste (in m^3)		SWP	Location	Waste (in m^3)	
		2015	2022			2015	2022
1	Pasar Taji	3.9	4.1	52	Desa Gatak	6.2	6.4
2	Pasar Menggah	3.0	3.1	53	Desa Ciran	6.2	6.4
3	Pasar Wedi	6.0	6.2	54	Dukuh 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	Dukuh Gringging	0.8	0.9
10	Dukuh 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	Dukuh 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	Dukuh Gatak 1	0.9	1.0	69	Dukuh Kaloran	1.0	1.1
19	Dukuh Tambaksari	0.9	1.0	70	Dukuh Sumberejo 1	1.0	1.1
20	Dukuh Jagalan	0.9	1.0	71	Desa Merbung 1	1.0	1.1
21	Dukuh 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	Dukuh Prigi Wetan	0.9	1.0	74	Gudang Sumberejo	1.0	1.1
24	Desa Ngrundul	9.0	9.3	75	Desa Trunuh	9.9	10.2
25	Desa Basin	9.0	9.3	76	Dukuh Tegalyoso	1.0	1.1
26	Dukuh Balang	1.0	1.1	77	Desa 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	Desa Glodogan	9.9	10.2
29	Pasar Srowot	5.0	5.2	80	Dukuh Bendo	1.0	1.1
30	Desa Srowot	7.6	7.9	81	Dukuh Padangan	1.0	1.1
31	Pasar Manisrenggo	5.0	5.2	82	Desa 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	Dukuh Drono	3.5	3.6	85	Pasar Klaten	15.0	15.5
35	Dukuh 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	Dukuh Ngeseng	3.5	3.6	89	Dukuh 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	Dukuh Gergunung	1.0	1.1
41	Dukuh 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	Dukuh 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				

The year 2022 data, on the other hand, were 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 of the SWPs in the same year.

Data on the SWCSs are 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 2. Data on SWCSs

SWCS	Location	Capacity (in m^3)	SWCS	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	Desa Gatak	12.0
5	Desa Gadungan	24.0	59	Dukuh 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	Dukuh Kradenan	3.0	63	Pasar Jurangjero	4.5
10	Pasar Temuwangi	5.0	64	Pasar Ngendo	15.0
11	Pasar Babad	6.0	65	Dukuh 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	Dukuh 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	Dukuh Gatak 1	4.5	74	Dukuh Kaloran	15.0
21	Dukuh Tambaksari	3.0	75	Dukuh Sumberejo 1	4.0
22	Dukuh Jagalan	3.0	76	Desa Merbung 1	60.0
23	Dukuh Tebon Gede	4.0	77	Perum Danguran	12.0
24	Perum Griya Cipta	8.0	78	Desa Danguran	6.0
25	Dukuh Prigi Wetan	3.0	79	Gudang Sumberejo	6.0
26	Desa Ngrundul	3.0	80	Desa Trunuh	16.0
27	Desa Basin	20.0	81	Dukuh Tegalyoso	6.0
28	Dukuh Balang	2.0	82	Desa Tonggalan	20.0
29	Desa Plawikan	6.0	83	Perum Glodogan	6.0
30	Pasar Kraguman	12.0	84	Desa Glodogan	5.0
31	Pasar Srowot	9.0	85	Dukuh Bendo	2.0
32	Pasar Manisrenggo	9.0	86	Dukuh Padangan	4.0
33	Pasar Puluhwatu	6.0	87	Desa Gumulan	6.0
34	Pasar Totogan	6.0	88	Sungkur	6.0
35	Dukuh Drono	5.0	89	Pasar Srago	16.0
36	Dukuh Besole	4.5	90	Pasar Klaten	16.0
37	PUSPETA	12.0	91	Srago Gede	6.0
38	Dukuh Mondakan	5.0	92	Sendangan Mojayan 1	7.5
39	Dukuh Ngeseng	6.0	93	Sekarsuli	6.0
40	Perum Kurung 1	3.0	94	Dukuh Plembon 1	6.0
41	Perum Kurung 2	3.0	95	Dukuh 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	Dukuh Karwingan	2.0	103	Dukuh Belangwetan	6.0
50	Perum PNS	6.0	104	Rusunawa	16.0
51	Pasar Pedan	20.0	105	Pasar Plembon	6.0
52	Desa 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. Figure 1 and Figure 2 provide the screenshots of the experiment's output with regard to the 2015 dataset, whereas the screenshots of the 2022 dataset-related computational experiment's output can be seen in Figure 3 and Figure 4.

From the figures, it is shown that both of the 2015 dataset and 2022 data have a total of 10,916 decision variables, 10,914 out which are integer ones. The same figures also provide information that each of the dataset has 11,012 constraints, none of them in nonlinear forms.

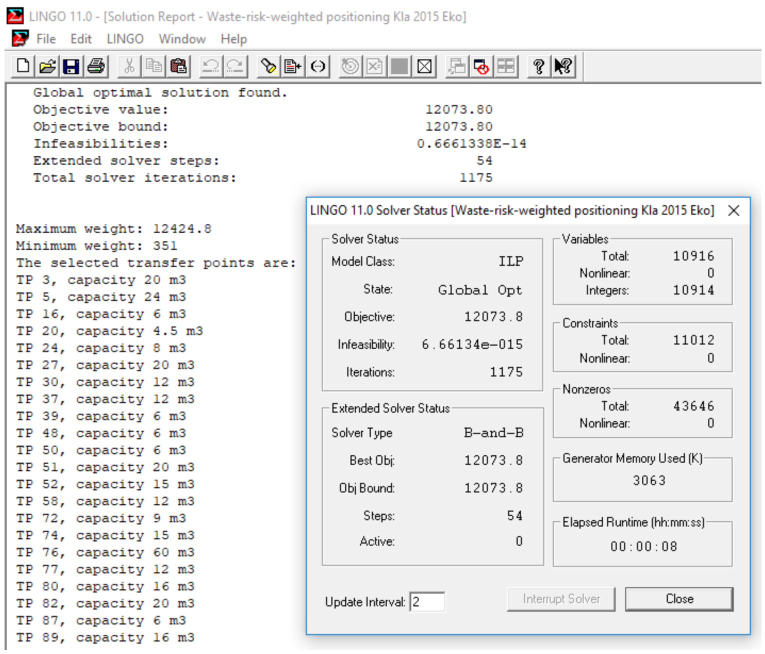

Figure 1. The 2015 dataset-related experiment: the optimal solution

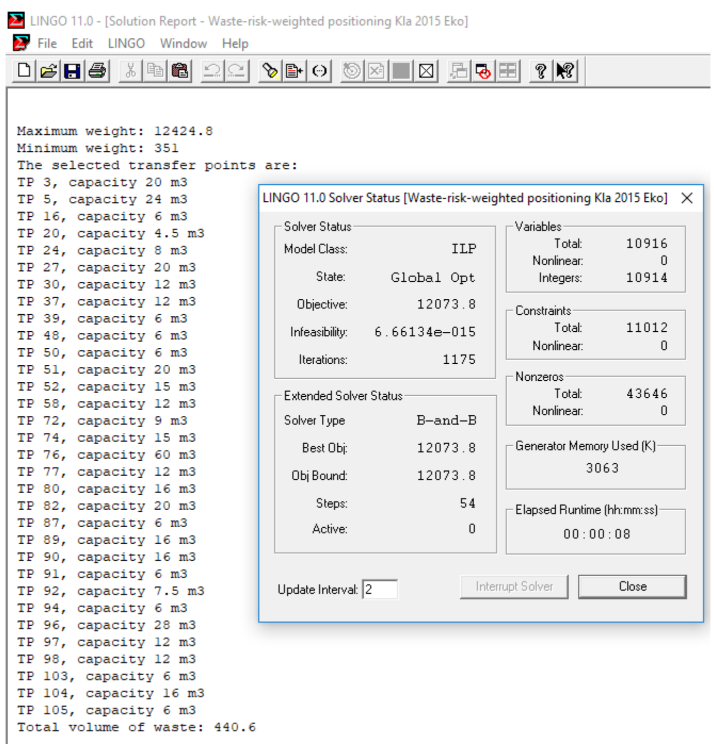

Figure 2. The 2015 dataset-related experiment: the selected alternative sites

Regarding the 2015 dataset, it is suggested by the experiment that 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. The minimum waste-induced disaster risk and the maximum one are 351 m^3-minutes and 12424.8 m^3-minutes, respectively, resulting in a minimum gap of 12073.8 m^3-minutes. The computational result came out in about 8 seconds of the experimental run. The solution is obtained within 1,175 iterations for the 2015 dataset.

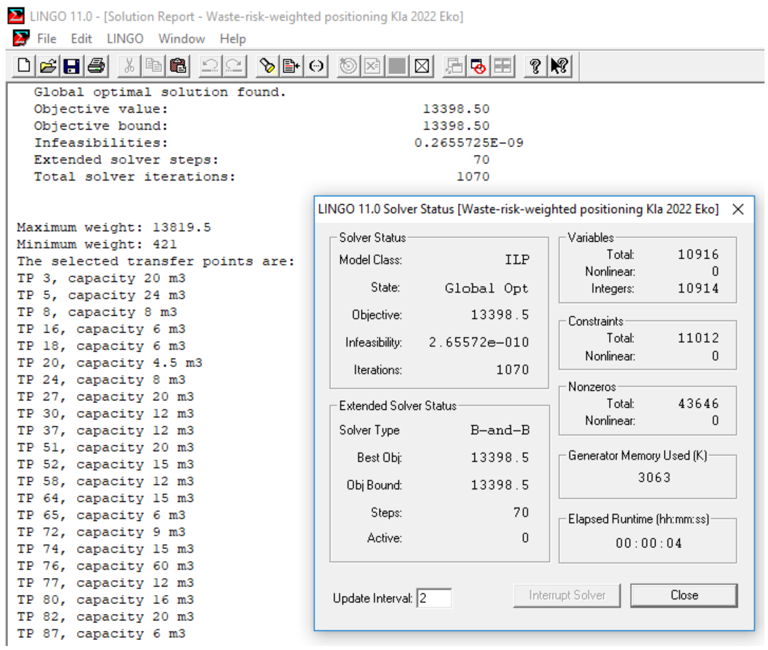

Figure 3. The 2022 dataset-related experiment: the optimal solution

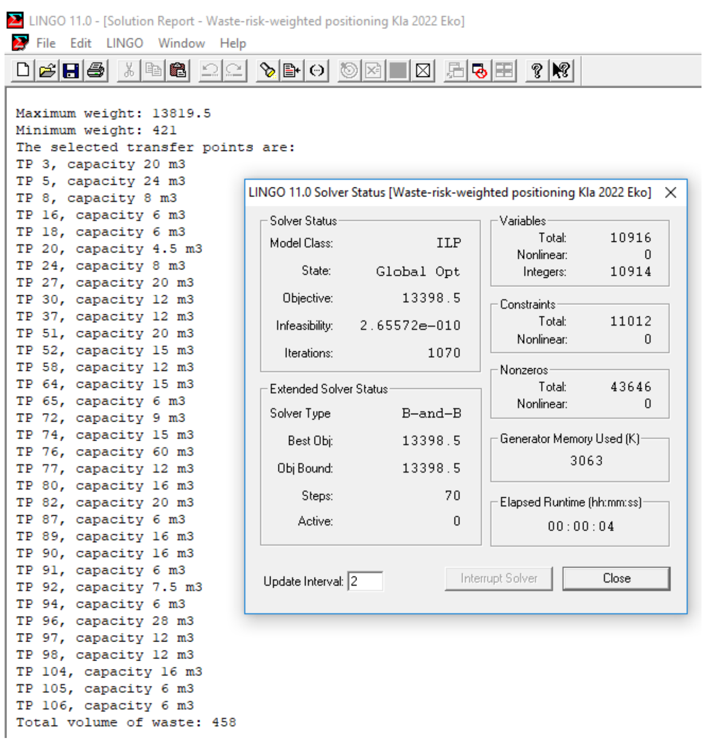

Figure 4. The 2022 dataset-related experiment: the selected alternative sites

The application of the same model to projected 2022 problem context in the same region, in the meantime, shows that having a waste-induced disaster risk gap of 13,398.5 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. The gap is obtained from a maximum waste-induced disaster risk of 13,819.5 m^3-minutes and a minimum one of 421 m^3-minutes. About 4 seconds and 1,070 iterations of computational experiment is needed in order for the output to be available.

With respect to the alternative selected in each of the experiment, it can be seen that 28 alternative sites are selected in both of the outputs. The 28 alternative sites account for 417 m^3 of waste capacity.

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 within an acceptable time frame.

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