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Research Article
Landfill Site Selection Model Using an Integrated Approach of GIS and Multi Criteria Decision Analysis (MCDA): Example of Selangor, Malaysia

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Abstract
Background and Objective: Municipal Solid Waste (MSW) is disposed mainly in the landfill. Planners face great difficulties in the selection of suitable area for waste landfill especially in urbanized state, such as Selangor due to land scarcity, land price and increased solid waste generation. The current site selection approach known as Constraint Mapping Techniques (CMT) produced weak evidence to support the selection because the evaluation was based on the exclusionary criteria only. Therefore, this study was aimed to identify the optimal suitable areas for waste landfill. **Materials and Methods:** Integrated approach of Geographical Information System (GIS) spatial analysis and Multi Criteria Decision Analysis (MCDA) consists of Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC) were applied in this study. Six factors involved in the selection process namely as proximity to urban area, surface water, protected area, major road and railways, groundwater vulnerability and slope. **Results:** The 7% of the state or 560 km^2 were suitable for MSW landfill. Majority of the sites were classified as high and very high suitability except for C13. The largest area was determined as C1, where 55% (19,168 ha) of the land have high suitability and 44% (15,555 ha) have very high suitability. All of the candidate sites were located on agriculture land, which could be a challenge to agricultural industries and food safety in Selangor. **Conclusion:** The model is useful to identify suitable area for landfill sites and assist the decision maker to plan for the waste landfill construction. The model used in this study is in clear form of map that was easy to explain and understood. The approach is easy to expand to other parameters.

Key words: Municipal solid waste, landfill, geographical information systems, multi-criteria decision analysis, analytical hierarchy process

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Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Rapid urbanization process had increased MSW generation in the country, resulting to the needs for new landfills. Planners face great difficulties in establishing suitable locations for landfills due to complicated issues, such as land scarcity, land use, land price, financial constraints and political interference. Site selection process is complicated, which involved many factors, such as environment, socio-culture, technical and economy.

Landfilling is the main disposal method of Municipal Solid Waste (MSW) in Malaysia[1]. In total, 296 MSW landfills were recorded in the country, which 131 have been closed. Selangor state produce one-third of the total waste of the country and responsible to manage waste from Kuala Lumpur, the capital of Malaysia. The current landfills in Selangor only could receive 1.6 million t of waste per year, which is only half of the total waste[2]. This fact implies that new location for landfills is needed in near future.

The Malaysian Department of Environment had published a guideline for landfill sites selection in 1995, namely as Constraint Mapping Technique (CMT). This method was used to specify areas with unsuitable physical and environmental features. This method excludes the unsuitable areas based on the constraint features and the potential sites were selected from the remaining areas subject to rapid preliminary screening. This is to narrow down the search to the most desirable sites, which would then require detailed studies. However, CMT was not a comprehensive method and produced weak evidence or arguments to support the selection because the evaluation was based on the exclusionary criteria only.

This study was aimed to identify the suitable areas for waste landfill in Selangor using an integrated model of Geographical Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA). The study used in MCDA is a combination of Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC). This study is widely used in siting process[3-7] and has been recommended as a powerful tool to solve landfill site selection issues[4]. This model divides the process into small understandable parts, analysis them separately and integrates them in a logical manner[8]. It provides clear and understandable results, which assist the local government practitioner in getting support especially from the decision makers and public.

MATERIALS AND METHODS

Description of study area: Study was conducted in Selangor, Malaysia, a highly developed state with diversified economy of agriculture, industry, commerce and tourism. Selangor provide good context for this study as it is the major waste producer in the country. Agricultural activities utilize 51% of the total area in Selangor[9], which limit the selection area for waste disposal site. The total area of Selangor is 8,104 km^2 (Fig. 1) with 5.4 million inhabitants (2010), which approximately 20% of Malaysia's total population[10]. To date, Selangor has 22 landfill sites, which only eight landfills in operation.

Landfill areas determination: The total required area for landfill was calculated using formula in Eq. 1. The waste mass (kg) was projected based on the waste growth rate and number of population (Table 1). The waste specific density of 800 kg m^{-3} from Chong *et al.*[11] was used in the calculation while the depth (m) of a landfill was assumed to be 15 m:

$$\text{Area (ha)} = \frac{\text{Waste mass (kg)/Waste density (kg m}^{-3}\text{)}}{\text{Depth (m)}} \qquad (1)$$

The use of clay soil as waste covering materials adds 15% to the volume and additional space of 40% was added to the total area for emergency evacuation purpose and for other facilities construction[11].

Landfill siting method: Table 2 list the variables considered in the site selection model in this study. The relative important of these variables were identified through a pair-wise comparison matrix in Analytical Hierarchy Process (AHP) survey, where the expert is allowed to rate each row factor as compared to the column factor on a nine point scales[12-14] (Fig. 2). For example, proximity to surface water is classified as moderately less important compared to town and settlement areas. Thus, the eigenvalue for this criteria's was classified as 1/3 or 0.333 (Fig. 3). The AHP survey was distributed to the main experts of the Department of Drainage and Irrigation, the National Hydraulic Research Institute (NAHRIM), the Ministry of Housing and Local Government (MHLG) and the Department of Environment and Mineral and Geo-Science Department (JMG). The expert from universities; Universiti Putra Malaysia (UPM), Universiti Malaya (UM), Universiti Kebangsaan Malaysia (UKM) and environmental consultant companies also were involved in the survey. Twelve of the experts had involved in the survey.

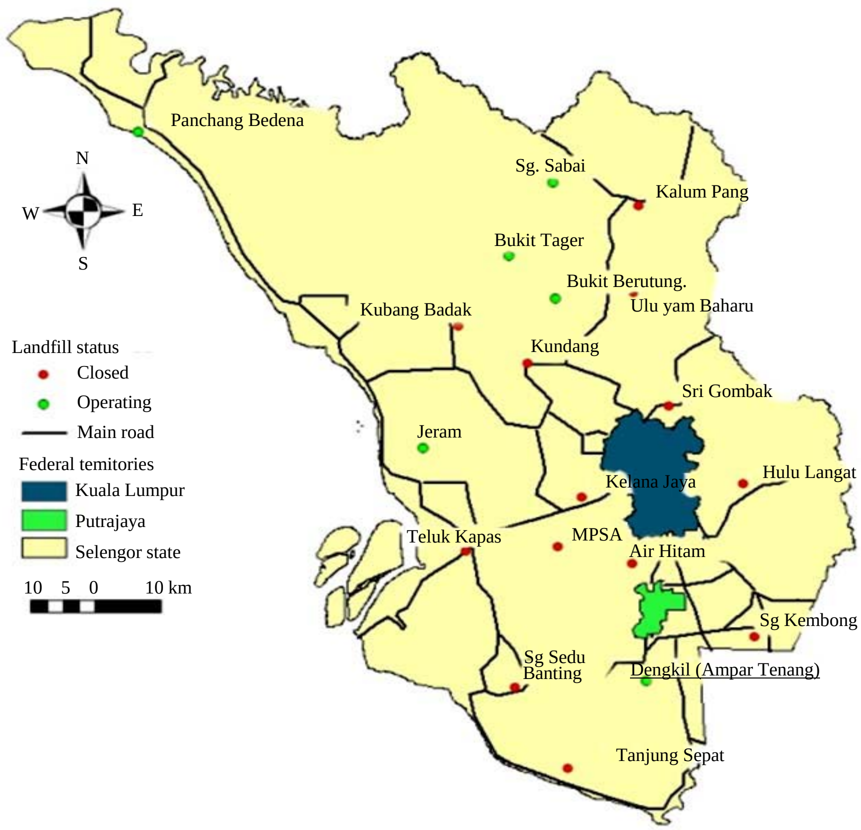

Fig. 1: State of Selangor and the landfills location

Table 1: Waste projections for Selangor and the federal territory of Kuala Lumpur

	Selangor[a]		Kuala Lumpur	
Years	Population ('000)[c]	Waste generation ('000 t year^{-1})[d]	Population ('000)	Waste generation ('000 t year^{-1})
2000[b]	4.190	1.240	1.420	1.082
2005	4.857	1.438	1.645	1.137
2010	5.631	1.666	1.908	1.195
2015	6.528	1.932	2.212	1.256
2020	7.568	2.239	2.565	1.320
2025	8.773	2.596	2.973	1.387

[a]Includes Putrajaya, [b]The volume of waste generated in 2000 reported by Tarmudi *et al.*[22] underpins the calculation, [c]The population was estimated at 3.0% per year, [d]The waste generation was estimated based on the average waste growth (1998-2000), 3.0% for Selangor and 1.1% for Kuala Lumpur

Table 2: Constraints and buffer distances used

Criteria	Buffers	References	Study Site
River, lakes and reservoirs	100 m	Gaim[23]	Sabah, Malaysia
Major roads and railways	100 m	Gaim[23]	Sabah, Malaysia
Protected area (wetland and forest)	500 m	Gemitzi *et al.*[19]	Greece
Slope	>12% (unsuitable)	Gaim[23]	Sabah, Malaysia
Urban, populated area and aitport	< 3 km and >25 km	Gaim[23] and El-Alfy *et al.*[24]	Sabah, Malaysia, Egypt
Groundwater vulnerability area	Extreme and high (unsuitable)	Wang *et al.*[20]	China

High eigenvalue indicate the most important criteria. The eigenvalue with Consistency Ratio (CR) between $\leq$0.10-$\leq$0.20 was considered to be used as the weight in Weighted Linear Combination (WLC) operation. The CR was calculated by the ratio of Consistency Index (CI) and Random Index (RI) (Eq. 2). Random Index (RI) is the

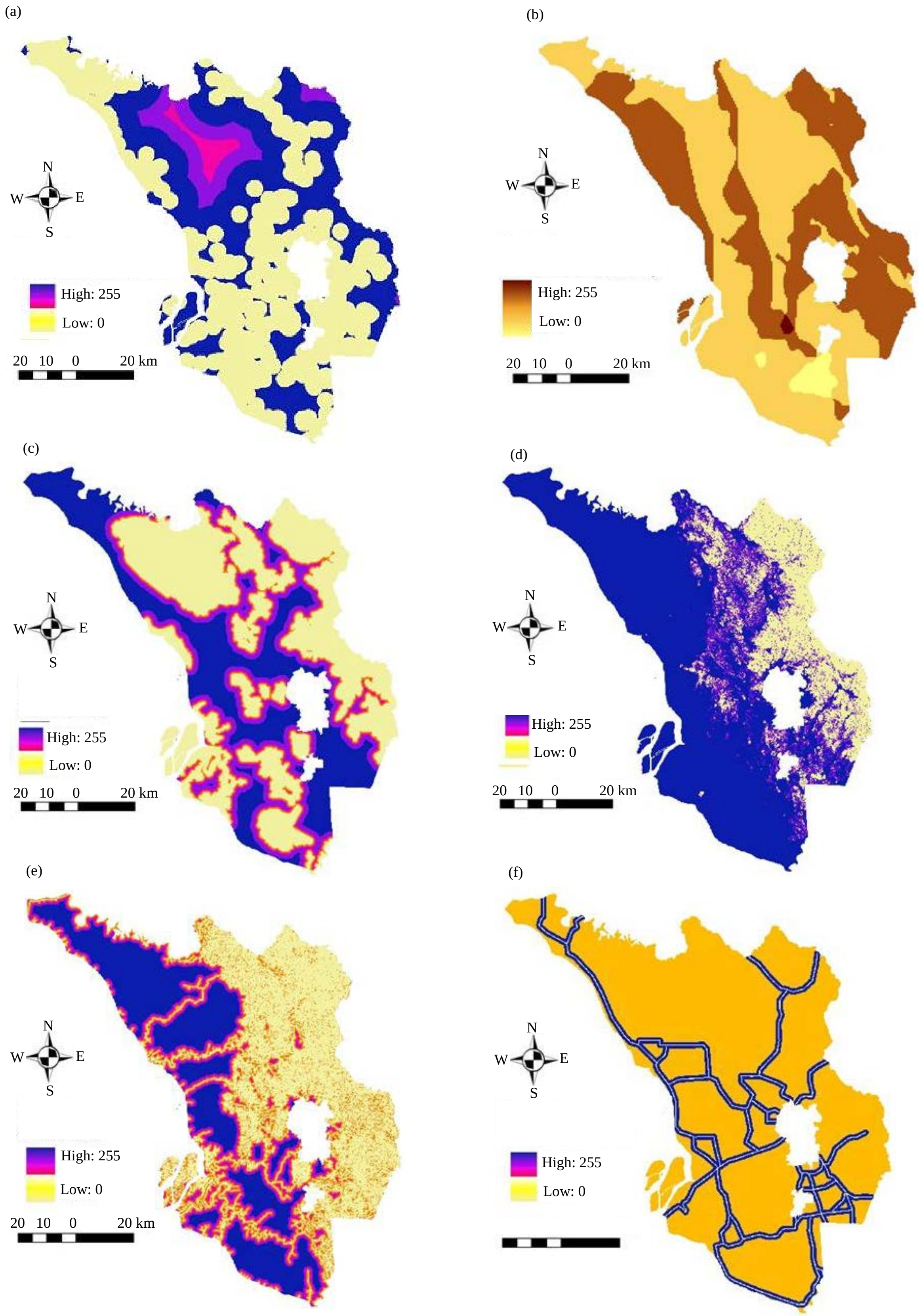

Fig. 2(a-f): Sactor maps used in the analysis, (a) Urban and residential area, (b) Groundwater vulnerability, (c) Protected area, (d) Slope, (e) Surface water and (f) Transportion routes

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely

← Less Important　　　　More Important →

Evaluation of row factor relative to column one	Proximity to town and settlement area	Proximitly to surface water (i.e., lakes, rivers and reservoir)	Distance from protected areas
Proximity to town and settlement area	1	Intentionally leave blank	
Proximitly to surface water (i.e., lakes, rivers and reservoir)	1/3	1	
Distance from protected areas	3	5	1

Fig. 3: Sxample of a pair-wise comparison matrix

average of CI calculated as in Eq. 3. The λmax is the maximal eigenvalue and n is the number of factors:

$$CR = \frac{CI}{RI} \quad (2)$$

$$CI = \frac{(\lambda max\text{-}n)}{(n\text{-}1)} \quad (3)$$

The WLC determines the suitability index for a site as the sum of the products of the standardised score for each criteria multiplied by the weight of each criteria[15,16]. This process can be expressed as the following formula:

$$S = \sum w_i c_i * \prod c_j \quad (4)$$

where, S is the suitability, w_i is weight of factor I, c_i is criterion grading of factor map I and c_j is the criterion score of the constraint j. The weight of factor I (w_i) is the eigenvalue weight from AHP.

The variable maps were assigned with a reasonable buffer obtained from literature (Table 2) using GIS. The buffer is to protect these areas from possible pollution of waste landfill. For example, 100 m buffer was the minimum distance used in most of the literature for rivers, lakes and major road. The buffer is used to constraint the area with Boolean logic 0/1, where the unsuitable land parcel was assigned as 0 (e.g., less than 100 m from river) and the suitable land was assigned as 1 (e.g., more than 100 m from river). The final map was converted into raster format with a uniform cell size of 100$\times$100 m to be used in the Weighted Linear Combination (WLC) operation. Euclidean distance Spatial Analyst of GIS was used to developed the factor map and was standardised using a linear scale of 0 (east suitable or not suitable) to 255 (most suitable) prior to combination. The standardised maps were multiplied by the weight values assigned from AHP procedure to calculate the suitability index in WLC operation.

RESULTS

The total waste volume for Selangor and Kuala Lumpur in 15 years (from 2010-2025) was projected as 43 million t (Table 1). One third of this waste (15 million t) was assumed to be disposed in the current landfills and the remaining 28 million t of waste will be disposed in new landfills. Based on this volume, the total land size required for the landfill in this study were 374 ha.

Table 3 shows the AHP eigenvalue weights of the variables and the Consistency Ratio (CR) based on the expert judgment. Seven of the experts have CR values between 0.07-0.17 and 5 experts have CR values between 0.21-0.35. According to Saaty[12], CR >0.1 was classified as poor consistency and untrustworthy because the judgments are too close for comfort to randomness. However, in numerous pair-wise comparison, perfect consistency (CR$\leq$0.10) is difficult to achieve[17]. In order to ensure the views of experts were taken into account and yet exclude the greatest inconsistencies it was decided to lower the acceptable consistency limit in this study to $\leq$0.1 to $\leq$0.20. This had the effect of including seven respondents with CR values between 0.07-0.17 and exclude 5 respondents with CR values between 0.21-0.35 from the analysis.

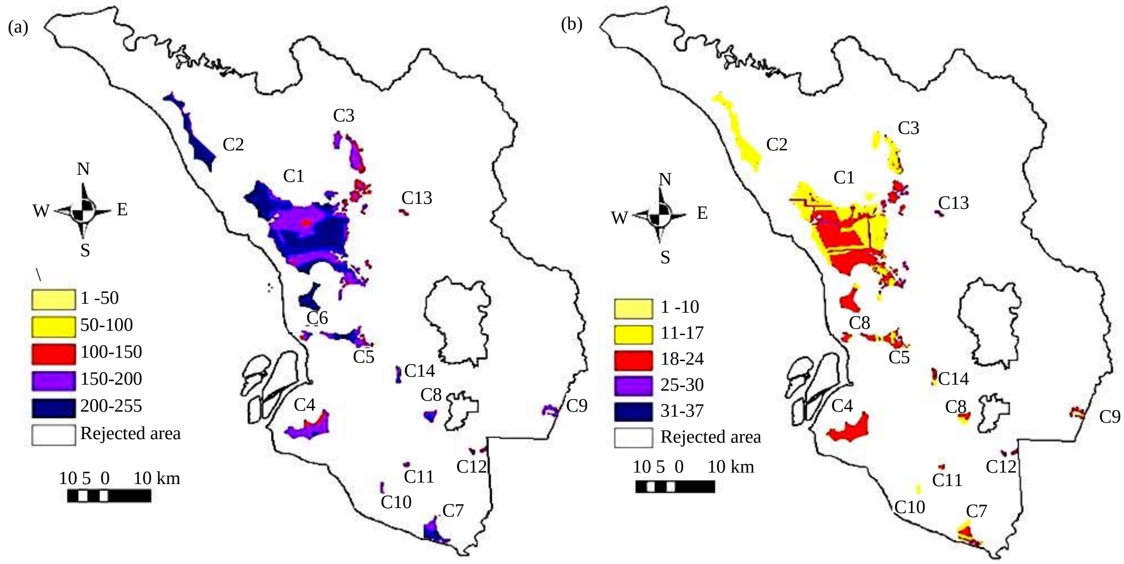

Fig. 4(a-b): (a) Mean suitability index and (b) Standard deviation

Table 3: Weights and CR values from the AHP pairwise comparison of the expert

Sector	Urban area	Surface water	Protected area	Transportation routes	Groundwater resources	Slope	CI	CR
Environmental consultant	0.164	0.337	0.337	0.024	0.114	0.024	0.12	0.10
MHLG[a]	0.351	0.068	0.081	0.140	0.117	0.243	0.13	0.10
NAHRIM[b]	0.062	0.181	0.181	0.051	0.285	0.240	0.15	0.12
NAHRIM[b]	0.044	0.091	0.141	0.241	0.241	0.241	0.22	0.17
University	0.318	0.129	0.318	0.025	0.140	0.070	0.08	0.07
University	0.117	0.201	0.262	0.047	0.286	0.087	0.14	0.11
University	0.024	0.290	0.154	0.107	0.344	0.081	0.15	0.12
Average	0.127	0.179	0.162	0.084	0.269	0.180	0.226	0.183
SD	0.111	0.138	0.100	0.061	0.103	0.148	0.117	0.096
Min	0.017	0.029	0.019	0.024	0.114	0.024	0.080	0.070
Max	0.351	0.498	0.337	0.241	0.409	0.540	0.430	0.350

[a]Ministry of Housing and Local Government, [b]National Hydrology Institutes Malaysia, CI: Consistency index, CR: Consistency ratio

Table 4: Area of suitable candidate sites by the index value and land use

	Average suitability index/area			
Candidate sites	Moderate (100-150)	High (150-200)	Very high (200-255)	Land use
C1	256 ha (1%)	19,168 ha (55%)	15,555 ha (44%)	Oil palm, rubber and cocoa
C2	-	1,088 ha (26%)	3,092 ha (74%)	Paddy field
C3	1,120 ha (25%)	3,372 ha (75%)	-	Oil palm
C4	357 ha (10%)	3,084 ha (86%)	129 (4%)	Oil palm and cocoa
C5	103 ha (4%)	1,996 ha (74%)	585 ha (22%)	Oil palm
C6	-	-	1,791 ha (100%)	Oil palm
C7	-	1,146 ha (66%)	602 ha (34%)	Oil palm
C8	-	878 (89%)	109 (11%)	Oil palm
C9	10 ha (2%)	627 ha (98%)	-	Rubber
C10	-	185 ha (100%)	-	Oil palm
C11	32 ha (19%)	138 ha (81%)	-	Oil palm
C12	126 ha (37%)	213 ha (63%)	-	Oil palm
C13	137 ha (67%)	66 ha (33%)	-	Oil palm
C14	-	335 ha (92%)	28 ha (8%)	Oil palm

Figure 4 shows only 7% of the state or 560 km^2 (55,953 ha) area was suitable to develop waste landfill. The figure shows the mean suitability index value of WLC operation and the standard deviation. Five categories of suitability index, which is very low (1-50), low (50-100), moderate (100-150), high (150-200) and very high suitability (200-255). Table 4 highlights the land parcels size by the suitability index value and the land use in details. There were 14 land parcels (C1-C14), where majority of the area with high and very high suitability and mainly located on agricultural land. The C1 was the largest area with high suitability (99%, 34,723 ha). C2 (4,180 ha), C3 (3,372 ha) and C4 (3,213 ha) also have high suitability and big land size of >3,000 ha. The C13 was the area with less suitability where only 33% (66 ha) of the land has high suitability.

The C2 and C5 were a reasonable option to represent the north and central of the state. These areas were located less than 10 km from the population town. Meanwhile, C9 was the best option for the south as 98% of this site has high suitability and close to the city. Some candidate sites such as C3, C10, C11 and C12 were not attractive due to far from the population area, which may increase the cost of waste disposal management. Other area such as C4 and C7 were too close to the coastal, which toxic element from the landfill possibly seepage and migrate to the sea water. Site that close to the federal administrative office in Putrajaya also was not attractive (C8) as it may impair the view of the city and leave bad impact to the tourism activity.

DISCUSSION

This study integrates the spatial analyst of GIS and Multi Criteria Decision Analysis (MCDA) in the site selection model. The approach used in this study was proven to be able to develop a clear result, which may assist the decision makers in the waste management planning. The approach used was practical and direct and the results produced were easily explained and understand. The GIS-aided siting methodology is easy to expand and the process helps to structure the decision problem. The technology provides the capabilities of data acquisition, storage, retrieval, manipulation and analysis to develop information that can support decisions. The GIS models not only support the decision procedure but also facilitate the communication and mutual understanding between the decision maker and the wider public, since the implications of solid waste management are important for the well being of a society[8,18].

The use of WLC in this study has standardized continuous criteria to a common numeric range and combined them by means of a weighted average. In this case, the choice of weights and weighting techniques played a crucial role, where Pairwise matrix AHP was used to consider the opinions from experts and decision-makers. The factors used in this approach are not fixed where they can be varied from area to area and the criteria can be changed accordingly in the analysis process. This flexibility enabled the selection of a site considered to be compatible with the available resources, such as land size and cost in particular region. The pairwise comparison in AHP offered a quite objective weight assignment process as supported by a review of relevant landfill siting literature[7,18-20]. This approach also allows to check the consistency of the weights through Consistency Ratio (CR). However, it must be noted that the presented method is only to aid decision makers to provide insights and understand the problem rather than to prescribe a decision itself[8,18]. The final decision of where to site a landfill is as much a political decision as a scientific one and strongly depends on public opinion[18,21]. The sites suggested in this study satisfy the minimum requirements of the landfill sites and the final ones should be selected after thorough field checks and further assessment of geotechnical and hydrogeological aspects.

A limitation of this method is the selection of the sites was dependent on the judgments of experts in defining the factor weights and the grading values. It is possible that in certain situations, two experts may have contradicting judgments about the weight of different factor and the rating curves depicting the relationship between suitability and the quantity of a factor. Therefore, it is important that people with local knowledge or expertise are involved in the project to ensure that the outcomes are adequately ground-truth and are relevant to the local context.

There are still several topics regarding the spatial MCDA in GIS that could be explored. For example, the selection of attributes as suggested in Malczewski[8], need to consider of their completeness, independence and real influence or weight, the scale and methods of aggregation of attributes, error in assessment and the incorporation of database and decision rule uncertainty and sensitivity analysis. Several recommendations can be made to improve this study. For instance, soil type can be considered in the siting model as it is an important factor to determine the contamination potential. Soil has different hydraulic conductivities and attenuation properties that produce different contamination potentials. Furthermore, the sensitive and uncertainty analyses of the map produced from the model to validate the result.

CONCLUSION

In conclusion, the GIS-MCDA as decision support tools for landfill siting is proven to be practical and useful in this study. The approach has identified suitable area for landfill sites in clear form of map that was easy to explain and understand. The model used in this study is an aid to decision makers to provide insights and understand the problem. The approach is easy to expand to other parameters and the process helps to structure the decision problem. It also offered an objective weight assignment process.

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