MODELING LANDFILL SUITABILITY BASED ON MULTI-CRITERIA DECISION MAKING METHOD

W.M.A. Wan Hussin[1] and Shahid Kabir [2]
[1]*School of Civil Engineering, Universiti Sains Malaysia, Penang, Malaysia*
[2]*Sustainable Materials and Infrastructure, Collaborative µElectronic Design and Excellence Centre (CEDEC), Universiti Sains Malaysia, Engineering Campus, P. Penang, Malaysia*
M.A. Mohd Din[3] and W.Z. Wan Jaafar[3]
[3]*Department of Civil and Environmental Engineering, Faculty of Engineering, Universiti Malaya Kuala Lumpur, Malaysia*

ABSTRACT: Despite great efforts to reduce and recycle solid waste, landfill disposal is still the most preferable method of solid waste management. One major problem, however, concerns selecting an appropriate landfill site. This research aims to develop a landfill siting methodology employing GIS, and a multi-criteria decision making (MCDM) rule, consisting of analytical hierarchy processes (AHP) and weighted linear combinations (WLC). The proposed method was applied to the study area of the District of Klang, Selangor, Malaysia. Through this study, a few potential sites for a new landfill facility were identified by considering the various environmental, social and economic factors. The GIS is used for inputting, managing and visualizing the geographic data, while the AHP and WLC methods are employed for analyzing the data, to determine weights for the criteria, and to rank potential areas based on their suitability for landfill siting, according to suitability index (SI) values. Application of the presented method indicated 5 potential sites for landfill with SI values ranging from 2.67 to 4.00. The results show that the use of GIS along with the MCDM method provides a very useful decision support system for policy makers in solid waste management issues.
KEYWORDS**:** GIS; analytical hierarchy process (AHP); weighted linear combinations (WLC); landfill siting

1. Introduction

Landfill disposal is the most widely used method of solid waste management because it is the most economically and environmentally acceptable method throughout the world. Even with waste incineration, the ash produced is sent to a landfill for final disposal.[1] Currently, Malaysia is facing solid waste management issues as landfills are rapidly filling up, the amount of waste generated is increasing, the shortage of disposal land is on the rise, and the resulting environmental and human health impacts are becoming more and more serious. These circumstances are due to the escalating amount and various types of waste generated, caused by the growth in urban populations and industries, as well as the rising standard of living.

Historically, landfills have created various problems, such as groundwater contamination. Since these problems have a great impact on the community, the public has become increasingly aware of landfill issues. Therefore, associated problems could be minimized by implementing a proper siting technique that involves parties such as planners, engineers, politicians, as well as representatives of the public. Consequently, numerous criteria, factors, and regulations must be taken into account, such as avoiding floodplain areas, wetlands, surface waters, residential areas, etc.[2] These siting factors must be carefully analyzed in order to select an appropriate site that would have minimum environmental and economic impact, that would be accepted by the public, and that would comply with regulations as well. Without full consideration of all the current regulations and environmental, socio-cultural, engineering, and economic factors, policy makers may end up making inappropriate decisions.[1]

Since various input factors need to be considered in landfill-site selection, the conventional processing approach for landfill siting analysis becomes difficult, complex, and tedious. For instance, spatial data pertaining to the environmental, social, economic, and engineering factors need to be assessed, which is very time consuming. In addition, the siting process may need to be repeated several times until the most suitable site is selected.[3] The Geographical Information System (GIS) is widely used in landfill site selection to achieve the combination of the identified criteria in order to generate suitability maps.[4] It is the most reliable tool, as it is capable of storing, retrieving, and analyzing a large amount of data, as well as providing output visualization. Furthermore, landfill siting analysis using GIS allows greater time-effectiveness. Consequently, GIS has been utilized to conduct initial screenings in order to find suitable areas for locating landfill. Several techniques using GIS for landfill site selection were found in the literature.[5-6]

Multi-criteria Decision Making (MCDM) approaches are used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into smaller understandable parts, to analyze each part separately and then to integrate the parts in a logical manner.[7] The purpose of this study is to develop a landfill siting methodology that integrates a multi-criteria decision making method, which consists of the analytical hierarchy process (AHP) and weighted linear combination (WLC) methods, within a GIS environment. The presented methodology is applied to the Klang District, in Selangor, Malaysia, as a case study area, in order to evaluate the potential areas for landfill siting and to identify the best area for locating landfill.

2. Materials and Methods

2.1 *Study Area*

Klang, the Royal Capital of the State of Selangor, Malaysia, is located about thirty-two kilometres to the west of Kuala Lumpur and six kilometres east of Port Klang. This district covers an area of approximately 61,800ha, and contains residential, commercial, industrial, and agricultural land uses. The growing population in Klang has led to increasing contributions to daily waste. According to the Klang Department of Environment[8], the Teluk Gong waste disposal site, which operated up until 2000, was closed down because the leachate produced contained a significant amount of contaminants causing water pollution to the surrounding areas. In addition, the capacity of Teluk Gong had reached the maximum level, which is almost thirty meters. In 2001, a new waste disposal site opened in Teluk Kapas to replace Teluk Gong. The overall area is almost 44 acres and its lifespan is between 3 to 5 years. This site is still operating today, as there is no suitable area to replace it. For this reason, the Klang district was chosen as the study area.

2.2 *Siting Methodology*

GIS is capable of providing spatial analysis tools for sorting, retrieving, and manipulating geo-referenced computerized maps.[1] Since it efficiently displays information according to user-defined specifications,[9] GIS is an ideal method for preliminary site selection studies, and is widely used in various research fields, including landfill siting.[10] In the presented methodology, spatial analysis tools provided by the ArcGIS software has been integrated with the multi-criteria decision making procedure to facilitate landfill siting for the entire study area. The process of landfill site selection employed in this study is shown in Fig. 1.

Before the spatial analysis is performed, the constraint and factor criteria must be identified according to the local regulations, international practices, as well as from suitable literature related to the study area, and then outlined based on the evaluation of the environmental, social, and engineering-economic issues[11]. Constraint criteria represent the unsuitable areas according to the regulations, which prohibit landfill sites from being located within these areas due to possible conflict with the regulations and/or threat to the environment. Factor criteria are used to evaluate the remaining areas for landfill based on their suitability.

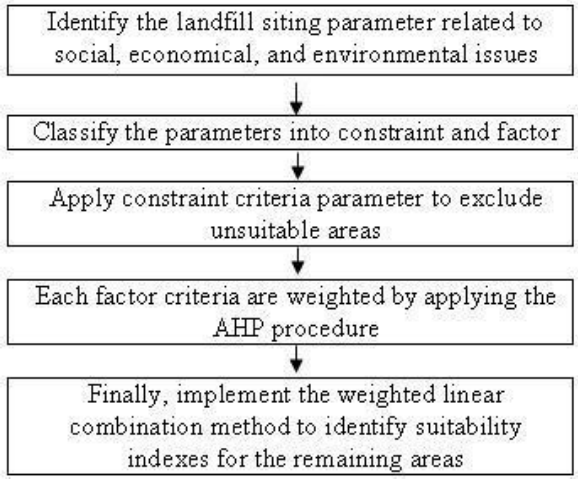

Fig. 1. Steps of the landfill selection process criteria.

There were eleven criteria identified for siting a landfill in the study area, namely historical site, swampland, flood prone, railway, residential, surface water, road accessibility, soil type, slope, land use, and urban. These criteria were divided into the two categories of constraint and factor criteria. All the data pertaining to the criteria were obtained from several government agencies, and most were already in the GIS format, except for archaeology, flood prone, and railway, which were in hardcopy format. Therefore, manual digitizing was performed to convert these data from hardcopy into the GIS format.

3. Results and Discussion

3.1 *Constraint Criteria*

The first step in this analysis is applying the constraint criteria to create a map of the excluded areas. There were seven criteria identified under this category:

(i) Surface water: water pollution is certainly one of the most important issues today and must be addressed accordingly in landfill selection processes. Pollution of surface water resources by leachate is a principle concern in relation to landfill location. Leachate generated by water passes through waste materials in landfills and becomes exposed, mobilizing a range of contaminants. Therefore, 100m buffer distance was applied around the surface water.

(ii) Residential: landfill should not be located near residential areas in order to protect the public from the nuisance and health impacts due to the potential hazards from landfills[6]. For this criterion a buffer distance of 500m was chosen.

(iii) Railway: this criterion is included since Klang has a railway system. Thus, any conflict with this railway system must be avoided. Hence, a 500m buffer zone is appropriate to be applied around the railway.

(vi) Flood prone: landfills cannot be located in areas that are prone to flooding in order to prevent the waste from washing out. These flood prone areas must be avoided when locating landfills.

(v) Swamp: swampy areas are not suitable for any kind of development. Thus, its natural ecological state must be protected.

(vi) Historical site: there are several historical sites in the Klang District, which must be preserved. Hence, they need to be avoided in landfill siting.

(vii) Urban: the goal of this criterion is to protect ‘‘sensitive’’ areas under economic development from being affected by the landfill siting areas, and to prevent decrease in land value and future development. Normally, these types of urban areas, such as port, industry, infrastructure, utility, institution, and business are definitely not suitable. Therefore, a buffer distance of 500m was applied around these areas.

The unsuitable areas were screened out by using the overlay function in GIS, based on the criteria used for the aforementioned issues. Fig. 2 shows the map layer of the combination of all the constraint criteria after buffering and restriction. The map layer in Fig. 3 indicates the areas that are suitable and unsuitable for locating landfill.

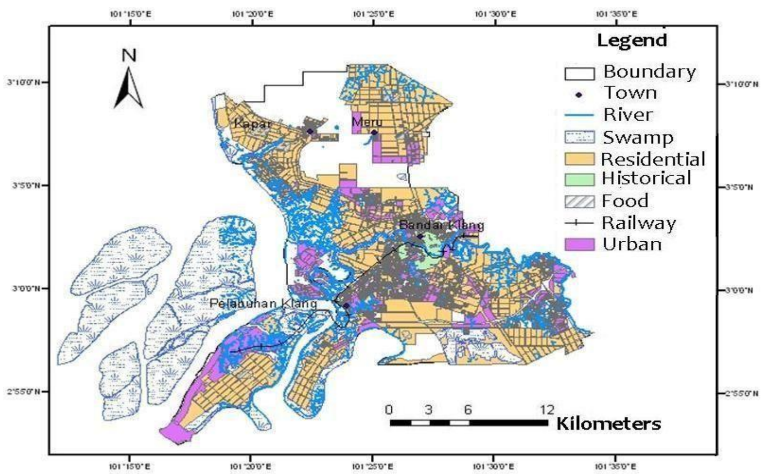

Fig. 2. Combination of all constraint criteria.

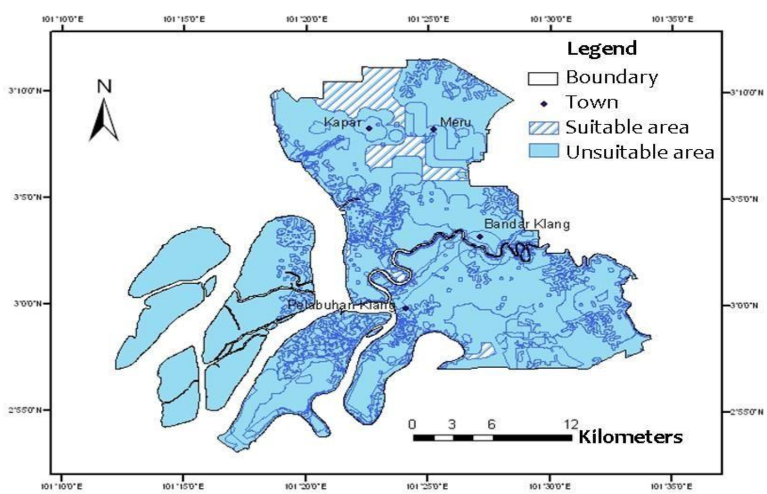

Fig. 3: Suitable and unsuitable areas for landfill siting.

The study site covers about 61,800ha. As can be seen in Fig. 3, most of the study area is unsuitable; these unsuitable areas were excluded from further analysis leaving only 3,588ha of suitable area. This suitable-area map serves as a mask layer for the next process, making it easier to spot possible landfill sites in the subsequent analysis by focusing on potential sites only.

3.2 *Factor Criteria*

The next process is to further examine the suitable areas for landfill. Factor criteria were used in order to further evaluate those areas. According to the Town and Country Planning Department[12] guidelines, the minimum requirement for a landfill site is 50ha. Fig. 4 presents the map layer of all the potential areas, while the map layer in Fig. 5 contains the selected areas with more than 50ha.

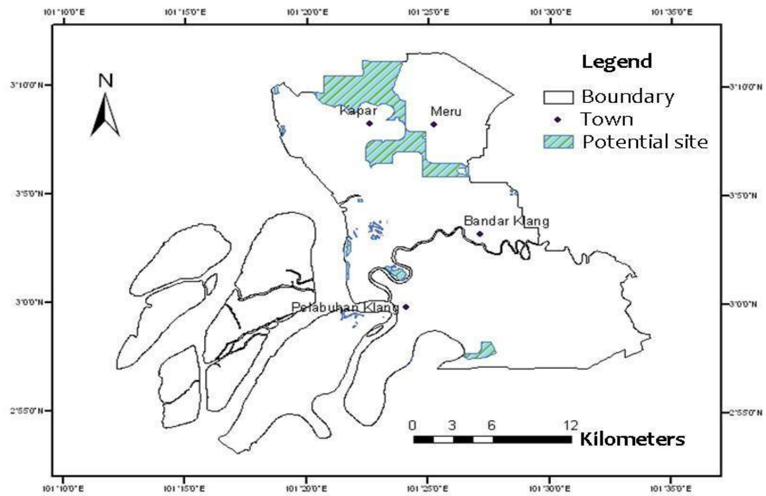

Fig. 4: Potential sites.

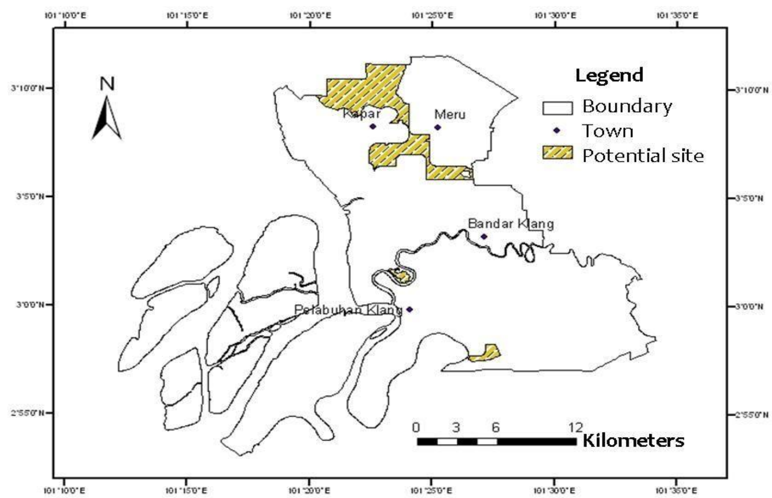

Fig. 5: Selected potential sites with area > 50ha.

These selected potential site maps undergo further analysis. At this stage, factor criteria were used to further evaluate these sites according to their suitability in order to indicate the most preferable site for locating landfill. In doing so, four factor criteria were identified and each one was categorized according to its suitability. The grading value of 1 to 4 was assigned to each category based on the suitability condition. These grading values indicate the landfill suitability condition ranging from the least to the most suitable. Thus, the explanation for each of the factor criteria below is in terms of its suitability according to that scale.

(i) Land use: in this study area, there are more than ten types of land use, from which, only five categories can be considered under this criteria. Table 1 presents the grading values for the various types of land use, and Fig. 6 shows the map layer for the land use classification.

Table 1: Grading value for land use.

Criteria	Grade
Lakes	1
Forest	2
Grassland	3
Agriculture / New clean area	4

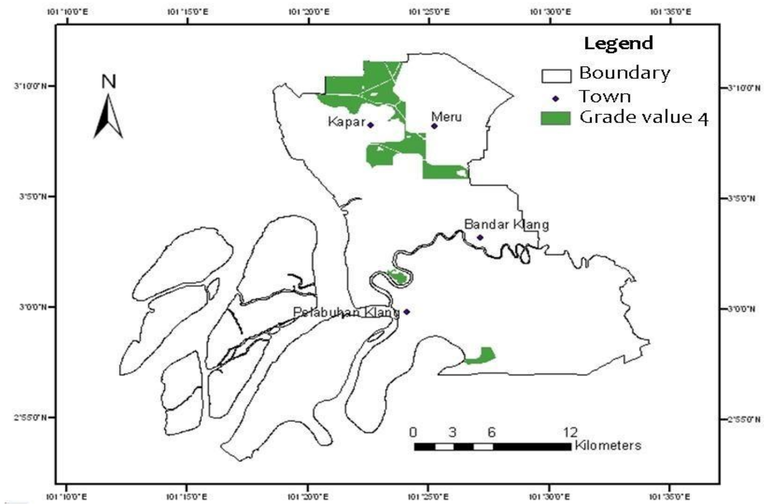

Fig. 6: Land use classification.

(ii) Soil type: there are six types of soil series that were identified. Preference was given to the soil types with very poor drainage or low permeability characteristics, as this is the most suitable for landfill. The grading values for each soil type are shown in Table 2, and the corresponding map layer classification is given in Fig. 7.

Table 2: Grading value for soil type.

Soil Type	Grade
Selangor	1
Urban land / Kranji	4
Steepland	3
Peat / Serdang	2

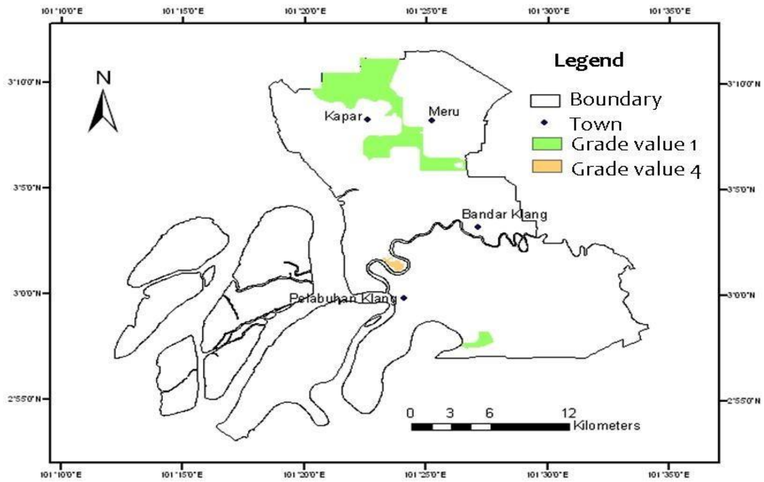

Fig. 7: Soil type classification.

(iii) Road Accessibility: if landfill is placed too far away from the existing road networks, costs for solid waste collection and transportation will increase. At the same time, it cannot be too close due to aesthetic value. Table 3 provides the grading values for road accessibility, and Fig. 8 presents the map layer for the road classification.

Table 3: Grading value for road

Buffer Distance (m)	Grade
0 - 500	1
500 - 1000	4
1000 - 1500	3
>1500	2

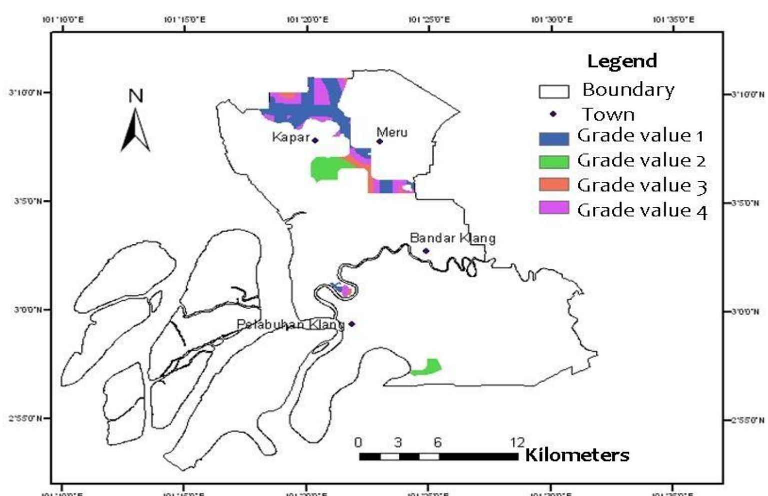

Fig. 8: Road accessibility classification.

(iv) Slope: the best slope to locate landfill is ranged between 0 to 25 degrees in order to minimize erosion and water runoff. The grading values for different slopes are shown in Table 4, and the map layer for slope classification is provided in Fig. 9.

Table 4: Grading value for slopes

Slope (degrees)	Grade
> 25	1
20 – 25	2
6 – 20	3
0 – 6	4

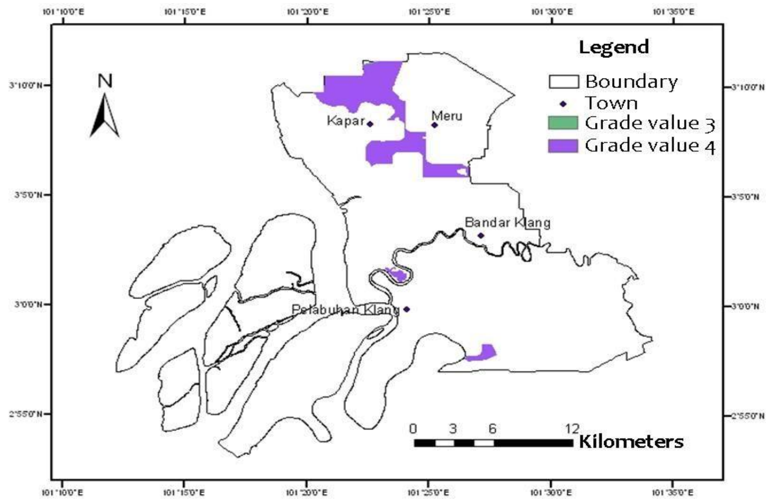

Fig. 9: Slope classification.

3.3 ***Application of Factor Criteria***

The analytical hierarchy process (AHP) and weighted linear combination method were used to identify the most suitable site within the selected potential areas. Decision-making is a sequential process[13]; it begins with the definition of the problem or the objective to be reached. Once the decision problem is defined, a set of criteria is determined that reflects all concerns of the problem and measures are determined as to what degree is achieved. The analytic hierarchy process (AHP) is a widely used method, which is utilized to determine the relative importance of the criteria in a specified decision making problem. The AHP method developed by Saaty[14] is an effective approach to extract the relative importance weights of the criteria. It is based on pair-wise comparisons that are used to determine the relative importance of each criterion. A matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9. Then a weight estimate is calculated and used to derive a consistency ratio (CR) of the pair-wise comparison; if CR > 0.10, then some pair-wise values need to be reconsidered and the process is repeated until the desired value of CR < 0.10 is reached.

Fig. 10 demonstrates the hierarchical structure of the factor criteria, which consists of a number of levels. The highest level, which is level 1, is the objective or goal for landfill siting. Level 2 consists of two categories of factor criteria: environmental and economic criteria, and slope, road accessibility, land use, and soil type criteria, while level 3 represent spatial attributes.

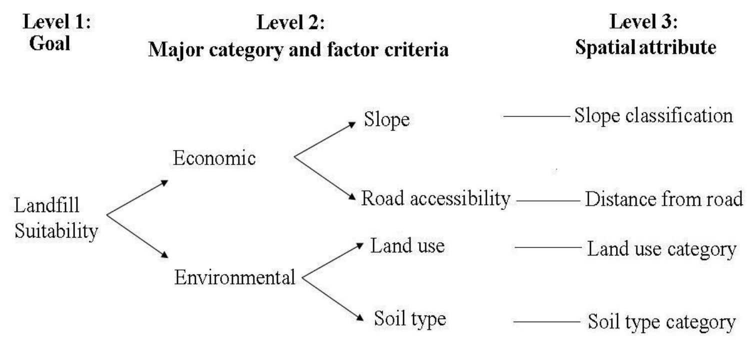

Fig. 10: Hierarchical structure of the factor criteria.

Then, a pair-wise comparison matrix is developed to determine the relative importance of each criterion. Here, decision makers can quantify the importance of these criteria by comparing pairs of criteria on a scale of 1 to 9, from least to most important, respectively. Table 5 shows the scale of relative importance developed by Saaty[14].

Table 5: Scale of relative importance

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocal Values	For inverse comparison

The pair-wise comparison matrix for this work is presented in Table 6. The relative importance weights are shown in the last column of the table. This pair-wise comparison judgment and relative weight of each criterion seem to be reasonable as the consistency ratio (CR) value is less than the threshold value. The last step of the process is the utilization of the weighted linear combination (WLC) method in order to calculate the suitability index. This method can be applied by using any GIS system that has overlay capabilities[7]. The overlay technique allows the evaluation of the factor map layers (input data) to be combined in order to produce a composite map layer (output map).

Table 6: Pairwise comparison matrix and relative importance weight for factor criteria

Factor criteria	Land use	Soil type	Road	Slope	*Priority Vector*
Land use	1	3	5	6	0.542
Soil type	1/3	1	3	5	0.264
Road	1/5	1/3	1	4	0.138
Slope	1/6	1/5	1/4	1	0.058

$\lambda max = 4.225$ CI = 0.075 RI4 = 0.9 and CR = 0.0833 < 0.1

The suitability index was calculated by using the grading values of the evaluation criteria, as discussed in Table 1 to Table 4, with their corresponding relative importance weight, or priority vector, taken from the last column in Table 6. The land suitability map layer for landfill siting of the Klang District, as calculated by the suitability index, is shown in Fig. 11. As can be seen, land suitability increases as the suitability index increases. Areas with a suitability index from 2.00 to

2.67 can be generally considered as less suitable for landfill siting. Sites with grades ranging from 2.67 and above are considered the most suitable areas for landfills. Finally, these most suitable areas were further screened in order to select areas with a minimum of 50ha. Five sites were identified that fulfil all the requirements; Table 7 provides a description of these areas and Fig. 12 shows the selected sites.

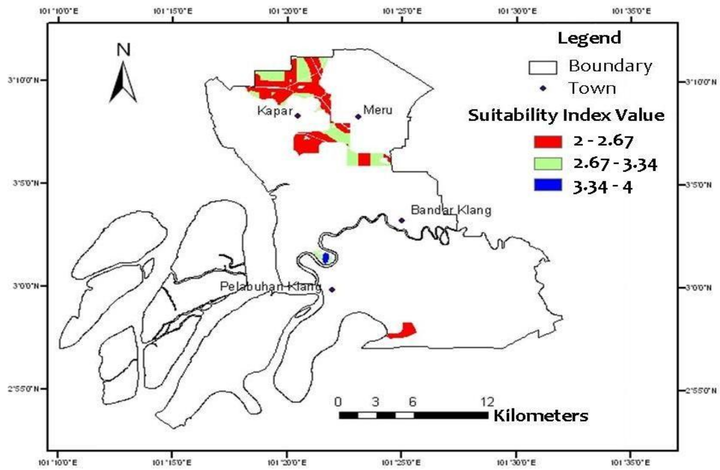

Fig. 11: Land suitability map layer for landfill siting.

Table 7: Description of the five selected sites suitable for landfill

Site	Area (hectare)	Description
Area 1	207	Eng Soon and Bukit Kerayong Estate
Area 2	181	Jalan Acob Estate
Area 3	215	Bukit Rajah Estate Harpenden Section
Area 4	121	Bukit Rajah Estate
Area 5	126	Bukit Rajah Estate

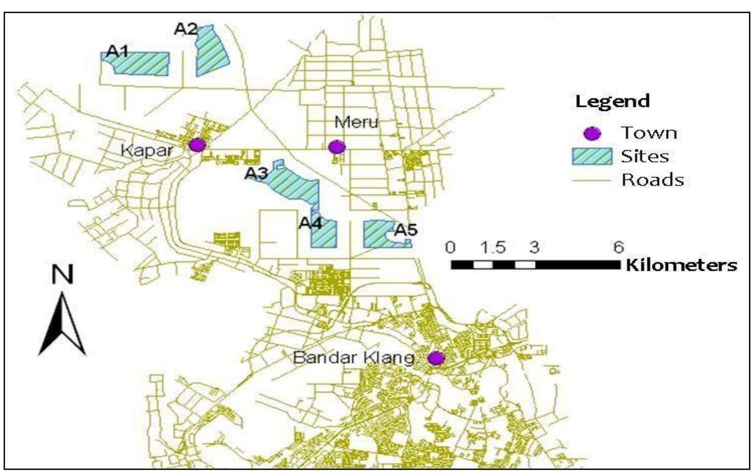

Fig. 12: The selected suitable sites with area > 50ha.

The weighted linear combination that was employed allows each factor to demonstrate its potential through the factor weights. Factor weights are very important in WLC because they determine how individual factors will aggregate. Thus, deciding on the correct weights becomes essential. Therefore, the analytical hierarchy process method was utilized to calculate the factor weights. The advantage of the WLC method is that all factors contribute to the solution based on their importance.

The evaluation criterion developed in this study is according to the local guidelines, such as those found in the Town and Country Planning Guidelines, international practices, as well as related literature. However, there were some limitations concerning the criteria used in this study, due to the difficulty of data availability. In real-world situations, various other parameters must be taken into account when siting a landfill, besides compliance with rules and regulations. The methodology presented in this study is flexible as far as the criteria determination is concerned. The criteria used can be expanded by adding other needed parameters for landfill siting.

4. Conclusion

The methodology described in the presented paper is an efficient approach for a landfill siting process. This study integrates the use of GIS along with multi criteria decision-making methods in order to site a landfill. The GIS has proved to be a useful tool for the integration of separate data sets and the creation of new ways for data visualization. The AHP and WLC are the decision-making procedures that have been employed in this study.

The conclusion that can be drawn from this study is that the GIS has the capability to combine information from various sources into a spatial context, and is well suited to support decision making procedures. GIS can be an invaluable tool in helping decision makers evaluate alternatives, visualize choices and explore other options. Furthermore, it should be noted that the siting methodology presented here is simply an approach to aid in preliminary site screening.

References

1. Kao, J.J., Chen, W.Y., Lin, H.Y., and Guo, S.J., Network expert geographic information system for landfill siting. *Journal of Computing in Civil Engineering,* **10** (4) (1996) 307–317.
2. Rimberg, D., *Municipal solid waste management* (New Jersey, London: Noyes Data Corporation. 1975).
3. Kao, J.J., and Lin, H.Y., Enhanced spatial model for landfill siting analysis, *Journal of Environmental Engineering,* **125** (9) (19990 845–851.
4. Leao, S., Bishop, I., and Evans, D., Spatial temporal model for demand and allocation of waste landfills in growing urban regions, *Journal of Computers, Environment, and Urban Systems,* **28** (2004) 353–385.
5. Sener, B., Suzen, M.L., and Doyuran, V., Landfill site selection by using Geographical Information Systems. *Journal of Environmental Geology,* **49(**2006) 376–388.
6. Basagaoglu, H., Celenk, E., Marino, M.A., and Usul, N., Selection of waste disposal sites using GIS, *Journal of the American Water Resources Association*, **23** (2) (1997) 455–464.
7. Malczewski, J., *Propagation of errors in multi criteria location analysis: a case study* (New York: Springer. 1997).
8. Department of Environment (DOE), *Environmental Impact Assessment (EIA) guidelines for municipal solid waste and sewage treatment and disposal projects* (Ministry of Science, Technology, and Environment Malaysia 1995).
9. Daneshvar, R., Fernandes, L., Warith, M., and Daneshfar, B., Customizing ArcMAP interface to generate a user-friendly landfill site selection GIS tool, *Journal of Solid Waste Technology and Management,* **31** (1) (2005) 1–12.
10. Kontos, Th.D., Komilis, D.P., and Halvadakis, C.P., Siting MSW landfills on Lesvos Island with a GIS-based methodology, *Journal of Waste Management,* 21 (3) (2003) 262–277.
11. Tchobanoglous, G., Theisen, H., and Vigil, S.A., *Integrated solid waste management: engineering principles and management issues* (New York: McGraw-Hill. 1993).
12. Town & Country Planning Department (TCPD), *Planning guidelines for toxic and solid waste disposal site* (Ministry of Housing and Local Government Malaysia. 2002)
13. Malczewski, J., *GIS and multi criteria decision analysis* (Canada: John Willey & Sons. 1999).
14. Saaty, T.L., *The Analytic Hierarchy Process* (New York: McGraw-Hill. 1980).