Mapping out the municipal solid waste generation and collection model using spatial multi-criteria evaluation

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Abstract. As of 2017, only 47% of Sukmajaya Sub-district’s waste was collected and transported. The City of Depok targeted to improve this rate to 73% by 2020. This research aims to evaluate the waste collection system in Sukmajaya Sub-district. Data were collected from government agencies, interviews, and field surveys. Data analysis was conducted using Spatial Multi-Criteria Evaluation (SMCE). Results showed that waste generation in Sukmajaya Sub-district was divided into three categories based on its quantity: three villages generated more than 150 m³ waste/day, two villages generated 50–100 m³ waste/day, and one village generated lower than 50 m³ waste/day. Sukmajaya Sub-district had three types of residential waste collection models: indirect individual physical Waste Collection Point (WCP), indirect individual non-physical WCP, and direct individual door to door. Evaluation revealed four out of six existing physical WCP facilities were suitable in terms of spatial and physical conditions and posed low threat to pollute the surrounding environment.

1. Introduction

Urban waste management is one of several significant problems faced by many countries in the world [1] and thus considered one of the important points to be improved in Sustainable Development Goal (SDG) 11: sustainable cities and communities and SDG 6: clean water and sanitation [2]. Particular attention is given to developing countries that continue to prioritize development and economic growth. Following this, on a global average, urban waste collection in developing countries has improved from 50% in the 1990s to around 65% in 2012 [3]. This progress is also observed in Indonesia; in 1995, only 40% of the total generated waste was transported to landfills and in 2004, this figure improved to 60% [4]. However, waste management issue continues to be a challenge to the environment, as uncollected waste is either burned or thrown into waterways or open land [4].

Urban waste management issue is also observed in Depok, one of the most crowded cities in Indonesia. The waste generation rate in Depok keeps increasing, while only 56% of the total waste generated is transported to landfill [5][6][7]. By 2020, the City of Depok’s waste management service aims to improve its waste collection and transportation rate to 73% of total generated waste as part of its operative goals in the Regional Policies and Strategies document or Kebijakan dan Strategi Daerah (JAKSTRADA). This implies a funding hurdle since this goal is not comparable to the costs allocated for waste collection and transportation, 72% of the total budget for waste management in 2008 (IDR 9,588,734,350 IDR or 650,020 USD) [7]. Also, Sukmajaya Sub-district, which has the lowest waste collection rate, has to make unprecedented efforts to achieve this target; as of 2017, only 47% of
Sukmajaya Sub-district received waste collection and transportation service. This study finds it necessary to optimize the waste collection rate as part of the efforts to reduce unmanaged waste’s environmental impact.

The waste collection rate is determined by the technical aspects of the waste collection system and depends on the suitability of the waste collection point (WCP) facility location. Previous studies on this subject proposed Spatial Multi-Criteria Evaluation (SMCE) [8][9] as a robust decision support system (DSS) to develop sustainable waste management [10], since this method allows spatial analysis of land suitability by accounting for spatial and aspatial factors. This research aims to analyze the amount of waste generated in the Sukmajaya Sub-district, to analyze the waste collection rate, and to evaluate the suitability of waste collection facilities in the Sukmajaya Sub-district in order to achieve the City of Depok’s waste management operative goal for 73% waste collection and transportation rate in the 2020 Regional Policies and Strategies.

1.1. Theoretical background

Developing countries are said to have difficulty achieving sustainability, including in the waste management sector [3], but Curitiba City in Brazil is an example to refute this view [11]. Curitiba is known as a pilot city for sustainable urban planning [11]. It has many slum areas and is included in developing countries, but many innovative programs prioritize sustainability [11].

“The Garbage That Is Not Garbage” is a successful waste management program that encourages residents to separate waste into two major groups [12]. The implementation of this program uses ordinary waste transport cars to transport waste. This program’s implementation is also assisted by educational institutions that use interactive games to increase public awareness [12][13]. This effort is aided using geographic information system (GIS) technology, which is generally used in efforts to optimize waste management systems [14][15] through the determination of the shortest and optimal route for the waste transportation stage using network analysis and Djikstra’s algorithm [16]. As many as 70% of the residents in Curitiba are involved in this program, 13% of the waste has been recycled. The limited number of waste collection vehicles is overcome by the Green Exchange Program [12]. This program allows the poor to exchange sorted waste for harvest products, which are obtained from local farmers whose vegetable trades are not sold out [12].

Waste generally has three forms: solid, liquid, or gas. Urban waste can further be classified into two: industrial waste or municipal solid waste. Industrial urban waste is produced by mining areas, livestock, and industry providing goods or services [17]. On the other hand, municipal solid waste is the combined result of municipal solid waste produced by households and workplaces other than industry; this study focused on this type of urban waste. Urban waste generation is defined as an activity to throw away or to collect items that no longer have value to be disposed of. Until now, urban waste generation is not an activity that can be fully controlled. Scavengers play an essential role in reducing urban waste generation because 1-10% of urban waste is reduced due to scavengers’ role [18].

Optimization of waste collection and transportation consists of three types of optimization models that are continuously developing. The first type of model focuses on the process of shortening the route [19]. The second model type is developed from the first, but considers waste collection containers’ placement to be carried out more quickly [19][20]. The third model type is also developed from the first type, but focuses on interventions in the number of operating vehicles [19][21]. This research applied the second model type to analyze waste generation and waste collection systems and evaluate current operating waste collection sites. This study seeks to take a comprehensive look at the technical issues of garbage collection system and analyzes the interrelationships of involved aspects through a spatial perspective.
2. Material and Method

2.1. Materials
The location of this research is Sukmajaya Sub-district in Depok City, West Java Province (Figure 1). The research location was chosen because Sukmajaya Sub-district has the lowest waste collection and transportation services, even though it has the highest population density in Depok. This study’s population were all WCPs located in Sukmajaya Sub-district, Depok City Environment and Sanitation Service or Dinas Lingkungan Hidup dan Kebersihan (DLHK), and the Regional Planning and Development Agency or Badan Perencanaan dan Pembangunan Daerah (BAPPEDA). Sampling was carried out by census at all WCPs in Sukmajaya Sub-district; on the other hand, sampling of target government was done purposively to the head of DLHK and head of BAPPEDA to represent their organizations.

![Figure 1. Research location.](image)

Population data and waste generation were calculated from the population to answer the first research objective, which was to calculate the amount of waste generation. The waste collection model, including the capacity and amount of waste collected in each of these models, was analyzed to achieve the second research objective. The WCP suitability map was developed for the third research objective. The suitability map was generated from the synthesis of four variables: distance to road, distance to settlement, distance to river, and landslide vulnerability. Non-spatial variables such as road conditions and placement of WCP facilities were also included in land suitability analysis considering their significance in waste management.

2.2. Methods
This paper’s object of analysis is the WCP, a facility used to collect waste before it is transported to landfills temporarily.
The first objective of calculating the total amount of waste generated in Sukmajaya Sub-district was done by multiplying the total sub-district population with waste generation assumption on big cities following Indonesian National Standard or Standar Nasional Indonesia (SNI) number 19-3983-1995 [22], which is 2.75 liter/person/day. The resulting calculation was then compared to the waste collected by the City of Depok’s waste management service [8][14]. The WCP location evaluation was carried out using Spatial Multi Criteria Evaluation (SMCE) to create a land suitability map [9]. ArcGIS and QGIS applications were used to run SMCE. SMCE model is a multi-criteria decision model for spatial data [10]. This method was chosen due to its ability to combine qualitative and quantitative criteria, which resulted in recommendations to aid decision-making [10]. Each factor was assigned a weight through weighted linear combination by summation of results to yield a suitability map [9]. The weighted evaluation was expressed in the following equation:

$$S = \sum w_i x_i$$

S is suitability, w is the corresponding weight of each factor, and x is the factor score.

Table 1. Variable and scoring for SMCE [9][10][22][23][24][25].

| No. | Variable                     | Indicator                                                      | Score (x) | Variable Weight (w) |
|-----|------------------------------|----------------------------------------------------------------|-----------|---------------------|
| 1.  | Road condition               | Good, with pavement and/or non-corrugated asphalt              | 2         | 2                   |
|     |                              | Bad, without pavement and/or corrugated asphalt                | 1         |                     |
| 2.  | Placement of Facility        | Allocated, facility is separated from the road and does not interfere with public facilities | 2         | 1                   |
|     |                              | Unallocated, facility is located on the side road and disturb public facilities | 1         |                     |
| 3.  | Distance to road (m)         | 0-500                                                          | 4         | 2                   |
|     |                              | 500-1,000                                                     | 3         |                     |
|     |                              | 1,000-1,500                                                   | 2         |                     |
|     |                              | >1,500                                                        | 1         |                     |
| 4.  | Distance to settlement (m)   | <50                                                            | 1         | 3                   |
|     |                              | 50-100                                                        | 3         |                     |
|     |                              | >100                                                          | 2         |                     |
| 5.  | Distance to river (m)        | 0-15                                                           | 1         | 3                   |
|     |                              | 15-30                                                         | 2         |                     |
|     |                              | 30-45                                                         | 3         |                     |
|     |                              | >45                                                           | 4         |                     |
| 6.  | Landslide prone areas        | High prone                                                    | 1         | 1                   |
|     |                              | Medium prone                                                  | 2         |                     |
All variables in Table 1 were a product of overlay analysis from the SMCE method so that each variable is assigned a weight based on the respective value of each variable [9][10][22][23][24][25]. The Road Condition, Facility Placing, and Distance to road variables were a combination of spatial and non-spatial factors, which were important factors for evaluating waste management as input for the SMCE method [16]. The Road Condition variable took into account the pavement type around the WCP location and its condition. All physical WCPs in the Sukmajaya Sub-district were categorized under an allocated facility variable placement, not on the sideroad. This type of placement allowed the waste management process to be carried out without disturbing vehicles’ flow. Road networks that became the analysis reference in this variable were identified as primary, collector, and local roads. Other road classes were not included because they did not allow waste trucks to pass through. A higher classification weight was given to WCP that was closer to the road network because it determined whether a garbage collection vehicle could access the facility [16]. Therefore, the highest weight was assigned to the 0-500 m category (Table 1). For the Distance to Settlement variable, the optimal distance was at 50-100 m, thus, this category was assigned the highest categorical value [24]. If the WCP distance was less than 50 m, it would have disturbed the surrounding settlements, but if it were farther than 100 m it would have encouraged residents to make illegal WCPs because the legal WCP distance was too far [25]. The Distance to River variable was an effort to maintain environmental quality conditions from garbage piles. In this variable, the farther the distance was from the river, the higher the weight, so that the highest weight was assigned for the > 45 m category.

3. Results and discussion

3.1. Distribution of urban waste generation
The highest waste generation rate of the Sukmajaya Sub-district was 160.62 m$^3$/day in Abadijaya Village, while the lowest waste generation rate was 44.14 m$^3$/day in Cisalak Village. Villages in Sukmajaya Sub-district that generated more than 150 m$^3$ waste/day were Abadijaya Village, Mekarjaya Village, and Baktijaya Village. These three villages were located in the center of the sub-district. On the other hand, Sukmajaya Village and Tirtajaya Village on the southern side of the sub-district generated 50-100 m$^3$ waste/day. Lastly, Cisalak Village in the Northeast generated less than 50 m$^3$ waste/day.

3.2. Three types of residential waste collection models
Sukmajaya Sub-district had three types of residential waste collection: indirect individual physical WCP, indirect individual non-physical WCP, and then direct individual pick up from stable housing or called as a door-to-door service. A physical WCP had the form of a building or a container; on the other hand, a non-physical WCP was a meeting place between motor vehicles that had picked up waste from door-to-door and waste pick-up trucks from DLHK. Sukmajaya Sub-district had six physical WCP spread across five villages out of six villages (Table 2).

| No. | Village  | Municipal Waste Generation 2019 (m$^3$/day) | Collected Municipal Waste Generation (m$^3$/day) | Total Collected Municipal Waste Generation (m$^3$/day) | Percentage of Municipal Waste Collected (%) |
|-----|----------|--------------------------------------------|-------------------------------------------------|-------------------------------------------------|--------------------------------------------|
|     |          |                                           | Physical Facility | Non-physical Facility | Door to door |                                               |                                               |
| 1.  | Sukmajaya| 81.24                                      | 4                 | 0                   | 16.36        | 20.36                                     | 25.06%                                     |
| 2.  | Tirtajaya| 52.62                                      | 0                 | 4                   | 1.29         | 5.29                                      | 10.05%                                     |

Table 2. Percentage municipal waste collected from 3 collection model.
3. Mekarjaya 155.6 64 32 30.45 126.45 81.27%
4. Abadijaya 160.62 10 0 7.19 17.19 10.70%
5. Baktijaya 154.22 70 0 20.47 90.47 58.66%
6. Cisalak 44.14 20 4 3.63 27.63 62.60%
Total 648.43 168 40 79.39 287.39 44.32%

The distribution of physical WCP locations was concentrated in the central area of the Sukmajaya Sub-district with the exception of Tirtajaya Village, where there was still no physical WCP service. On the other hand, there were seven non-physical WCP locations in Sukmajaya Sub-district. The distribution of five non-physical WCPs was concentrated in one housing complex centered in the middle, while two other non-physical WCPs were located on Tirtajaya Village and the east side of the Sukmajaya Sub-district. The collected waste from all of these non-physical WCP were transported to the landfill three times a week. The amount of waste generated at these non-physical WCPs varied from 2 m³ to 15 m³ of waste per day.

Thirteen settlements were served door-to-door. Bakti Jaya Village and Sukmajaya Village had the largest number of residential areas served door-to-door; four residential areas in each village were concentrated on the North and South sides of the Sukmajaya Sub-district. Gap areas where there were unserved zones were identified on the Southside of Sukmajaya Sub-district. One physical WCP in Pondok Sukmajaya Village and one non-physical WCP in the Green Depok City area on the South; on the other hand, the rest of this area received the door-to-door waste collection in each residential area. This had become a concern in this study because the WCP service area was wider than the door-to-door service area. Door-to-door service takes the longest time to collect the waste than the other service type. Since Tirtajaya Village had no physical WCP, waste collection service was done by non-physical WCP and door-to-door service in housing complexes. All physical WCPs are still underloaded in terms of waste quantity. However, spatially this can be explained by the fact that many areas in Sukmajaya Sub-district have not entered the service area.

The percentage of municipal waste collected of 44.32% of the entire residential area that is shown in Table 2 has not reached the City of Depok’s operational target in JAKSTRADA to improve its waste collection and transportation rate to 73% of total generated waste. There are two ways to increase the urban waste collection rate: reducing waste generation or improving waste collection facilities. The government’s social approach to society is key in the first approach, so this study adopted the second approach by adding non-physical WCP facilities that do not require land to build facilities.

Mekarjaya Village had the highest waste collection rate; 155.6 m³ waste was generated per day, and 126.45 m³ or 85% of the total generation was transported daily. On the other hand, Tirtajaya Village and Abadijaya Village had only 10% of their generated waste collected, which was the lowest. Tirtajaya Village had no physical WCP facility due to the limited land that could be utilized. Therefore, this study proposed the addition of non-physical WCP as part of the solution. Abadijaya had the highest rate of waste generation but the second lowest rate of waste collection. This was due to its low physical WCP capacity and lack of non-physical WCP. Based on the results of discussions with the City of Depok, the absence of non-physical WCP was due to rejection from local residents related to the potential for scattered waste during waste collection and transportation process as well as the aesthetic issue of waste carts or garbage trucks on stand by for garbage collection vehicles to arrive.

3.3. Evaluation of physical WCP with SMCE
Sukmajaya WCP’s road condition was categorized as good since it was paved and not potholed. Pondok Sukmajaya WCP had poor road conditions due to its rough sandy asphalt condition. The location of Sadewa WCP was on Sadewa Street, which was included in the category of local roads. Sadewa WCP’s road width was sufficient for two waste trucks and its shoulder could be used as a
transit place for waste carts. Sadewa Street was paved with cast materials and had no holes, the same as Cisalak WCP. Merdeka WCP was located on the side of the road within a large fenced area. Filled waste carts dominated waste collection bin under a semi-permanent building with a roof over it. In contrast to other WCPs where the waste was unloaded directly from the cart, collected waste in Merdeka WCP was left on the cart until waste transport vehicle to the landfill arrived.

The majority of activities and land use around the studied WCPs were service trade areas, vacant lands, and parks. This condition is ideal because it reduces the exposure of the Sukmajaya Sub-district residents to the negative impacts of the WCP. The results show that in Sukmajaya Sub-district, there are only two categories of road buffer area: 0-500 m and 500-1,000 m (Figure 2a). These results indicate that the road network in Sukmajaya Sub-district is evenly distributed and covers almost all areas. The overlay analysis results between the WCP locations and this variable indicate that all physical WCPs are within 0-500 m distance from the road. Overlay analysis results between WCP locations and distance to the river variable indicate that the physical WCPs are spread over three of the four existing categories (Figure 2b).

In terms of distance from the river, Sadewa WCP is located within 0-15 m from the river network, so that waste piles are prone to pollute the river body (Figure 2b). Next, Pondok Sukmajaya WCP is classified in the 30-45 m distance category. Finally, four WCPs are identified in the >45 m category: Griya Lembah Depok WCP, Merdeka WCP, Cimanuk WCP, and Cisalak WCP. These four WCPs are located the furthest from the river body and thus pose the lowest threat to pollute the river either from leachate or waste piles.

The result of overlay analysis between the WCP locations and Distance from the Settlement variable is summarized in Figure 2c. Analysis results show that all physical WCPs are located in the worst area category, which was <50 m from settlement. The result of overlay analysis between landslide-prone areas and WCP locations is visualized in Figure 2d. Four WCPs are located in moderately landslide-prone areas: Pondok Sukmajaya WCP, Merdeka WCP, Sadewa WCP, and Cisalak WCP. On the other hand, Griya Lembah Depok WCP and Cimanuk WCP are located in low landslide-prone areas. All variables identified were analyzed with overlay analysis with SMCE method to assign weight to each variable based on its respective value. Figure 3 is land suitability map from SMCE analysis method.
Figure 2. a. Road buffer area ; b. River buffer area ; c. Settlement buffer area ; d. Landslide prone area.

Table 3 shown WCP facilities with the highest suitability value are Griya Lembah Depok WCP and Cimanuk WCP with a total weight of 10 out of the maximum value of 12. These two WCPs are located in a low landslide-prone area, while two other WCPs in the less suitable category are located in a moderate landslide-prone area. The second differentiator is the relationship between the WCP and the river; two WCPs are in the less suitable category due to their distance to the river network. This assessment follows the ministerial regulation of the Ministry of Public Affairs of Indonesia’s efforts to protect the environment. Pondok Sukmajaya WCP can improve its suitability status by improving road networks or access to the WCP location. Sadewa WCP is less suitable because it is close to a network of rivers. This can be intervened by closing river networks that are prone to be polluted by waste collection and transportation activities.

Table 3. Summary of SMCE analysis for physical WCP.

| Facility Name    | Road condition | Placement of facility | Distance to the road (m) | Distance to settlement (m) | Distance to river (m) | Landslide prone areas | Total variable weight | SMCE result     |
|------------------|----------------|-----------------------|--------------------------|----------------------------|-----------------------|-----------------------|---------------------|-----------------|
| Pondok Sukmajaya | bad            | Allocated             | 0-500                    | <50                        | 30-45                 | Medium prone          | 7.92                | Less suitable    |
Table 1. Criteria for land suitability assessment of Sukmajaya Sub-district.

| Village          | Type | Allocated | <50 | >45 | Low prone | Medium prone | Suitable |
|------------------|------|-----------|-----|-----|-----------|--------------|----------|
| Griya Lembah     | good | 0-500     | <50 | >45 | 10        | 9.67         | Suitable |
| Depok            |      |           |     |     |           |              |          |
| Merdeka          | good | 0-500     | <50 | >45 | Medium    | 9.67         | Suitable |
| Sadewa           | good | 0-500     | <50 | 0-15| Medium    | 7.42         | Less suitable |
| Cimanuk          | good | 0-500     | <50 | >45 | Low       | 10           | Suitable |
| Cisalak          | good | 0-500     | <50 | >45 | Medium    | 9.67         | Suitable |

Figure 3. Land suitability Sukmajaya Sub-district.

4. Conclusion
Waste generation in the Sukmajaya Sub-district can be divided into three waste generation categories: three villages generate more than 150 m$^3$ waste/day, two villages generate 50-100 m$^3$ waste/day, and one village generates less than 50 m$^3$ waste/day. Sukmajaya Sub-district has three models of residential waste collection: indirect individual physical WCP, indirect individual non-physical WCP, and direct individual door-to-door. Our study shows that only 44.32% of the generated municipal waste are collected; thus this has not yet reached the City of Depok’s operational target in JAKSTRADA to improve its waste collection and transportation rate to 73% of total generated waste. Using SMCE, this study finds that the existing four out of six physical WCP facilities are suitable in terms of spatial and physical conditions so that they have a low threat of polluting the surrounding environment. Unequal waste service facilities indicate that waste management facilities are not sufficient only by paying attention to the quantity that can be served, but must also consider the equal
distribution of these facilities. There are two ways to increase the waste collection rate: reducing waste generation and/or improving waste collection facilities. This study adopted the second strategy by proposing the addition of non-physical WCP facilities that do not require land to build facilities. Pondok Sukmajaya WCP can improve its suitability status by improving road networks’ quality or access to the WCP location. Sadewa WCP is less suitable because it is close to a network of rivers. This can be intervened by closing river networks that are prone to being polluted by waste collection and transportation activities. Further research can be carried out using the data analysis results from this research to determine the best-proposed location for relocating existing facilities or adding new facilities.

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