

Sanitary Landfill Siting Using GIS and AHP

A Case Study in Johor Bahru, Malaysia

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Abstract—One of the major problems affecting municipalities is solid waste management. There is a difficulty in selecting suitable sites for waste disposal as it involves different factors to be considered before site selection. Currently, waste generation in Johor Bahru has steadily increased over the last few years and the only existing sanitary landfill is reaching its capacity limits, which means that a new sanitary landfill site needs to be constructed. In this study, geographic information system (GIS) and analytical hierarchy process (AHP) methods were utilized with the integration of dynamic data such as future population and projection of waste production in order to provide suitable sites for the construction of a sanitary landfill in the study area. Thirteen criteria were considered for this study, namely water bodies, soil, geology, slope, elevation, residential areas, archeological sites, airports, population, road, railway, infrastructure, and land use. AHP was used to determine the weights for each criterion from the pairwise comparison matrix. Consistency index and consistency ratio were checked and confirmed to be suitable. The results obtained from AHP were assigned to each criterion in GIS environment using weighted overlay analysis tool. The final potential site map was produced, and the three most suitable potential landfill sites were identified.

Keywords—geographic information system; analytical hierarchy process; landfill siting; sustainable solid waste management

I. INTRODUCTION

The most significant part of urban planning is identifying a desirable location for municipal solid waste disposal [1]. However, serious environmental problems or health hazards can arise from landfill locations and the disposing methods [2]. The greatest concerns associated with landfill environmental impacts are linked to its effects on ground and surface water, air, soil, odor emission, and issues regarding solid waste transportation [3]. In the majority of developed and developing

countries, the most common technique adopted for solid waste disposal is sanitary landfill [4-5]. Other methods are composting and incineration, but the landfill is the oldest and most common technique. Due to landfills, a lot of problems have risen in the waste management sector [6]. There is a need for effective and efficient solid waste management to prevent public health hazards or negative environmental impact. Global population increase and rapid industrialization mean an increase in the volume of waste. Managing the waste produced by a city has become more complex [7]. Getting rid of waste using landfills has become an unavoidable component of the entire solid waste management framework, regardless of reduction, reuse, and recycling activities and practices, there will always be a need for the transfer of the remaining waste into the landfill.

The goal of a site selection exercise is to find the optimum location that satisfies a number of predefined criteria. Locating a suitable and sustainable sanitary landfill site is very tedious, complex, and time consuming because it involves various different fields of knowledge (environmental, economic, political, social, technical, and engineering). GIS has been used as a system for management, manipulation, representation and analysis of geospatial data to facilitate and cut down costs in a site selection process [8]. According to [9], GIS is an ideal tool because of its ability to manage large amounts of spatial data acquired from different sources. The utilization of GIS for a preliminary screening is normally carried out by classifying an individual map, based on selected criteria, into exactly defined classes or by creating buffer zones around geographic features to be protected [10]. Meanwhile, multi-criteria decision analysis (MCDA) investigates a number of possible choices for a siting problem, taking into consideration multiple criteria and conflicting objectives [6]. Among the MCDA methods, AHP [11] is the most common and popular, used to identify criteria

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weights using a pairwise comparison matrix [12]. AHP is an MCDA technique used in solving different decision-making problems. It was developed with the aim of dealing with many-criteria complex decisions [13, 14]. Also, AHP is a well-structured mathematical and psychological method of organizing and analyzing complex decisions [15]. This method is widely used by decision-makers and researchers in understanding problems and choosing the solution which is best for their goal [16].

Technological development, globalization and population growth have accelerated the dynamics of the urbanization process in developing countries. Suitable solid waste sites must match with the rapid urbanization process [17]. Currently, waste generation in Johor Bahru has steadily increased over the last few years. Waste generation in Johor Bahru is about 1.06kg/person/d and according to estimations is expected to rise to 1.4kg/person/d by 2025 [18]. Solid waste produced in Johor Bahru has risen to nearly 30% from 2005 to 2010 and is estimated to rise to 50% by 2025 [19]. In this study, GIS and AHP were used with the integration of dynamic data such as future population and projection of waste production in order to provide suitable sites for the construction of a sanitary landfill in the study area, providing long-term solution to solid waste management.

II. MATERIALS AND METHODS

A. Study Area

The study area is situated in the southernmost part of the Peninsular Malaysia. It lies within latitude 1°29'0"N and longitude 103°44'0"E, with a total land area of about 220km². It covers the administrative boundary of the Johor Bahru (JB) which is the capital city of Johor, Malaysia.

B. Population Growth Rate and Waste Generation

The population of the study area was generated according to the estimated population of JB from the Statistics Department of Malaysia [20].

TABLE I. POPULATION AND SOLID WASTE PROJECTION FOR JB [21]

S/No	Year	Population	Solid waste (tons/year)
1	2010	815,600	315,556
2	2015	952,052	406,574
3	2020	1,104,843	520,215
4	2025	1,493,400	763,128

From Table I, we can see that the calculated sum of the projected solid waste from 2010 to 2025 is drastically increasing. According to Iskandar Malaysia Blueprint (2010), estimated land requirements based on 1,000 tons per day capacity and landfill lifespan of 15 year is 100 hectares excluding buffer. This justifies the need for locating new sanitary landfill sites to sustainably contain solid waste.

C. Data Collection and Processing

Landfill siting criteria guidelines such as Integrated Solid Waste Management Blueprint for Iskandar Malaysia [21] and National Strategic Plan for Solid Waste Management [22] were adopted. Three main criteria were used which were divided into 13 sub-criteria. The data used in this study were collected

from various sources: JB administrative boundary and land use/land cover map was acquired from the Iskandar Regional Development Agency. The geological map was derived from a scanned geological map of peninsular Malaysia published by the Director General of geological survey, Malaysia (1985). Road, water body, and railway maps were extracted from digitization of the topographical map series 4551 published in 1996. All the data are geo-referenced according to the Kertau RSO projection system. Data from the US Geological Survey Global Visualization Viewer (USGS GloVis) digital elevation model (DEM) needed for this study were accessed from their online archive <http://glovis.usgs.gov/>. ASTER GDEM with spatial resolution of 30m was used to extract elevation and slope information of the studied area. ERDAS Imagine software was used in processing and analyzing satellite images. ArcGIS software was used for digitizing and spatial data analysis. Considering secure and reliable distance to landfill site in order to allocate the buffer zones for each layer was based on governmental guidelines, experts' judgment, and local and international references. Each criterion was categorized into classes, and each class was given a suitability score from 0 to 10 where 0 means that the area is unsuitable and 10 means that it is most suitable. Distancing, reclassification and overlay analysis were undertaken in GIS, using the spatial analyst tool ArcGIS. In order to evaluate the site selection criterion, AHP was used to measure the relative importance weight of each criterion.

D. Buffers

Buffer zones for each criterion were first created in accordance with the structural hierarchy criteria for the decision-making tree. These zones were calculated based on the landfill siting guidelines and related reviews. The buffer zones for water bodies, residential areas, archeological sites, airport, roads, railways and infrastructures were generated at various distances of 1000m, 2000m, 1500m, 3000m, 1500m, 1000m, and 150m. Furthermore, slope, elevation, soil and geology maps were divided in different classes of suitability from less to most suitable. Land use such as public facilities, educational sites, agricultural land, forest and vacant land were assigned with scores of 0, 0, 6, 3, and 10 respectively. Pairwise comparison was then applied in order to determine the relative importance of each alternative in terms of each criterion. This is been measured according to a numerical scale of 1 (equal importance) to 9 (extreme importance). This procedure enables the decision maker to assess the contribution of each factor to reach the objective independently, thus simplifying the decision-making process [23].

III. RESULTS AND DISCUSSION

In this study, a total of 13 criteria were used for the sanitary landfill site selection analysis. Criterion map layers were extracted from different map sources including topographic sheets, geological and soil maps, land use/land cover maps, and DEM. The land use/land cover maps were used to obtain a five layer (residential, airport, archeological, infrastructures, and population) criteria-based map. DEM was used to derive the elevation and slope map of the area while topographic sheets were used to get roads, water bodies, and railways. All the data (map layers) were geo-referenced according to the Kertau RSO

projection system with 30m resolution pixels. Criteria weights were obtained using the AHP pairwise comparison matrix based on expert’s judgment.

A. Implementation of AHP

Using AHP, the problems were broken down in hierarchical order, thus making it easier to be analyzed independently. After the construction of the hierarchy, systematic evaluation of the different criteria by pairwise comparison was done creating the pairwise comparison matrix. Values have been assigned according to a numerical scale of 1 (equal importance) to 9 (extreme importance). This will enable the decision makers to assess the contribution of each factor to reach the objective independently through this comparison, thus simplifying the decision-making process [23].

B. Deriving Priorities (Weights) for the Criteria

Criteria importance may vary. The next step in AHP is weighting the criteria, because when siting a sanitary landfill not all the criteria are of equal importance. Therefore, pairwise comparison is necessary for the relative importance weight of the criteria used by applying the Saaty numerical scale of 1 to 9. The upper triangular of the matrix is filled with the values of

comparison criteria above the diagonal of the matrix. The lower triangular matrix was completed by the contents of the upper diagonal part of the matrix reciprocally. The element of row *i* and column *j* is *C_{ij}*, and the lower diagonal is completed by applying:

$$C_{ji} = \frac{1}{C_{ij}} \tag{1}$$

The values of *C* (*i*=1,2,3...*m* and *j*=1,2,3... *n*) are used to signify the performance values in terms of the *i*-th and *j*-th element in a matrix [24-25]. Thus, the complete comparison matrix for solving any decision-making problem and deriving weight for each criterion can be represented in a decision matrix as follows:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_n \\ C_{21} & C_{22} & C_{23} & C_n \\ C_{31} & C_{32} & C_{33} & C_n \\ C_{m1} & C_{m2} & C_{m3} & C_{mn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_n \end{bmatrix} \tag{2}$$

Experts’ decisions were entered in the comparison matrix and the weight of each criterion was used to evaluate the best potential sites for the sanitary landfill site in the area (Table II).

TABLE II. PAIRWISE COMPARISON MATRIX

Criteria	Residential	Water bodies	Geology	Soils	Land use	Slope	Elevation	Road	Infrastructure	Airport	Population	Archeological	Railway	Weights
Residential	1	3	4	3	5	5	7	7	5	7	2	5	8	0.239
Water bodies	0.33	1	2	3	5	4	5	5	4	5	2	5	9	0.168
Geology	0.25	0.50	1	2	3	3	4	4	3	4	4	3	6	0.121
Soils	0.33	0.33	0.50	1	3	3	1	3	4	4	4	3	5	0.099
Land use	0.20	0.20	0.33	0.33	1	2	3	3	2	3	2	2	4	0.067
Slope	0.20	0.25	0.33	0.33	0.50	1	2	2	2	2	3	2	3	0.056
Elevation	0.14	0.20	0.25	1	0.33	0.50	1	2	3	2	2	3	2	0.054
Road	0.14	0.20	0.25	0.33	0.33	0.50	0.50	1	1	2	2	2	2	0.036
Infrastructure	0.20	0.25	0.33	0.25	0.50	0.50	0.33	1	1	3	3	2	3	0.046
Airport	0.14	0.20	0.25	0.25	0.33	0.50	0.50	0.50	0.33	1	2	3	2	0.033
Population	0.50	0.50	0.25	0.25	0.50	0.33	0.50	0.50	0.33	0.50	1	2	2	0.038
Archeological	0.20	0.20	0.33	0.33	0.50	0.50	0.33	0.50	0.50	0.33	0.50	1	2	0.025
Railway	0.12	0.11	0.16	0.20	0.25	0.33	0.50	0.50	0.33	0.50	0.50	0.50	1	0.018

Furthermore, from the result of the weighting obtained, it was revealed that residential areas and water bodies are the most important criteria while railway was the least important.

C. Eigenvector

The eigenvectors of each row were calculated with the multiplication of each value of a given criteria in a column and same row of the original pairwise comparison matrix and then applying this to each row as shown in (3) [26]:

$$Eg_i = \sqrt[n]{(c_{11} \times c_{12} \times c \dots \times c_{1n})} \tag{3}$$

where *Eg_i* is the eigenvalue for row *i*, *n* is the total criteria number used in row *i*. The normalized eigenvector of the matrix, known as priority vector, was calculated from the pairwise comparison matrix by normalizing its eigenvalues to 1 as shown in (4):

$$Pr_i = Eg_i / (\sum_k^n = 1Egk) \tag{4}$$

These eigenvectors reflect weights of preferences [27] and can be defined as a method of normalized arithmetic averages [26]. The relative importance of the compared criteria was also computed from the values of the eigenvector [28]. *λ_{max}* is the highest eigenvalue of preference matrix. It was acquired from the addition of the products of multiplication between each element of the priority vector and the sum of columns of the reciprocal matrix (5).

$$\lambda_{max} = \sum_{j=1}^n [W_j \sum_{i=1}^m c_{ij}] \tag{5}$$

where *c_{ij}* is the criteria summation of a single column and *W_j* is the corresponding value of the priority vector for each criteria weight in the comparison pairwise matrix.

D. Consistency Check

Once the weight has been calculated, it is important to check for consistency. This is because the values used for the

computation of the weight are obtained from different opinions with different perspectives, therefore there is a possibility to encounter errors in the final stage of computation in the matrix [29]. The consistency index (*CI*) was computed using (6), λ_{max} is the greatest eigenvalue of preference and *n* is the total number of the compared criteria:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (6)$$

Calculation of consistency ratio (*CR*) was done by dividing the value of *CI* by the random consistency index (*RI*) [11]. *RI* is derived from the mean *CI* element gotten as a result of random simulation of the comparison pairwise matrix:

$$CR = \frac{CI}{RI} \quad (7)$$

where *CR* should be ≤ 0.10 for weight consistency check. If $CR \geq 0.10$ a revision in the judgement AHP matrix is required [30-31]. For this study, the *CR* value is 0.088, meaning that there is consistency in the AHP matrix, and the weights assigned to the criteria can be used for analysis [32].

E. Sanitary Landfill Suitability Evaluation

To find suitable potential areas for a sustainable sanitary landfill, the sum of the 13 weighted criteria thematic layers was put in the GIS environment using ArcGIS software. Criteria weights were assigned to each map layer which is in reclassified raster format using the Map Algebra tool based on:

$$A_i = \sum_{j=1}^n W_j \times C_{ij} \quad (8)$$

where *A_i* is the suitability index for area *i*, *W_j* is the relative importance weight of criterion, *C_{ij}* the grading value of area *i* under criterion *j* and *n* is the total number of criteria [32]. The *CI* value for this study is 0.137 and the *CR* value is 0.088 meaning that there is consistency in the AHP matrix and the weights assigned to the criteria can be used for analysis [32, 34]. Map algebra tool in the ArcGIS spatial analyst tool box was used to produce the final output map of the potential sites. The map was divided into four different categories: unsuitable, less suitable, suitable, and most suitable. The map in Figure 1 shows the distribution of the selected areas based on suitability where the most suitable are considered sites of higher priority. From the result of this map, it was found that most of the study area, 57% was unsuitable, 9% less suitable, 23% suitable and 11% most suitable. Moreover, to get the most suitable sites, the potential site map was then imported to the condition toolset in the Spatial Analyst tool in ArcGIS to identify the most suitable or highest priority sites for the determination of the best potential sites. From the most suitable sites, the best potential sites were identified by filtering the most suitable sanitary landfill layers. Thus, the output layer, in raster format, was converted into vector and then the areas that did not have an intersection with water bodies and railway were selected. Based on experts' judgment, using AHP criteria weighting and GIS analysis, 3 candidate sites appear to be the best from environmental, economic, and social perspectives (Figure 2). These sites fulfil the requirements for a sanitary landfill siting with a distance of at least 1000m away from roads, 1500m from residential areas, and far away from public and educational facilities.

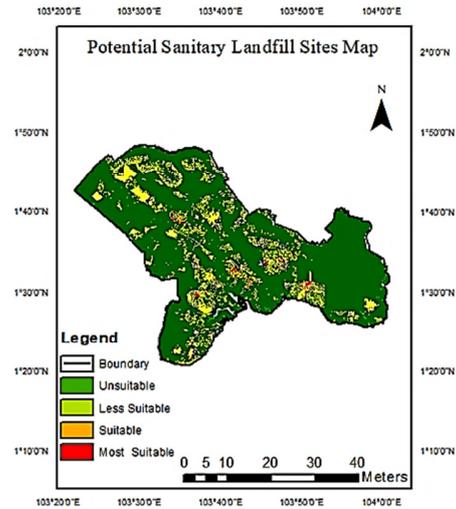


Fig. 1. Map of potential sanitary landfill sites.

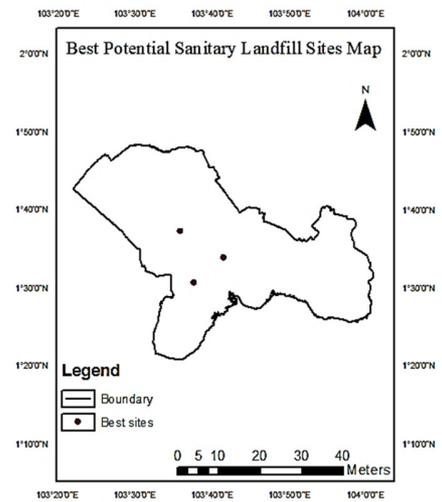


Fig. 2. Best potential sanitary landfill sites map.

Furthermore, after the integration of GIS and AHP, the final map was then converted to Keyhole Markup Language (.kml) file format which was used in the Google Earth PRO for further accuracy check, from which the 3 most suitable potential sites were selected among the most suitable class. The coordinates of these sites were taken from the Google Earth PRO for field check to determine the accuracy and precision of the sites.

IV. CONCLUSION

Rapid population growth and increase in economic and commercial activities have resulted to large increase of solid waste produced daily/annually. GIS and MCDA with 13 evaluation criteria were applied in this study for assessing the possible potential sites for sanitary landfill in Johor Bahru, Malaysia. AHP was used in calculating the relative importance weights of the criteria, which were assigned in the final suitability map production. The most important criteria for this study were residential areas with 23.9% and water bodies with 16.8%, while the least important criterion was railway with 1.8%. Based on experts' judgment, using the AHP criteria

weighting and GIS analysis, 3 most suitable potential sites were identified among the various sites from the most suitable class in the final map. Each of these sites fulfilled the necessary requirements of selection guidelines with a distance of at least 1000m from water bodies and roads, 1500m from residential areas, and far away from public and educational facilities. These sanitary landfill sites can serve as backups for the existing one that is almost attaining its maximum capacity. Finally, for the construction of the final sanitary landfill site, further geotechnical and hydrological analysis is required to prevent groundwater contamination caused by leachate.

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