GIS based sanitary landfill suitability analysis for sustainable solid waste disposal

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GIS based sanitary landfill suitability analysis for sustainable solid waste disposal

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Abstract. One of the major challenge in waste management is the issue of selecting an appropriate site for the disposal of municipal solid waste (MSW). This is because landfill siting analysis typically requires evaluating various rules, factors, constraints, and numerous spatial data such as environmental, economic, social etc. This paper introduced an integration of Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP) in selecting optimal and sustainable site for sanitary landfill for proper solid waste management in Johor Bahru, Malaysia with the consideration of future population and waste generation prediction. The site selection criteria were retrieved based on existing literatures, Malaysian landfill siting guidelines and expert judgements. Several input criteria were used for this study which include water body, road, slope, elevation, rail lines, forest, vacant and agricultural lands, soil, geology, and urban areas. All these criteria maps were prepared in the GIS environment after which the criteria weight was obtained from AHP pairwise comparison matrix and normalization. Furthermore, the weighted criteria were evaluated through GIS software by using the weighted overlay tool in ArcGIS. The results of the study are categorized into 'most, 'suitable' and 'unsuitable' landfill sites. The best sites are those that possess the optimal quality and characteristics for sustainable MSW disposal while the suitable sites can be kept as back up for future use.

1. Introduction

The oldest most common and popular method of solid waste disposal for many countries all over the world is landfilling. Presently, increase in population growth in most urban cities has given rise to an increase in waste production along with environmental pollution through human activities. Therefore, selection of sustainable site for sanitary landfill and proper disposal of solid waste is unavoidable [1]. Malaysia disposes about 28,500 tons of municipal solid waste directly into landfills daily(agamuthu). This fact alone necessitates sustainable landfills to avoid adverse impacts on the population and the environment [2]. Furthermore, the main waste disposal technique in Malaysia currently is landfilling, accounting for over 80 % of the collected MSW; However, this technique is becoming more difficult to use properly because of the issue of inadequate land available for the construction of landfill and the existing landfill sites are reaching their capacity limits which means that new sites needs to be constructed [3]. However, due to the consideration of the public health and social well-being, landfill cannot be constructed near the residential areas. Also the not in my back yard syndrome (NIMBY) meaning the community oppose the landfill siting near their residential areas [4] which has become a big challenge to the decision-makers.

In addition, the process of attaining a suitable sanitary landfill site is very tedious, complex and time consuming because it involves various experts from different field of knowledge such as environmental, economic, political, social, technical, and engineering. This makes the site selection process becomes more challenging as it involves dealing and evaluation of such large amount of data which is guided by rules, regulations, factors and constraints [5, 6]. Geographic information systems (GIS) is an ideal tool for this study because of its ability to manage large amount of spatial data acquired from different sources [7] while Multi-Criteria Evaluation (MCE) investigates a number of possible choices for a siting problem, taking into consideration multiple criteria and conflicting objectives [8].

The aim of this research is to select a proper sanitary landfill site for at least 30 years life span in Johor Bahru using both of GIS, MCE, and remote sensing. Various important criterion were being considered to achieve the objectives of the study such as water body, road, slope, elevation, rail lines, land use (forest, vacant lands, and agricultural lands), soils, geology, and urban areas.

2. Methodology

2.1 Study Area

The city of Johor Bahru is located in the southern region of Malaysia (Figure 1). It lies within latitude 1° 29′ 0″ N and longitude 103° 44′ 0″ E. It has a population of about 1.5 million by 2010 statistics and expected to be 2.8 million in 2025 [9] due to rapid increase in population and economic activities giving rise to an increase in solid waste generation consequently filling up the available landfill. A recent estimation indicates a solid waste generation of approximately 1.27 tons per day with average per capita of almost 562 g/day [9].

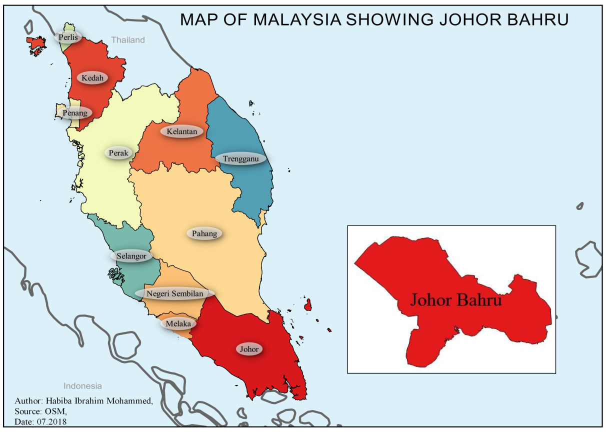

Figure 1. Map of the study area.

Moreover, the current sanitary landfill in Johor Bahru has almost reached its capacity limit hence, there is a need for an appropriate sanitary landfill siting [10]. But, the landfill sites must comply with the landfill siting rules, regulation, and guidelines. This is to prevent health hazard and water contamination which may occur from the negative impact of the landfill if not properly selected. Furthermore, properly selected landfill is paramount towards sustainable solid waste management.

2.2 Materials and Methods

Landfill siting criteria was firstly reviewed and identified based on literature and landfill siting guidelines for Malaysia in National Strategic Plan for Solid Waste Management [11]. There are three main criteria used (environmental and economic) which were divided into sub-criteria. For this study, GIS, AHP, and remote sensing techniques where used for sustainable sanitary landfill site selection. Slope and elevation were prepared from satellite images and the remote sensing methods. The topographical map was digitized, and several criteria maps were derived from it such as road, water body, and rail lines by digitizing, and topological error check. Comprehensive literature obtained about secured and reliable distance to landfill site is employed to allocate the buffer zones for each layer. This is based on governmental guidelines, experts' judgement, local and international references. Each criterion was classified into classes, and each class was given a suitability score within 0 to 10 where 0 applies that the area is unsuitable and 10 means the condition for that criterion is suitable [7, 12-14].

All the map layers were later transformed into raster data with 30m spatial resolution. The land use map was used to extract some data layers such as urban areas, commercial, industry, public facility, vacant land, forest, agricultural land. All these map layers preparation was done using the GIS techniques such as buffering, distance map generation, overlay anlysis. Furthermore, AHP technique was employed to determine weights to each criterion using expert judgement. The map layers were entered in the Map Algebra tool in ArcGIS software through the summation of the products of multiplying the weight of each criterion which was calculated using AHP method based on the rated value of each sub-criteria of each criterion.

2.2.1 Analytic Hierarchy Process (AHP)

The most popular and most commonly used MCDA method is Analytic Hierarchy Process (AHP) which was introduced and established by Saaty [15]. It is a decision-making tool used in solving multiple criteria problems because of its ability in the determination of relative weight of multiple criteria which are expressed in numerical order of 1 to 9. Pair wise comparison method is carried out among the criteria through the scores and weights assigned to each criterion [16, 17]. AHP is complicated when there is large number of criteria to be the considered in the decision-making process. Saaty [18] explain the scale values and their definition as shown in Table 1.

Table 1. Pair wise comparison scale

Intensity of importance	**Definition**
1	Extremely less important
2	Very strongly less important
3	Strongly less important
4	Moderately less important
5	Equally important
6	Moderate important
7	Strongly important
8	Demonstrate important
9	Extreme important

The pair wise comparison method was used also in this study to compare each criterion in the AHP excel template, and relative importance of each criterion to another was determined. Which after the completion of comparison, the weights of each criterion was produced (See Table 2).

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Table 2. Criteria weight and ranking

Main Criteria	Weight	Sub-Criteria	Weight	Buffer zones	Ranking
		Water bodies	0.20	<500m	0
				500-1000	2
				1000-2000	6
				2000-3000	8
				>3000	10
		Soil	0.14	Low permeable	8
				Medium permeable	5
				Highly permeable	0
Environmental	0.70	Slope	0.03	$0\text{-}5^0$	6
				$6^0\text{-}10^0$	4
				$10^0\text{-}15^0$	3
				$>15^0$	0
		Elevation	0.04	500-1000m	0
				1000-1500	3
				>1500	5
		Residential	0.17	<500m	0
				500-1000	3
				1000-2000	5
				>2000	9
		Airports	0.05	<3km	0
				3-6km	6
				6-9km	7
				9-12km	8
				>12km	10
		Geology	0.05	Intrusive	7
				Intermediate	6
				Acidic	0
Economic	0.30	Road	0.06	<500	0
				500-1000	2
				1000-2000	6
				2000-3000	5
				>3000	0
		Population	0.03	Low density	7
				Medium density	5
				High density	3
		Infrastructures	0.03	Power lines	0
				Pipe lines	0
		LU/LC	0.20	Agric land	6
				Forest	3
				Vacant land	10

3. Results and Discussion

An optimized sanitary landfill siting process must undergo a rigorous process of criteria evaluation in order to prevent subsequent adverse long-term negative impact to the environment such as groundwater contamination, air and noise pollution. Also, it should be situated very far away from population density areas for prevention of public health. Due to economic factor landfill is not advisable to be located far from the main road, this is to reduce cost of transportation and collection. About thirteen sanitary landfill criteria maps were prepared based on literature review and Malaysian guidelines for landfill siting.

3.1 Landfill Siting Criteria

3.1.1 Surface water

Sanitary landfill sites cannot be constructed adjacent to water bodies such as rivers, lakes, streams, and ponds [19]. This is due to adverse environmental effects which can occur and contaminates the water body as a result of leachate being produced from the landfill site area [20]. Thus, a 500m buffer zone was created for each of the water body in the study area which is in line with the Malaysian landfill siting guidelines (see Figure 2).

3.1.2 Distance to road

The topo-sheet map of the study area was used to extract the road data. The road data include information on highways, major and minor roads, and their connections. This data is necessary because when selecting landfill sites, accessibility of the site must be considered especially for the vehicles used for collection and disposal of waste to landfill. Due to this reason, high scores were given to areas near the roads (see Figure 3).

3.1.3 Slope

Slope is an important criterion when siting a sanitary landfill site. From economic perspective, cost of construction in areas with steep and high slope will be more expensive than in areas of medium slope. The slope layer for this study was generated from the digital elevation model (DEM). The areas with slopes greater than 15^0 are considered unsuitable for sanitary landfill [21] see (Figure 4).

3.1.4 Land Use/Land Cover (LU/LC)

The LU//LC map was derived from Iskandar Regional Development Agency (IRDA). There are different types of land use in the study area. Therefore, values were assigned to each land use type based on its suitability level. Areas such as sensitive ecosystems, protected forest, and historical sites were assigned with 0 scores while areas like vacant and agricultural lands were given the scores of 10 and 6 respectively (see Figure 5).

3.1.5 Soils

Soil is one of the key criteria to be considered when siting a sanitary landfill. This is to prevent groundwater contamination from landfill leachate. The soils of the study area are divided into three permeability zones which are high, medium, and low zones. Therefore, the areas with high permeability rate are considered unsuitable for sanitary landfill sites [22] and were assigned with 0 score. This is because leachate infiltration is possible to occur there by contaminating both the ground and surface water of the neighboring areas. In addition, areas with low permeability rate were given much preferences and are considered suitable for sanitary landfill sites with a given score of 10 (see Figure 6).

3.1.6 Geology

There are seven different geological structures presence in the study area based on the geological map, three out of them are of intrusive rocks which are intermediate, acidic, and basic (mainly gabbro).

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Scores are assigned to these geological structures according to their suitability level based on reviewed literatures, thus making sure it is not located in geological fault area (see Figure 7).

3.1.7 Residential Areas

This criterion does not permit landfill siting in the area. The presence of any waste disposal site near or within the urban and rural residential area may cause health and environment problems. According to [20, 23], desirable distance from landfill sites to the residential should be 1km and above. Therefore, distance of 500m and above was taken into consideration as suitable landfill location.

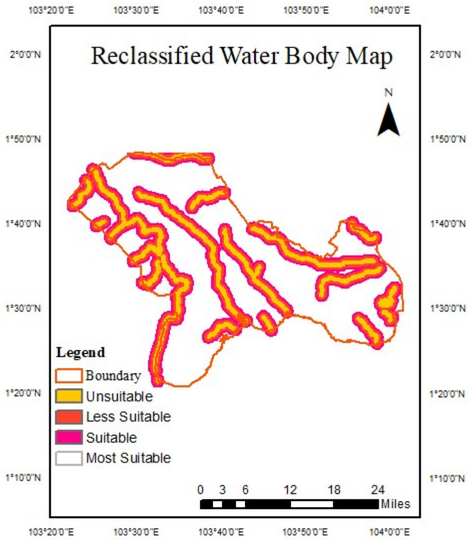

Fig. 2. Reclassified water body

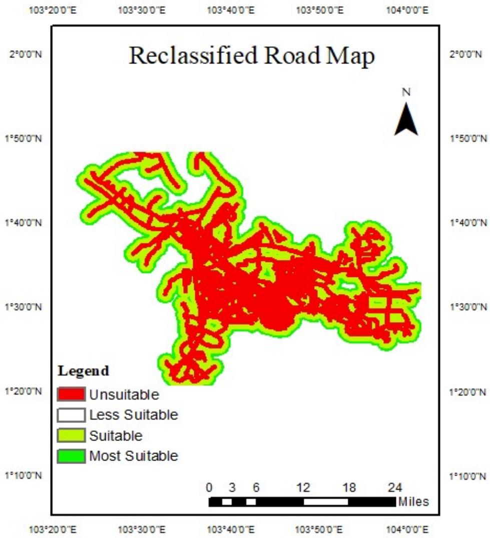

Fig. 3. Reclassified road

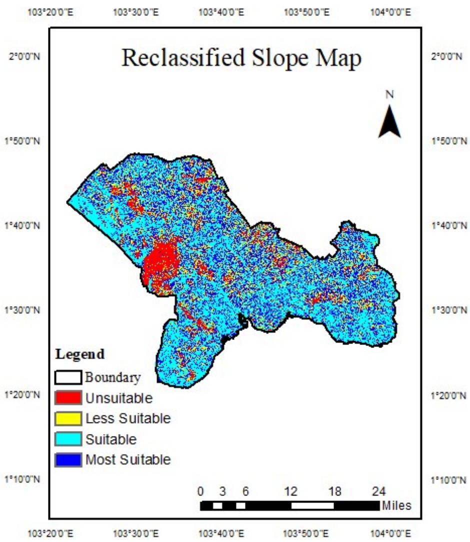

Fig. 4. Reclassified slope

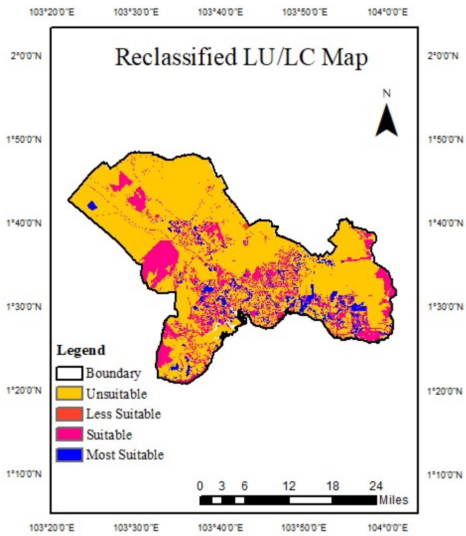

Fig. 5. Reclassified LU/LC

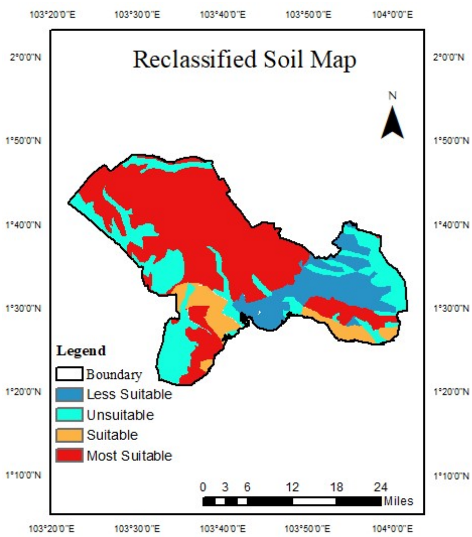

Fig. 6. Reclassified soil

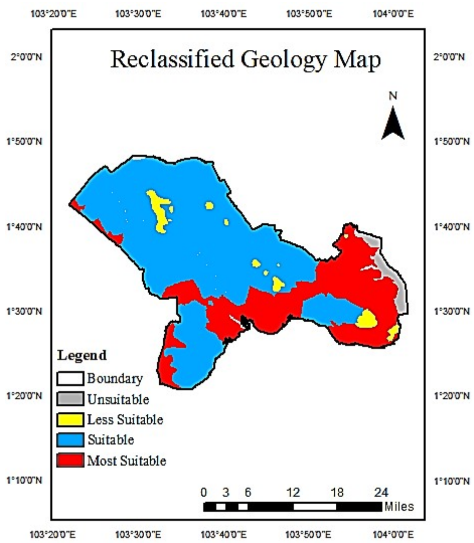

Fig. 7. Reclassified geology

Final suitability map was obtained after assigning weight to each criterion through the AHP method and sub-criteria weighting, the ArcGIS was used to reclassify each criteria map which was converted from vector to raster format. Map algebra tool was further used to execute the analysis by multiplying each criterion with its weight plus another criterion for the suitable landfill sites. The results were classified based on four classes which are unsuitable, less suitable, suitable, and most suitable (see Figure 8).

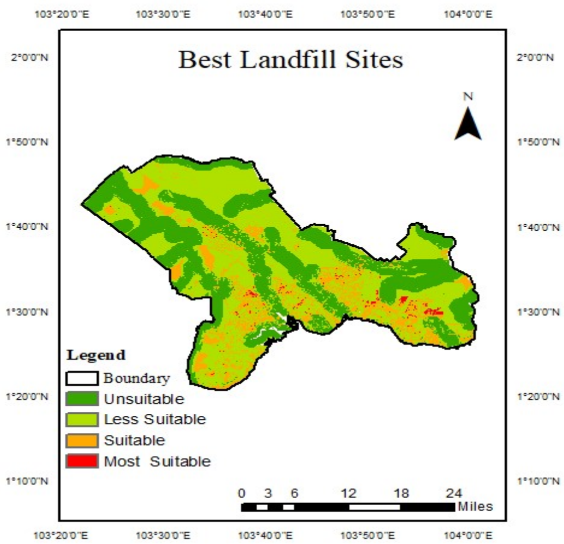

Fig. 8. Landfill suitability map.

4. Conclusion

The reason for sanitary landfill site selection process is to evaluate the best and optimized sites before the construction of landfill. The current study was able to analyze the convenient and suitable sanitary landfill sites for sustainable solid waste disposal in Johor Bahru, Malaysia. GIS-Based AHP method was selected as one of the most common techniques in MCDA, also because of its accuracy and efficiency in landfill site selection studies. The AHP method was implemented in allocating criteria weight to each parameter based on its relative importance in the landfill decision process. In addition, for the construction of final sanitary landfill site, further geotechnical and hydrological analysis is required to prevent groundwater contamination caused by leachate as well as surface water.

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