ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE March 2023. Vol. 19(1):51-70
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

GEOSPATIAL MULTI CRITERIA SELECTION OF BEST SANITARY LANDFILL SITE AND THEIR GEOTECHNICAL AND DIGITAL IMAGE ANALYSIS

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ARTICLE INFORMATION

Submitted 7 August, 2022
Revised 3 October, 2022
Accepted 6 October, 2022

Keywords:
Geographic information system
Geotechnical engineering
Permeability
Solid waste management
Digital image technique

ABSTRACT

Contaminations caused by municipal waste affect not only the soil but also water and air. In many parts of the world, there are many uncontrolled landfills that often lack the necessary anti-fouling barrier systems which causes leachate to permeate the underlying groundwater making it toxic for consumption. This research presents a sustainable method in which sanitary landfills can be sited using geospatial multi criteria method and the subsequent application of geotechnical and digital image analysis. Due to the large volume of spatial data, thus, Geographic Information System was used to handle, evaluate, and process these data. Meanwhile, Analytical Hierarchy Process was applied to solve decision making problems where multiple alternatives and competing objectives are involved. The results revealed three most suitable sites for sustainable sanitary landfilling in the research area. These most suitable sites were further examined using geotechnical criteria in laboratory to obtain the best site. Engineering property relating to permeability was investigated. The results show that only one amongst the three sites achieved maximum regulatory range of permeability value of 10-9 m/s. Additionally, computer modeling through digital image technique was used to visualize the leachate flow and validate the laboratory experimentation. The leachate migrated through the soil covering a depth of 2.51 mm in one month, having a velocity of 10-9 m/s which is within the recommended permeability value. Therefore, this model could be used as a guide for sustainable sanitary landfilling in developed and developing countries

1.0 Introduction

In urban planning, one of the most important part is the identification of an appropriate location for municipal solid waste landfills (Bahrani *et al.*, 2016). Environmental hazards to inhabitants could arise from this landfill sites (Sharholy *et al.*, 2008). Some of the environmental impacts of landfill includes; contamination of air by greenhouse gases and odour emission, soil, and ground and surface water (Chabuk *et al.*, 2017a). Contaminations caused by municipal waste affects not only the underlying soil, but also water and air (Mohammed *et al.*, 2019a). However, there are many methods which are employed in the waste management, but the commonest technique being used is landfill (Jeswani and Azapagic, 2016). As a result of landfilling method, a lot of issues arisen in the waste management sector (Nas *et al.*, 2010). One of the major challenges in waste management is the issue of selecting an appropriate site for sustainable sanitary landfilling for the disposal of municipal solid waste (MSW) due to the complexity of various factors that must be considered and integrated such as environmental, economic, and social (Aziz *et al.*, 2019).

It is of great challenge and interest to integrate geotechnical criteria into the site selection model to achieve an optimal, sustainable, economical, and environmentally friendly site for proper solid waste management. Moreover, before siting new landfill for solid waste disposal, it is important to process significant large volume of spatial data, regulations, and acceptance criteria. Table 1 shows the landfill siting criteria ranking of different parts of the world and World Bank (WB) to their estimated distance where the landfill should be situated.

Table 1: Landfill siting criteria ranking of different parts of the world and World Bank

Parameter	Australia	China	Germany	India	Iran	Malaysia	USA	WB
Residential area (km)	0.25	0.50	0.50	0.50	0.30	0.50	2	1
Water bodies (km)	0.10	0.50	0.50	0.10	0.20	0.10	0.50	0.50
Groundwater (km)	0.10	1.5	1	1	0.05	1	1	1.5
Source generation (km)	20-25	25	25	20-25	30	25	25-40	25
Protected forest (km)	0.50	0.10	0.10	0.10	1.6	0.10	0.10	0.50
Airport location (km)	8	3	3	20	3	3	4	3
Distance to road (km)	0.10	0.10	0.50	0.20	0.30	0.50	0.10	3
Maximum slope (%)	20	10	10-20	15	20	10	15-20	20
Soil permeability (cm/s)	$<10^{-6}$	$<10^{-7}$	$<10^{-7}$	$<10^{-7}$	$<10^{-6}$	$<10^{-6}$	$<10^{-6}$	$<10^{-6}$
Fault lines (km)	0.10	0.10	0.10	0.50	0.10	0.10	0.10	0.50

(Ahmad *et al.*, 2014)

Existing methods for landfill site selection regards many objectives and criteria, however, an integrated method that inculcates all policies for optimum landfill site is lacking. Regarding this, a hybrid model is required which simultaneously considers important criteria as environmental, economic, social, and geotechnical. Landfill development and construction depends on the initial geospatial site location. Though, the site soil should be investigated to check its geotechnical suitability as a liner material. The soil liner must possess the quality of impeding the migration, which is the downward movement of landfill leachate to protect the groundwater (Yamusa *et al.*, 2022; Yamusa *et al.*, 2020; Ahmad *et al.*, 2018). The guidelines in most regulatory agencies as well as researchers stated that 1×10^{-9} m/s maximum permeability, minimum of 200 kN/m^2 shear strength, maximum of 4% volumetric shrinkage, and minimum of 30% soil fines content are specified for soil liners (UKEA, 2014; Amadi and Eberemu, 2013; USEPA, 1993; USEPA, 1991; USEPA, 1989).

Permeability also referred to as hydraulic conductivity is the major factor affecting the performance of hydraulic barriers. Soils with high permeability are not considered for landfills since the infiltration of water through this soil is high and the possibility of groundwater pollution may increase. To protect the groundwater, it is recommended that the soil content of the liner is clayey that has very low permeability (Ahmad *et al.*, 2014).

The digital image technique (DIT) is a validation for the geotechnical properties of the overall best site. It involves the laboratory physical modeling results of compacted sample soil in an acrylic column simulating leachate migration in sanitary landfill were fed into a computer for processing and analysis. Contour plots (2D) of HSI intensity value provide details and useful information to understand the characteristic of leachate migration behavior.

The use of geospatial technology such as remote sensing with geographic information system (GIS) to prepare the required input data in GIS-based site selection for improved decision-making was used in this study. Analytical Hierarchy Process (AHP) as a well-structured mathematical and psychological method of organizing and analyzing complex decisions is applied. Presently, AHP is a common and popular MCDA method for geospatial analysis (Saaty, 1988). The method remained widely used by decision-makers and researchers in understanding of problems and choosing the one which is best for their goal (Madurika and Hemakumara, 2015; Djokanović *et al.*, 2016; Khademalhoseiny *et al.*, 2017; Ghobadi *et al.*, 2017). In this method, the problems are broken down into a hierarchical order making it easier to be analyzed independently (Chen *et al.*, 2013).

Selection of suitable and most important criteria is the first step in any sanitary landfill siting (Mohammed *et al.*, 2019a). In this study, three main criteria were identified; environmental, social, and economic which were divided into thirteen sub-criteria i.e. water bodies, geology, soils, elevation, slope, residential areas, archeological sites, airports, population, roads, railways, infrastructures, and land use. All these data were prepared and processed accordingly based on related literature, expert's judgement, and guidelines for sanitary landfill site selection. Finally, potential sites for sustainable sanitary landfill were produced. The map layers were generated using GIS techniques.

Indeed, researchers constantly attempt to improve the techniques to mapping the best sites for waste disposal and resolve the problems associated with the current mapping techniques that are still ongoing. In this case, an innovative approach based on geotechnical criteria was developed in this study to improve the accuracy of the landfill sites selection process. This is because when environmental measures were not put in place with respect to the construction, problems are bound to occur (Bruno, 2007; Depountis *et al.*, 2009; Önal *et al.*, 2013). Therefore, for a sustainable sanitary landfill site selection, the geotechnical, environmental, economic, and social factors need to be evaluated and assessed collectively.

2. Materials and Methods

To determine the best potential candidate location for sanitary landfill in the study area, the GIS and its spatial analysis tools, integrated with MCDA, and geotechnical analysis were used to this aim according to the recommended criteria. The overall methodology employed in this research is presented in Figure 1.

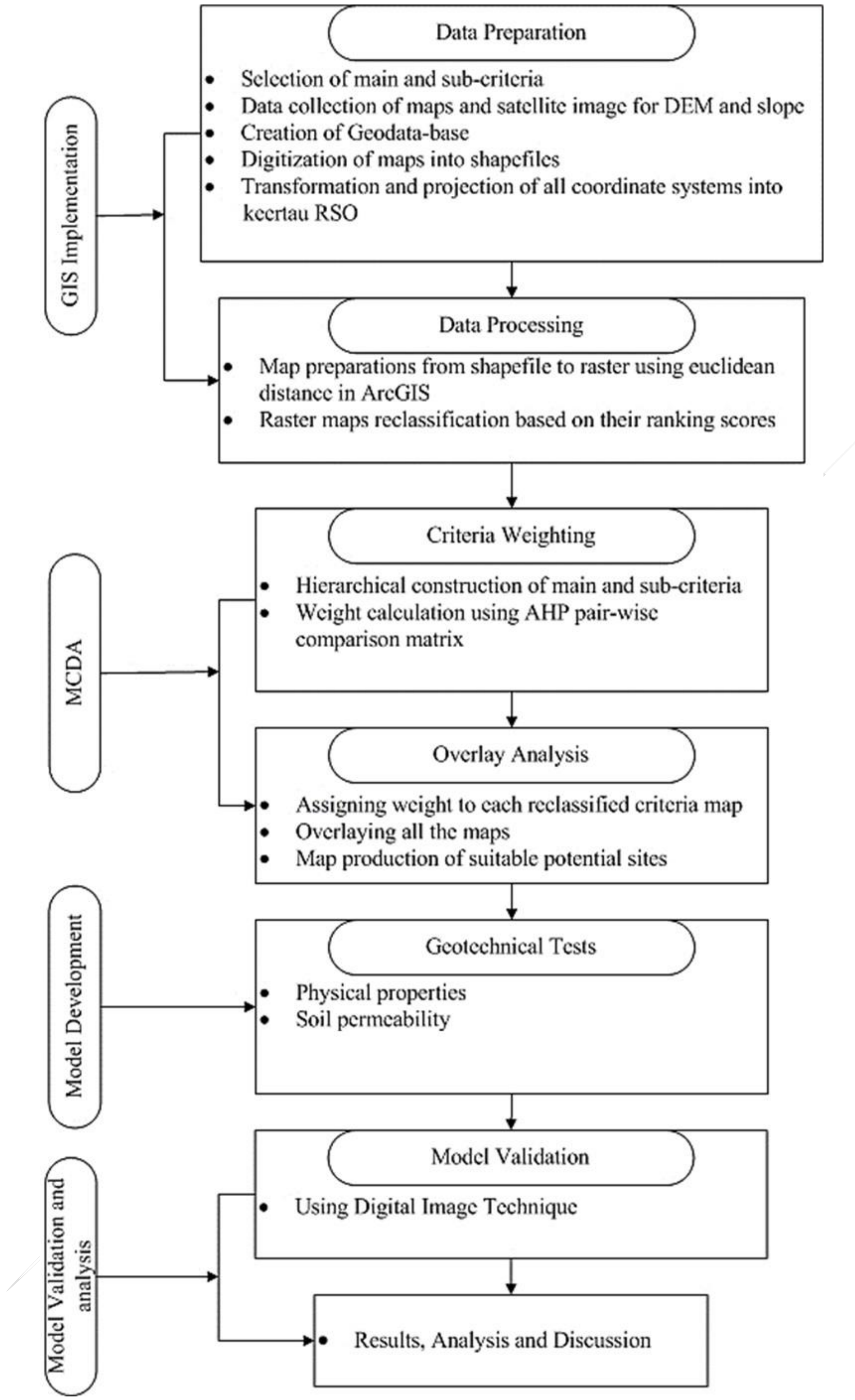

Figure 1: Flow chart of the methodology

The study area covers Johor Bahru (JB), Malaysia. It lies within latitude 1° 29′ 0″ N and longitude 103° 44′ 0″ E. JB was chosen in this study as it is one of the rapid developing area in Johor State with increasing amount of solid waste generation. Therefore, selecting sustainable sanitary landfill site in this area is needed because the existing sanitary landfill cannot accommodate the waste produced in the long run.

GIS is an influential tool that assists in choosing waste disposal sites based on its capability of dealing with a massive amount of data from several sources. AHP is a common and popular MCDA method for geospatial analysis. It has a unique ability for determination of comparative weight of multiple criteria in decision-making used in solving multiple criteria problems. According to Mohammed *et al.* (2017), most occurring or used criteria are water bodies and roads due to their high level of significance, while the least used criteria are soil permeability. Therefore, to synthesize a cost-effective sanitary landfill site selection model for sustainable and integrated solid waste management, geotechnical criteria such as soil permeability also referred to as hydraulic conductivity was introduced in this study in order to strengthen the research gap.

2.1.1 Selection of Important Criteria for Sustainable Sanitary Landfill Siting

Criteria have been reviewed from the previous literature, local and international guidelines for proper sanitary landfill site selection as presented in Table 2. The relative importance weight of every criteria used in this study was by applying the Saaty (2005) and other references numerical scale of 1-10. Thus, not all criteria have equal important some are of high significant while others less significant. Selected criteria for sanitary landfill siting adopted in this study are water bodies, archaeological sites, roads, population, slope and elevation, airport, residential areas, land use, infrastructure, soil, geology, geotechnical criteria that are most crucial. Table 2 shows the Sub-criteria ranking used in this study. The determination of level of importance of criteria was done through pairwise comparison matrix. The relationship between each criterion was compared to the others rated in a percentage which is believed to provide easier ranking.

Table 2: Sub-criteria ranking used in this study

Sub-Criteria	Buffer zones	Ranking	References
Water bodies	<100m	0	(MHLG, 2005; Eskandari *et al.*, 2012; Kontos *et al.*, 2005; Şener *et al.*, 2005; BIM, 2010)
	100-500	5	
	500-1000	7	
	>1000	10	
Soil	Low permeable	10	(Chabuk *et al.*, 2016; Ahmad *et al.*, 2015)
	Low to medium	7	
	Medium permeable	5	
	Highly permeable	0	
Slope	$0\text{-}5^0$	8	(MHLG, 2005; Effat and Hegazy, 2012; Barakat *et al.*, 2017; Chabuk *et al.*, 2017b; USEPA, 1993)
	$6^0\text{-}10^0$	7	
	$10^0\text{-}15^0$	6	
	$>15^0$	0	
Elevation	>750m	0	(Şener *et al.*, 2005; Torabi-Kaveh *et al.*, 2016)
	750-1000	7	
	1000-2000	4	
	>2000	2	

Residential	<1000m 1000-1500 1500-2000 >2000	0 3 9 5	(MHLG, 2005; Eskandari *et al.*, 2012; Barakat *et al.*, 2017; USEPA, 1993)
Airports	<3km 3-6km 6-9km >9km	0 4 7 10	(MHLG, 2005; Şener *et al.*, 2005; USEPA, 1993)
Geology	Intrusive Intermediate Acidic	7 6 0	(Barakat *et al.*, 2017; Ahmad *et al.*, 2015; Şener *et al.*, 2011; Şener *et al.*, 2005)
Road	<500m 500-1000 1000-1500 >1500	0 2 10 3	(Alanbari *et al.*, 2014b; Şener *et al.*, 2005; MHLG, 2005; Chabuk *et al.*, 2016)
Population	Low density Medium density High density	7 5 3	(Chabuk *et al.*, 2016; Aksoy and San, 2017)
Infrastructures	<50m 50-100 100-150 >150	0 5 8 10	(Demesouka *et al.*, 2013; Chabuk *et al.*, 2016; Şener *et al.*, 2005)
LU/LC	Public facilities Educational site Agricultural land Forest Vacant land	0 0 6 3 10	(Torabi-Kaveh *et al.*, 2016; Barakat *et al.*, 2017; Alavi *et al.*, 2013; MHLG, 2005)
Railway	<500m 500-1000 1000-1500 >1500	0 2 4 10	(Alanbari *et al.*, 2014a; Demesouka *et al.*, 2013; Chabuk *et al.*, 2017b)
Archeological	<500m 500-1000 1000-1500 >1500	0 2 5 10	(Djokanović *et al.*, 2016; Eskandari *et al.*, 2012; Chabuk *et al.*, 2017b; Alkhuzaie and Janna)

2.1.2 GIS Method

Two main type of data was used in this study; primary data and secondary data. The primary data was acquired by visiting the existing sanitary landfill site and municipal solid waste management authority in Johor Bahru, Malaysia. This was carried out via questionnaire aimed to evaluate the sanitary landfilling system needed for disposing Johor Bahru municipal solid waste according to a set of guidelines and standard. The questionnaire focused on comparative analysis between the thirteen sub-criteria (parameters). Basically, the questions were based on the of scale of pairwise comparison by using AHP method. The secondary data used in this study included topographic maps, geology map, soil map, land use map, and digital elevation map of the study area. All these maps were obtained and digitized. Google Earth PRO was used for georeferencing. Also, verification and validation were made during the field survey. The secondary data were inputted for the site suitability analysis process in the GIS environment.

Landfill siting criteria guidelines such as Integrated Solid Waste Management Blueprint for Iskandar Malaysia (BIM, 2010) and National Strategic Plan for Solid Waste Management (MHLG, 2005) 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. Comparison matrix for the parameters used in the decision was created first to perform the pairwise comparison in accordance with Uyan, 2013 as shown in Equation 1.

$$C_{ji} = \frac{1}{C_{ij}} \qquad (1)$$

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

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* in the matrix.

It is important to check for the consistency because the values which were used for the computation of the weight are obtained from different opinion of experts with different perspective of preferences, therefore, there is a possibility to encounter errors in the final stage of computation in the matrix (Saaty, 2005). The consistency index (CI) was computed using Equation 2.

$$CI = \frac{(\lambda \max - n)}{(n-1)} \qquad (2)$$

Where λ_{max} is the greatest Eigen value of preference, and n is the total number of the compared criterion used.

In this study, the raster calculator operation was performed in Map Algebra tool to identify the potential sites map. This was carried out by overlaying all the criteria weights assigned to each map layer and the final potential sites map was produced based on this analysis. From the most suitable sites, the best potential sites were identified by filtering the most suitable sanitary landfill layer. This was carried out by converting the output layer which is in raster format into vector and then selecting the areas that does not have an intersection with water bodies because of its high level of significant.

2.2 Geotechnical Method

After producing the potential sanitary landfill sites map, the introduction of geotechnical criteria was employed. Thereafter, soil samples from the selected potential sites were taken and subjected to laboratory experiments. The geotechnical properties of the soils one of which is permeability of each sample were studied to get the best location for the sanitary landfill.

The soils used in this study were obtained below 0.5 m below the ground surface to avoid organic matter using disturb sampling method. Each soil sample was dried and then passed through BS 4.75 mm aperture sieve to remove oversized gravel. The geotechnical properties were divided into two: First, the physical properties tests which include specific gravity, Atterberg limit, and particle size distribution to classify the soils adopting the BSI (1990). The specific gravity of the soil particles is calculated using Equation 3.

$$G_S = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \tag{3}$$

Where;
G_S = Specific gravity
W_1 = mass of density bottle, stopper (g)
W_2 = mass of density bottle, soil, and stopper (g)
W_3 = mass of density bottle, stopper, water, and soil sample (g)
W_4 = mass of density bottle, stopper, and water only (g)

The Atterberg limit tests cover the determination of liquid limit (*LL*) and plastic limit (*PL*) of the soil. The difference between liquid and plastic limits equals to Plasticity Index (*PI*). Using these three values, sample is classified using Plasticity Chart of British Standard Classification System (BSI, 1999). The detailed procedures followed in performing Atterberg limit tests were in accordance with BS 1377: Part 2: 1990.
The plasticity index was determined from the liquid limit and plastic limit results for the soils using the expression in Equation 4.

$$PI = LL - PL \tag{4}$$

Second, the engineering properties tests that involve hydraulic conductivity or permeability with respect to moulding water content using the falling head permeability test as explained by Head and Epps (2011). The coefficient of permeability was calculated from Equation 5.

$$k = 2.3\frac{aL}{At}\log_{10}\frac{h_1}{h_2} \tag{5}$$

Where;
k = Coefficient of permeability (m/s)
a = Area of the standpipe (m^2)
L = Length of sample (m)
A = Cross sectional area of sample (m^2)
h_1 = Initial height of water in standpipe (m)
h_2 = Final height of water in standpipe (m)
t = Time required to get head drop (s)

2.3 Geotechnical Validation Using Digital Image Technique

The geotechnical criteria were validated using a non-invasive method called digital image technique (DIT) where the migration of leachate was monitored using Surfer and Matlab computer software. This laboratory technique shows successive images of leachate migration in compacted soil simulating the actual landfill leachate migration. Basically, DIT employed in this study follows the concept of Yamusa *et al.* (2019) and Sa'ari *et al.* (2015) presented in Figure 2.

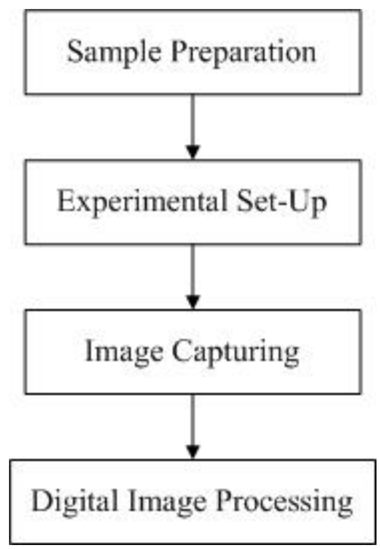

Figure 2: Flow chart of model validation process

The laboratory experiment covers the migration of leachate in a 100 mm height of soil in acrylic column. The dimension of acrylic cylinder to form the soil column was 150 mm high, 100 mm diameter and 6 mm thick. The acrylic column is placed in-between two-faced mirror to provide a complete visualization of 360º. These mirrors were placed at 105° of angle with offset distance of 0.2 m behind the soil column and facing the digital camera (Sa'ari et al., 2015). A Hitachi 40-Watt lamp was installed overhead the soil column so that the whole setup was illuminated. The acrylic column was chosen to provide a clear visualization of leachate migration into the soil. Using acrylic column implies that the leachate migration through the soil is observed promptly at any point and time throughout the experiment. A Nikon D90 digital camera was the main equipment used for image acquisition of the leachate migration at designated time intervals.

The digital images captured during the laboratory experiments were saved in JPEG format. Images were then taken to Surfer, a scientific data mapping, modeling, and analysis software. This software converted the digital image grid coordinate into surfer grid coordinate. The grid line images were then digitized and save as generic data files (DAT files) so that the files could be opened or referenced by a specific application like Matlab, Excel and Surfer. In the object manager of the surfer, a post layer was added and saved as surfer file (SRF file). The DAT files were then copied from the surfer and pasted in Excel. The copy and paste were necessary in order to sort and filter the values and then saved them as Excel files (XLS file). A Matlab image processing routine called REIVAL was used to perform the digital image processing tasks.

The prediction of leachate migration was carried out to evaluate the velocity (*v*) parameter over some presumed time. Thus, the velocity of any fluid is the ratio of its distance and time covered as expressed in equation 6.

$$v = d/t \tag{6}$$

Where: v = velocity (m/s), d = distance (m) and t = time (s).

3. Results and Discussion

3.1.1 Identification Criteria

According to the judgement from the developed pair wise comparison matrix for the thirteen criteria used for this study, the results of the criteria weight and their percentages are shown in Table 3. More importance was given to residential areas with weight of 0.239, while railway criteria have the least importance with weight of 0.018. This is because of the strict rules and regulations governing the prohibition of sanitary landfill near the residential areas (Mohammed *et al.*, 2019b).

Table 3: Criteria Weight and Percentage

Criteria	Weight	Percentage
Residential	0.239	23.9%
Water bodies	0.168	16.8%
Geology	0.121	12.1%
Soils	0.099	9.9%
Land use	0.067	6.7%
Slope	0.056	5.6%
Elevation	0.054	5.4%
Road	0.036	3.6%
Infrastructure	0.046	4.6%
Airport	0.033	3.3%
Population	0.038	3.8%
Archaeological	0.025	2.5%
Railway	0.018	1.8%
Total	1	100%

3.1.2 Final Potential Sites Map for Sanitary Landfill

The potential map of the sanitary landfill sites is displayed in Figure 3. The map shows the distribution of the selected areas based on suitability where the most suitable are considered the highest priority sites. The legend was used to provide visual clarity of the map showing the various classes of suitability. From the result of this map, it was found that most of the areas are unsuitable with the highest total of 54% of the study area, 12% less suitable, 21% suitable and 13% most suitable

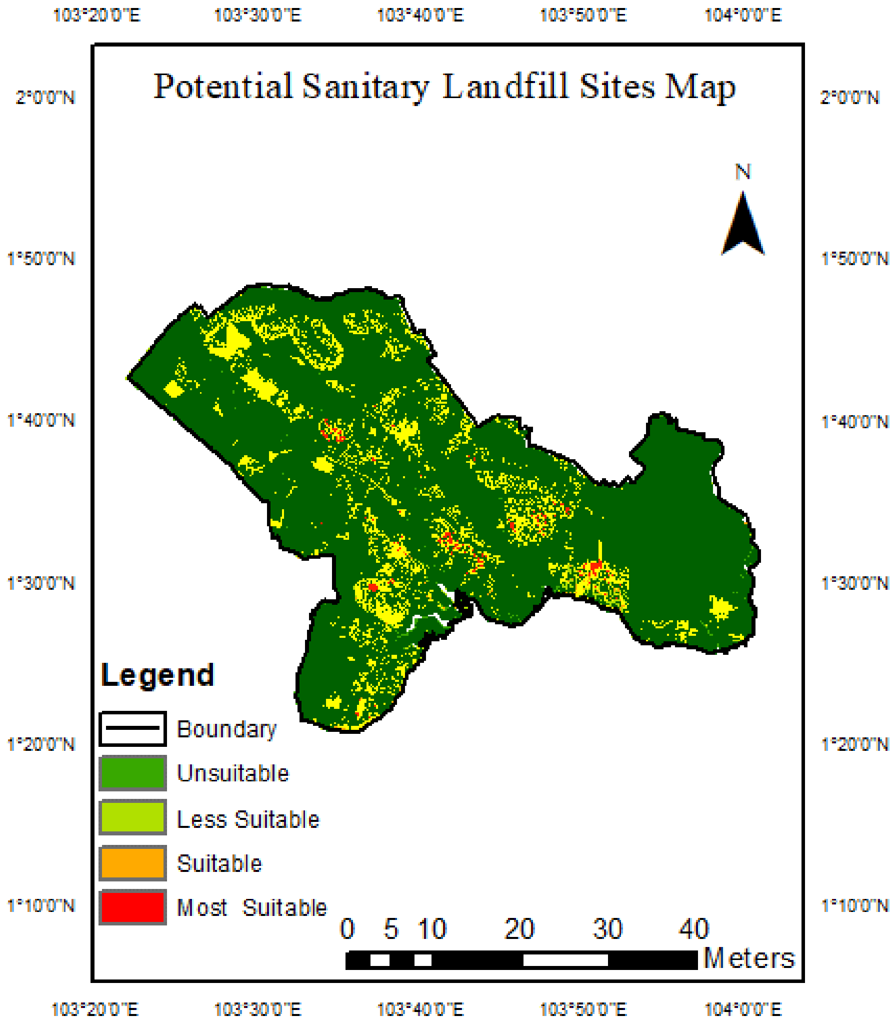

Figure 3: Potential Sanitary Landfill Sites Map of Johor Bahru

3.1.3 Best Potential Sites Map

Based on expert's judgment using the AHP criteria weighting and GIS analysis, three candidate sites appear to be the best from environmental, economic, and social perspectives. These sites have fulfilled the requirements for sanitary landfill siting with a distance of at least 1000m away from roads, 1500m away from residential areas, and far away from public and educational facilities. These three sites as displayed in Figure 4 were used to further accomplish the remaining objectives of this research.

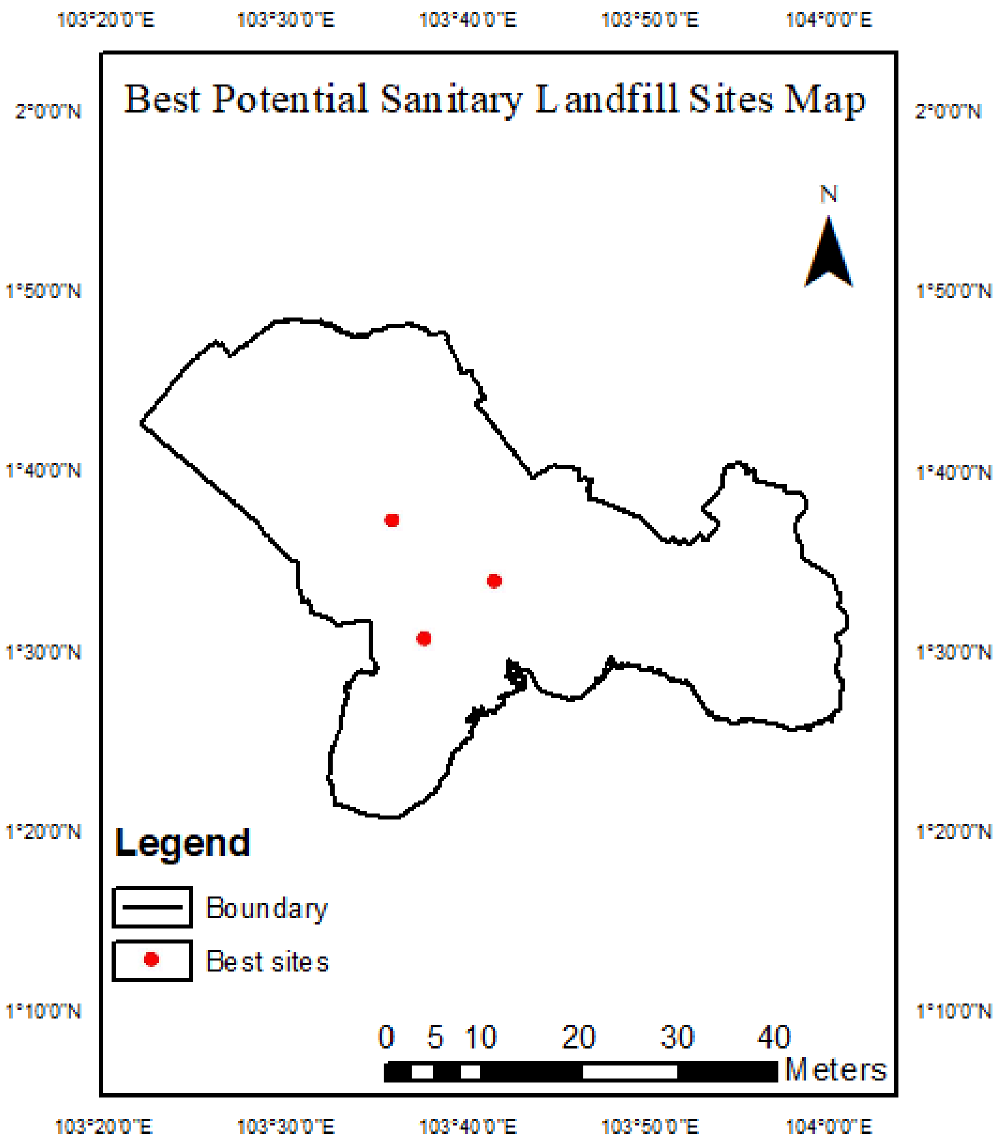

Figure 4: Best Potential Sanitary Landfill Sites Map of Johor Bahru

3.2 Geotechnical Properties of the Best Landfill Sites

The geotechnical properties were obtained from the laboratory testing of representative soil samples of the study areas. To ascertain the properties of the soil material, the study commenced with detailed physical properties and engineering properties.

3.2.1 Physical Properties

Table 4 shows the physical properties of soil samples from the study areas. According to the British Standard (BS) classification, the soil sample for site A is classified as sandy clay of high plasticity (MH). Site B soil sample is classified as very silty sand of intermediate plasticity (MH). Soil sample of site C is classified as very silty sand of very high plasticity (MV).

Table 4: Physical properties of the soils from the study areas

Property	Value		
	Site A	Site B	Site C
Specific gravity	2.70	2.74	2.70
% Fines	51	29	14
% Sand	46	61	46
% Gravel	3	10	40
OMC, %	27.9	19.3	17.8
MDD, Mg/m^3	1.38	1.52	1.51
Liquid limit, %	64	50	76
Plastic limit, %	37	29	37
Plasticity Index, %	27	21	39
BS Classification	MH	MH	MV
Colour	Brown	Reddish Brown	Red

Literature suggests that soils with the following index properties: percentage of fines ≥ 30%, plasticity index ≥ 7 and liquid limit ≥ 20% can be specified for landfill liners (Daniel, 2012; Benson *et al.*, 1994). Comparing the index properties of the sites soil used in this study and that of the literature shows that the soil is suitable to be used as liner material for site A only. Sites B and C have their fines content less than 30% and they might not likely impede the flow of leachate through them.

3.2.2 Engineering Properties

Hydraulic conductivity is the major factor affecting the performance of hydraulic barriers. Soils with high permeability are not considered for landfills since the infiltration of water through this soil is high and the possibility of groundwater pollution may increase. To protect the groundwater, it is recommended that the soil content of the liner is clayey that has very low permeability (Ahmad et al., 2014). The hydraulic conductivity is discussed with respect to the effects of moulding water content. Figure 5 shows a general decrease in hydraulic conductivity with increase in moulding water content for all soil samples. This trend is in line with Yamusa *et al.* (2022) and Bello (2013). Samples from site A had the lowest permeability of 2.1×10^{-9} m/s, followed by site B with 2.08×10^{-8} m/s, and then site C with the highest permeability of 1.5×10^{-7} m/s at *OMC*. The results show that only site A used in this study was within the range of maximum regulatory hydraulic conductivity value of 1×10^{-9} m/s (Yamusa *et al*., 2022; Yamusa *et al*., 2018b). Sites B and C did not meet the hydraulic conductivity criteria.

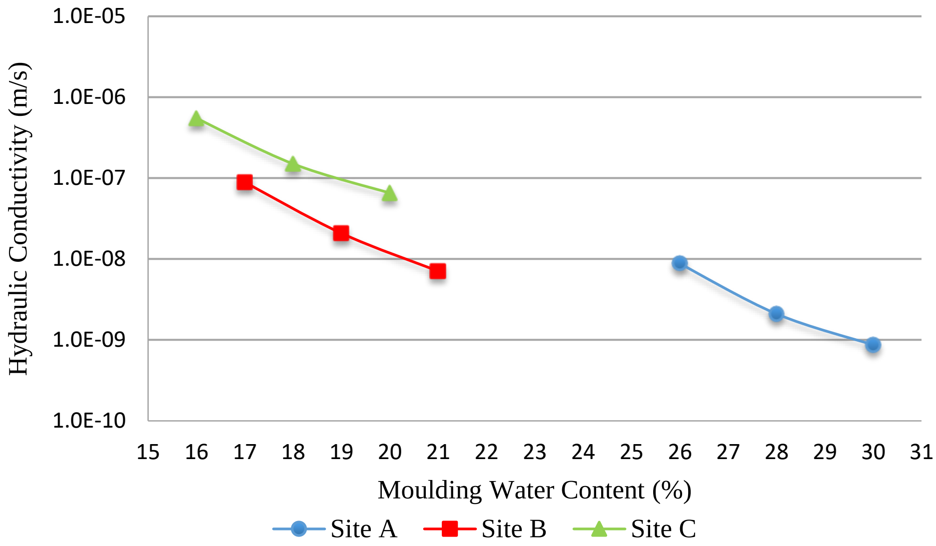

Figure 5: Variation of Hydraulic Conductivity with Moulding Water Content

3.3 Model Validation using Digital Image Technique

Figure 6 shows the gradual successive leachate migration within the first day until the seventh day, and then it becomes constant after the seventh day until the end of the experiments of twenty-eight days. This could be explained in terms of energy loss due to hydraulic gradient. According to Viswanadham (2018), water flows in soils only when there is a gradient in energy or head loss. In soils, water or (permeant) always flow down the gradient from high energy regions to low energy regions. As a particle of water proceeds from high energy regions to low energy regions it exerts a frictional drag on soil particles which steadily decreases the hydraulic head on every flow line. When the hydraulic head becomes too small, the water finally loss energy to move further and therefore becomes stagnant (Yamusa *et al.*, 2019; Yamusa *et al.*, 2018a). The leachate migrated through the soil covering a depth of 2.51 mm in one month, having a velocity of 1.04 x 10^{-9} m/s which is within the recommended permeability value.

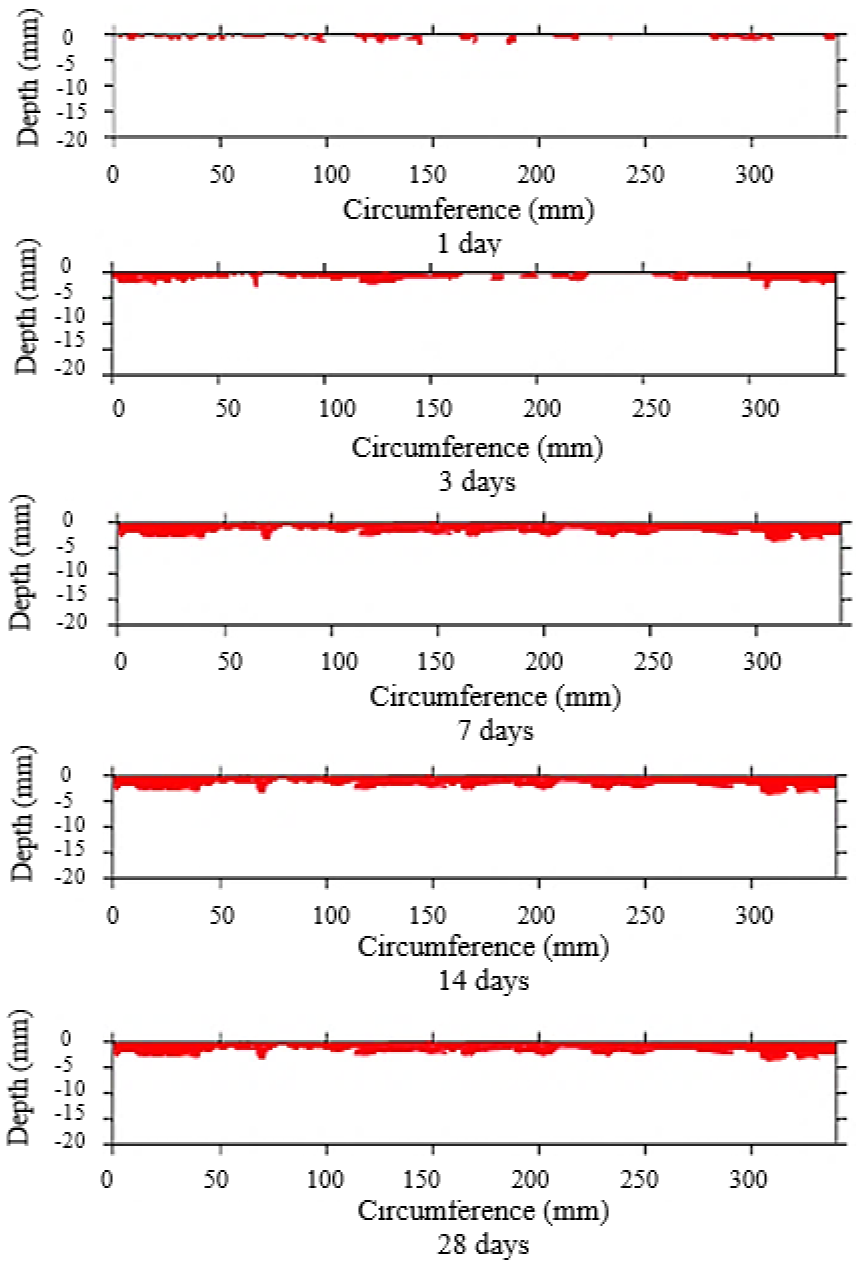

Figure 6: Leachate migration in soil column

Figure 7 illustrates the velocity values against time for the site A soil sample. Generally, the velocity decreased with increase in duration of time. The calculated velocity of the leachate at 28 days for sample A is 1.04 x 10^{-9} m/s. Thus, sample A used in this study can be used as landfill liner material because it has a permeability within the minimum range value (Yamusa *et al.*, 2020; Yamusa *et al.*, 2019; Daniel, 2012; USEPA, 1991).

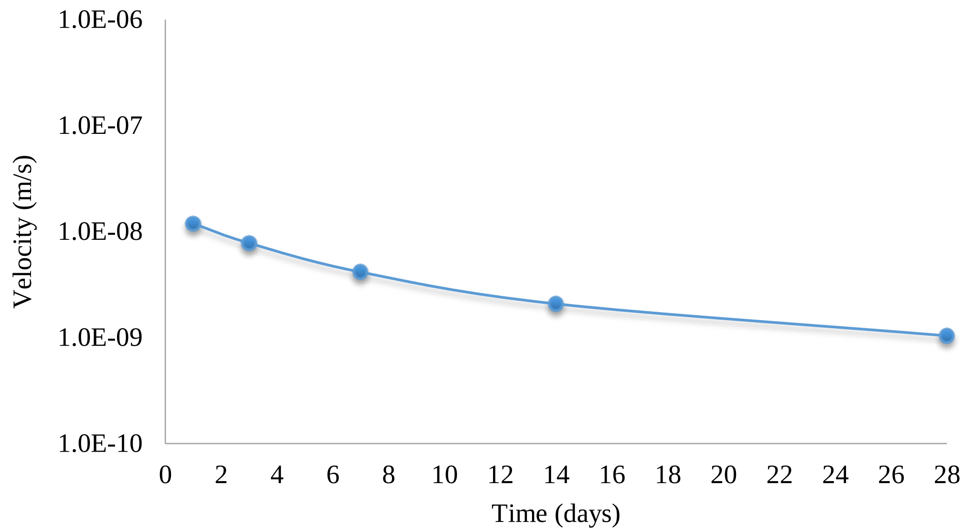

Figure 7: Leachate migration in soil column from DIT

4. Conclusion

The GIS and MCDA (using AHP) were applied in this study for assessing the possible best potential sites for sanitary landfill in Johor Bahru, Malaysia. The most important parameters for this study were residential areas and water bodies while the least important criteria was railway. The study further revealed that, 54% of the study area were unsuitable areas for sanitary landfill site, 12% less suitable, 21% suitable and 13% most suitable. Three most suitable potential sites were identified among the various sites.

The introduction of geotechnical analysis to further selects the overall best sanitary landfill site amongst the three suggested by geospatial method. The physical properties of the soils used in this research shows that only site A is suitable to be use as liner material. Sites B and C have their fines content less than 30% and they might not likely impede the flow of leachate through them. Moreover, the engineering properties showed that only site A used in this research attained within the range of maximum regulatory permeability value of 10^{-9} m/s. Sites B and C did not meet the permeability criteria.

The validation of leachate migration through the compacted soil using digital image technique was attained. The leachate migrated through the soil covering a depth of 2.51 mm in one month, having a velocity of 1.04×10^{-9} m/s which is within the recommended permeability value.

This research work has implemented the use of latest geospatial techniques to select a sustainable sanitary landfill site in the study area focusing on geotechnical criteria as a key factor in siting sanitary landfill. This is to ensure that the soil beneath the ground surface can support the threats of varying climatic conditions of wet and dry season, loads bearing capacities, and conditions posed on it by transportation facilities before any further construction process begins

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