Faecal sludge treatment facility site selection using GIS-based multi-criteria analysis and AHP: Case study of Bogor Regency

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Abstract. Sanitary condition is one of the components that influencing public health. Bogor Regency has total area 2,663.81 km², with total population 5,965,410 in 2019. The sanitation of Bogor Regency nearly 100% is using on-site systems. Utilization of septic tank reduces the level of contamination of surface water and groundwater. However, the sludge still containing high E. Coli that potentially caused diarrhea, vomiting disease, and others, so that the handling of the sludge needs Faecal Sludge Treatment Facilities (FSTF). Before 2016, Bogor Regency already had 10 units of faecal suction truck services, but the disposal process still was done in Kalimulya FSTF, Depok City. So, this study aims to find a feasible FSTF site location which fulfills the spatial plan, technical, and non-technical criteria. The process on the determining feasible FSTF location was employing multicriteria analysis by using Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP). Several spatial data such as the land slope, the soil type, distance from water bodies/river, the administration of Bogor Regency, as well as land use and land capability were used for FSTF site selection. Spatial analysis using GIS results in 22 locations in 15 different districts. By reconsidering the area, only 8 selected locations were surveyed and evaluated using AHP. Based on the weighting, the locations which chosen for the eastern, central, and western parts of Bogor are Cileungsi, Cibinong, and Cigudeg districts respectively.

1. Introduction
In the past, wastewater management only concerning with off-site systems with sewerage. But, in the presentecal sludge management was developed in many cities around the world especially in developing countries. The perception of onsite sanitation has changed and is considered a sustainable long-term sanitation technology that can be applied in urban areas in developing countries that do not have sewerage infrastructure [1]. The service chain of Fecal Sludge Management (FSM) consists of containment with on-site facilities continued with emptying and transport into fecal sludge treatment facilities (FSTF) [2].

FSM was applied in many countries in South East Asia, South Asia, South America, Africa [3,4]. Practically this system is still having problems/constraints such as poor containment in residential/households; illegal dumping on the sea, river, water bodies; lack of treatment facilities [5].
But, the onsite system with FSM also has advantages in investment and operational costs which only 11.63/capita annually. Five times cheaper than sewerage system [1]. Fecal sludge also has potential usage as a source of solid fuel [6,7].

Bogor Regency has total area 2,663.81 km² with total population 5,965,410 in 2019. Until today, the Sanitation system in Bogor Regency relies on on-site sanitation by using septic tank. Efforts using septic tanks actually reduced levels of groundwater and surface water pollution. However, the suctioned sludge generally still contains Escherichia coli bacteria and worm eggs, which have the potential to cause epidemics of vomiting, diarrhea, and cholera, so it requires an FSTF for further treatment [8,9]. Before 2016, The Bogor Regency already had 10 units of fecal suction truck services, but the disposal process still was done in Kalimulya FSTF, Depok City. So, FSTF is a very important infrastructure to be built in Bogor Regency.

One of the methods to determine the FSTF location is using the Geographic Information System (GIS). It is a computer-based system designed to collect, store, and analyze objects and phenomena where geographic location is an important and critical characteristic for analysis [10]. Several applications of GIS on similar analysis are rainwater harvesting facilities site selection, groundwater infiltration zone, groundwater vulnerability analysis, and solid waste dumping sites selection [11–14].

In this study, the selection of alternative FSTF locations is using the GIS method approach and the multi criteria decision making technique with the Analytical Hierarchy Process (AHP) method. The AHP method is used to determine the priority of FSTF location determination and evaluate a number of alternatives in terms of a number of decision criteria.

The AHP method, developed by Saaty is a method which measures through pairwise comparison and relies on the judgment of expert to derive a priority scale [15]. It is based on three principles: decomposition, comparative judgment, and synthesis of priorities. It has been widely used on multi-criteria decision-making tools in many fields such as manufacture, the oil industry, and education [16].

To overcome the sanitation problems in Bogor Regency, especially the absence of FSTF infrastructure, analysis of site selection and determination was conducted in this paper using spatial analysis using GIS and AHP respectively.

2. Materials and Methods
The methodology which was used in this research consists of data collection both primary data and secondary which then continued with data analysis as spatial analysis using Software QGIS 2.18. Before conducting site confirmation and site selection, the weighting of site selection was conducted using AHP.

2.1. Materials
The materials used for the research consisted of collecting primary and secondary data.

2.1.1. Primary data
Deep interviews based on questionnaires to 45 respondents were conducted to stakeholders which related to sanitation in Bogor Regency as the regulator, local citizens which especially affected by the FSTF, and academics as an expert.

2.1.2. Secondary data
Secondary data which were collected from the Government of Bogor Regency are Statistics Data of Bogor Regency (total population, the number of the faecal suction truck, land area, the standard of faecal sludge generation). The data were collected from several local agencies and some reports such as the Sanitation White Book of Bogor Regency and Environmental Health Risk Analysis Report. Spatial data which were needed for analysis were also collected such as map of administration, geology, soil type, slope, land used.
2.2. Methods
2.2.1. Faecal sludge generation and land requirement calculation
The land requirements for FSTF were analysed by measurement of the number of residences that received sanitation service according to population projection until the end of the planning period, percent of septic tank occupancy. The population projection was analysed by using linear, logarithmic, exponential, arithmetic, and geometric methods selected by $R^2$ and standard deviation. According to an EHRA report, the user of the septic tank is reaching 70% of the total population. While the faecal sludge standard was 0.5 L/person/day[17].

2.2.2. Spatial analysis using QGIS
The site selection was conducted using an open-source GIS application QGIS Desktop 2.18.13. Spatial analysis using several criteria such as the distance the site from the residential area, slope 0-3%, clay soil type, land owned by the government.

2.2.3. Analytical hierarchy process (AHP)
AHP is a method of decision making by compiling a hierarchy to simplify the problems[15]. In selecting the FSTF location, the AHP method is appropriate to be used as a support in selecting FSTF location candidates according to the criteria of the Ministry of Public Works which are technical aspects (Te), social aspects (So), economic aspects (Ec) and environmental aspects (En) as well as sub-criteria of them. The evaluation of the hierarchy was carried out by respondents who came from the stakeholders with some several sub-criteria which are the distance between FSTF and residence (Te1); Slope (Te2); the distance of water bodies (Te3); flood-free area (Te4); soil type (Te5); the number of workers (So1); Conflict potential between residence and FSTF Management (So2); human resource and skill for FSTF (So3); infestation value (Ec1); operational cost (Ec2); benefit (Ec3); sanitation and public health (En1); the potential of pollution (En2); aesthetic (En3).

3. Results and Discussion
3.1. Faecal sludge generation and land requirements for FSTF
This prediction is essential to determine the capacity of the FSTF capacity and estimate the dimensions and area of land for the construction. The following Table 1 shows the predicted discharge sludge and land requirement of 40 districts in 3 main regions. The FSTF area was calculated with the assumption that the treatment using conventional technology as a combination of anaerobic, facultative, and aerobic pond. The detention time of anaerobic pond facultative and maturation are 8-40 days, 20-40 days, and 5-15 days respectively [18,19]. The results showed that the Central Bogor Regency has the largest population of more than 4 million residences. The calculation showed that at least 1,000 m$^3$/day of faecal sludge needed to be treated. With the assumption that FSTF is two folds of required are for sludge treatment using the pond, the land area which is needed for FSTF at least 1 Ha.

Table 1. The estimated debit of faecal sludge and area for FSTF.

| Bogor Regency (Cluster) | Number of population (person) | Discharges of Faecal Sludge (m$^3$/day) | FSTF Dimensions (m$^2$) | Required area (Ha) | Area for FSTF (Ha) |
|------------------------|--------------------------------|----------------------------------------|-------------------------|------------------|------------------|
| West                   | 12 Sub districts               | 2,330,939                              | 489.50                  | 1,406.4          | 843.8            | 843.8            | 0.309            | 0.619            |
| Central                | 20 Sub districts               | 4,273,279                              | 1,046.95                | 2,437.7          | 1,462.6          | 1,462.6          | 0.536            | 1.073            |
| East                   | 8 Sub districts                | 1,995,358                              | 419.03                  | 1,067.4          | 640.4            | 640.4            | 0.235            | 0.470            |

Note: 1=Anaerobic pond; 2=Facultative pond; 3=Maturation pond
3.2. **Site selection using GIS**

Spatial analysis by using criteria from the Ministry of Public Works results in 22 location in 15 different districts are suitable in the Bogor Regency for FSTF location that can be seen in Figure 1. But most of them are selected locations with an area less than or equal to 1 Ha. Only 8 locations which are suitable and 5 locations are recommended by local government (Table 2). Fernandes *et al.*[20] stated that the determination of the location FSTF must consider land slope, soil type, land area, and is located on a flood-free area.

**Table 2.** Selected location based on spatial analysis (a) and recommendation by local government (b).

| Bogor Regency | Available Land Area | Bogor Regency | Available Land Area |
|---------------|---------------------|---------------|---------------------|
| West          |                     | West          |                     |
| Cigudeg       | 8 Ha                | Cibungbulang  | 17 Ha               |
| Tenjo         | 6.7 Ha              | Leuwiliang    | 7 Ha                |
| Parungpanjang | 16 Ha               | Central       |                     |
| Parungpanjang | 1 Ha                | Citayam       | 2 Ha                |
| Central       |                     | East          |                     |
| Caringin      | 1.6 Ha              | Cileungsri    | 7 Ha                |
| Cibinong      | 1.4 Ha              | Jonggol       | 11 Ha               |
| Sukaraja      | 1 Ha                |                |                     |
| East          |                     |                |                     |
| Cariu         | 3.6 Ha              |                |                     |

*Figure 1.* The overlay of land suitable with criteria and land owned by the government.

3.3. **Site evaluation using AHP**

The locations that were surveyed are 8 districts which were selected according to the criteria of the Ministry of Public Works and recommended by the Government of Bogor Regency. They are can be seen in Table 3.
Table 3. The location which evaluated.

|                | Bogor Regency | Available Land Area |
|----------------|---------------|---------------------|
| West           | West          | Cigudeg             | 8 Ha |
|                | Cibungbulang  | 17 Ha               |
|                | Leuwiliang    | 7 Ha                |
| Central        | Cibinong      | 1.4 Ha              |
|                | Cibinong      | 1 Ha                |
|                | Citayam       | 2 Ha                |
| East           | Jonggol       | 11 Ha               |
|                | Cileungsi     | 7 Ha                |

Table 4. The scoring of prospective FSTF location using AHP.

| Sub-          | Weight | West Bogor Regency | Central Bogor Regency | East Bogor Regency |
|---------------|--------|--------------------|-----------------------|--------------------|
| criteria      |        | S      V      | S      V      | S      V      | S      V      | S      V      |
|               |        | W1     W2     | W3     | M1     M2     | E1     | E2     |
| Te1           | 0.09   | 5       | 0.4    | 4       | 0.3    | 4       | 0.3    | 5       | 5      | 0.44   | 5       | 0.44   | 5      | 0.44   | 1       | 0.09   |
| Te2           | 0.21   | 5       | 1.0    | 3       | 0.8    | 3       | 0.8    | 3       | 5      | 1.03   | 5       | 1.03   | 5      | 1.03   | 5       | 1.03   |
| Te3           | 0.22   | 5       | 1.1    | 5       | 1.1    | 2       | 0.4    | 5       | 5      | 1.12   | 5       | 1.12   | 5      | 1.12   | 5       | 1.12   |
| Te4           | 0.21   | 5       | 1.0    | 4       | 1.0    | 4       | 0.4    | 5       | 5      | 1.04   | 5       | 1.04   | 5      | 1.04   | 3       | 0.62   |
| Te5           | 0.27   | 5       | 1.3    | 6       | 1.3    | 6       | 0.5    | 4       | 5      | 1.36   | 1       | 0.27   | 2      | 0.54   | 3       | 0.82   |
| So1           | 0.41   | 5       | 2.0    | 6       | 1      | 0.4    | 1      | 0.4    | 1       | 5      | 2.06   | 5       | 2.06   | 5      | 2.06   |
| So2           | 0.33   | 5       | 1.6    | 4       | 1      | 0.3    | 3      | 0.3    | 3       | 5      | 1.64   | 3       | 0.98   | 4      | 1.31   | 4       | 1.31   |
| So3           | 0.26   | 5       | 1.3    | 6       | 1      | 0.2    | 6      | 0.2    | 6       | 5      | 1.31   | 3       | 0.78   | 4      | 1.04   | 1       | 0.26   |
| Ec1           | 0.33   | 5       | 1.6    | 7       | 1      | 0.3    | 3      | 0.3    | 3       | 5      | 1.67   | 1       | 0.33   | 5      | 1.67   | 1       | 0.33   |
| Ec2           | 0.10   | 5       | 0.4    | 9       | 1      | 0.1    | 0      | 0.1    | 0       | 5      | 0.49   | 1       | 0.10   | 5      | 0.49   | 1       | 0.10   |
| Ec3           | 0.57   | 5       | 2.8    | 4       | 1      | 0.5    | 7      | 0.5    | 7       | 5      | 2.84   | 1       | 0.57   | 5      | 2.84   | 5       | 2.84   |
| En1           | 0.28   | 5       | 1.3    | 8       | 3      | 0.8    | 3      | 0.8    | 3       | 3      | 0.83   | 3       | 0.83   | 5      | 1.38   | 5       | 1.38   |
| En2           | 0.13   | 5       | 0.6    | 4       | 3      | 0.8    | 3      | 0.8    | 3       | 4      | 0.51   | 3       | 0.83   | 5      | 0.64   | 5       | 0.64   |
| En3           | 0.59   | 5       | 2.9    | 7       | 3      | 0.8    | 3      | 0.8    | 3       | 2      | 1.19   | 2       | 0.55   | 5      | 2.97   | 5       | 2.97   |
| Total         | 70      | 20      | 3.91   | 8       | 9      | 29     | 7.0    | 8       | 64      | 17.5   | 43     | 10.9   | 56     | 18.5   | 49     | 15.5   |

Note: S= Score; V= Value; W1=Cigudeg; W2=Cibungbulang; W3=Leuwiliang; M1=Cibinong; M2=Tajurhalang; E1=Cileungsii; E2=Jonggol; Te1=1st technical aspect/Distance between FSTF and residence; Te2=2nd technical aspect/Slope; Te3=3rd technical aspect/distance of water bodies; Te4=4th technical aspect/flood free area; Te5=5th technical aspect/soil type; So1=1st social aspect/the number of worker; So2=2nd social aspect/Conflict potential between residence and FSTF Management; So3=3rd social aspect/human resource and skill for
FSTF; Ec1= 1st economical aspect/infestation value; Ec2= 2nd economical aspect/ operational cost; Ec3= 3rd economical aspect/ benefit; En1= 1st environmental aspect/ sanitation and public health; En2= 2nd environmental aspect/ potential of pollution; En3= 3rd environmental aspect/ aesthetic

Each alternative is given a point for each consideration. Scale assessment which was conducted is scoring at 1 to 5. The grading scale will be multiplied by each weighting criteria for distributing the results of the questionnaire with the AHP method. The higher the profit that can be taken, the higher the score. The assessment of each alternative is shown in Table 4. Site evaluation using AHP method on 3 different regions in Bogor Regency results in 3 selected sites. They are located in Cigudeg, Cibinong, and Cileungsi district with total scores of 20, 17.53, 18.59 respectively.

4. Conclusions

FSTF is a very important sanitation infrastructure especially in a region that has an on-site sanitation system. FSTF location is needed to comply with government regulation so that several criteria need to be fulfilled. GIS application by using spatial analysis combined with AHP ease site FSTF selection analysis. In the case of Bogor Regency, the candidate which elected for FSTF in Western, Central, and Eastern part of Bogor are Cigudeg, Cibinong, and Cileungsi district.

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