

The Landfill Siting Technology: Challenging and Trends

Mohamed Osman Saeed*, Mohd Sanusi Ahamad and Hamidi Abdul Aziz
School of Civil Engineering, Universiti Sains Malaysia,
Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia
Tel: +604-5996201/6266, Fax: +604-5941009

*Corresponding Email: basheir2000@yahoo.com

ABSTRACT

Most of the landfill sites existing in developing countries are practicing open dumping on ground which has unpleasant consequences. This practice may be attributed to lack of legislations, public awareness, engineering knowledge and funds. This paper presents application of geographic information system (GIS) for new landfill siting. The multi criteria evaluation (MCE) technique integrated with analytical hierarchy process (AHP) that combined Boolean logic for constrains and FUZZY logic for factors is used to overlay the results in one final digital map. The proposed scheme is applied on a typical landfill site in south Seberang Perai (SSP), Penang State, Malaysia. Six criteria namely, land-use, utility, surface water resources, soil, road networks and topographic are examined to establish spatial decision support system. The IDRISI³² software, one family of GIS, is used to perform spatial analysis, AHP weights processing and visualization. As results, it is found that GIS utilizing for sanitary landfill selection minimizes the problems associated with the conventional landfilling technologies and time saving.

1. Introduction

One of the serious challenges faced by human beings in urban areas nowadays is the solid waste management (SWM). Obviously, the way to limit the impact on our planet's ecosystem is by reducing the amount of solid waste generation. Waste management (WM) must be achieved by intensive recycling program and composting. If these programs are not sufficient, solid waste must be incinerated and only as a last resort, should landfills be utilized with energy recovery mainly methane (CH₄) and carbon dioxide (CO₂) gases in order to prevent atmosphere contamination (Messineo and Panno, (2008)).

Extensive studies have been reported in this area and are still underway. In 2008, a study on plastic solid waste (PSW) generation in Kuwait has been reported by Al-Salem who developed a databank to assess the amount of PSW being generated from various sources. According to Karadimas and Loumos (2008), solid waste generation depends on the socio-economic profile of urban residents. Alhumoud (2005) presented recycling of solid waste should be integrated with other SWM options to abate degradation in urban environment; this can be accomplished through promotion of economical and environmental friendly WM practices. Troschinetz and Mihelcic (2008) analyzed the recycling of municipal solid waste (MSW) in developing countries. Twenty-three case studies provided MSW generation and recovery rates and composition for compilation and assessment. According to EPA (2003) about 56% of MSW goes to Landfill sites, 30% is recovered, recycled or composted and 15% is incinerated and in European Union EU around 45% is disposed by co-disposal methods (Haines, 1988).

In urban area, open dumping of landfill site was the most common form of disposal of MSW in populated cities Bolton (1995). Sanitary landfills can provide better solutions than open dumping for reducing many of the problems, still there is a potential for

improvement (Christian et al., 2003). Saeed et al., (2008) reported the generation of solid waste is directly proportional to population, industrialization, urbanization and the changing lifestyle, food, habits and living standard of the people. The rapid and constant growth in urban population leads to a dramatic increase in urban solid waste generation, with a severe socio-economic and environmental impact. The site selection of sanitary landfill is perhaps the most difficult and controversial issue of the planning process (Syed and Walter, (1994).

For many years, rubbish has simply been dumped on ground open areas. Failing in a proper way of siting landfill in developing countries, leads to some negative effects such as fires due to landfill gases, rodents, insects, and birds due to organic food, bad odours and leachate that causes groundwater pollution. In this case, the landfill is indentified as unsanitary which poses the issue of public health hazard. Ohman et al., (2007) reported the issues of SWM integrated in accordance with the decision making tools dated back to early 1960s, since then researchers continued to use operations research tools to help optimize landfill design and operating parameters. However, in developed countries, within the last thirty years, a significant change has occurred towards adopting sophisticated and technologically sound approaches of MSW disposal.

Benítez et al., (2008) established mathematical models that correlate the generation of per capita residential solid waste (RSW) to the following variables: education, income per household, and number of residents. This work was based on data from a study on generation, quantification and composition of residential waste in a Mexican city. A study from Greece by Karadimas and Loumos (2008) examined an innovative model for estimation of MSW generation and collection. In their model spatial geodatabase that is part of integrated GIS was applied for SWM. A landfill diagnosis method 'EVIAVE' integrated with GIS spatial data for landfill site in Spain has been assessed by Zamorano et al., (2008). They concluded that landfill siting should take into account a wide range of territorial and legal factors in order to reduce negative impacts on the environment. Yagoub and Buyong (1999) reported that the use of GIS in SWM not only save time and cost of design and spatial analysis of site selection, but also provides a digital data bank for future monitoring of the sanitary landfill site.

Siting of a new landfill using a multi-criteria decision analysis (MCDA) and overlay analysis using GIS has been addressed by Sumathi et al., 2008 and proposed a system that considered several factors in the siting process, such as geology, water supply resources, land use, sensitive sites, air quality and groundwater quality. Katoch and Kumar (2008) presented a mathematical model to optimize waste management systems related to environmental protection. This model could also help government bodies set guidelines and regulations, and evaluate prevailing strategies for handling and disposal of waste.

Saaty (1980) proposed for first time, the AHP that used a four step down approach to solve a multi criteria decision making problem. The decision problem was broken down into a hierarchy (Tree) of interrelated decision elements. Input data was then collected by pair wise comparisons of decision elements. The "eigenvalue" method was used to estimate the relative weights of decision elements. Then it was aggregated to arrive at a set of ratings for the decision alternatives. Chang et al., 2007 reported that siting landfill is a difficult, complex, tedious and protracted process that requires analysis of multi criteria through programming model. According to Lin et al., (2005) siting a new landfill

requires processing of a large amount of spatial data of the study area and they advised using optimization models to tackle the weaknesses of GIS.

In this paper, the GIS multiple criteria evaluation (MCE) for new landfill site in Penang state has being described. The spatial decision in accordance with MCE for new sanitary landfill problem was solved through the assessments of AHP. The pair-wise comparison model was utilized to determine the relative weights of the decision criteria which is then integrated with the GIS Boolean and FUZZY logic model to produce feasible sites for landfill siting in the study area.

2. Description of the site

The State of Penang is comprised of Penang Island and Seberang Perai. It is situated in the north east of Peninsular Malaysia. It has a total area of 1,046.3 km² and spatially located between 5^o 24' N, 100^o 14' E in coordinate. Seberang Perai has an area of 738 km², and divided into north, central and southern districts (JICA, 1989). The central Seberang Perai has the highest population followed by north and the south where is the study area. The issue of integrated solid waste management (ISWM) of Penang is a big challenge for the local authority and proper implementation of domestic waste collection, transferring, recycling and disposal into landfill is still a complex dispute. There are two separate municipalities in State of Penang; MPPP in the Penang Island and MPSP in Seberang Perai mainland. Both are managing the solid waste process and monitor the private waste contactors who collect, transfer and dispose of the residential waste from the waste source into landfill site through transferring station.

3. The methodology

3.1. The proposed GIS scheme

In the present study, IDRIS³², a member of the GIS software family is utilized as a tool for analysis and display. IDRIS³² software has a significant capability for raster digital map analysis. GIS digital map is available either as vector or raster base model. The vector model represent phenomena objects precisely stored in polygons (area) such as forest, points (centre) such as meteorology station and lines (arc) such as road features in a continuous coordinate space (Ahmad (2003) and Eastman (1999)). Whereas, raster model is grids or cells that represent the actual object obtained from satellite imagery. Six criteria maps' layers namely Utility (Power line), Topography, Drainage system, River streams, Road network and Soil are analyzed in this study.

The spatial data is converted from vector into raster model to fit the IDRISI³² software using interface function. This process is called 'rasterisation' which is defined as the process of subdivision of a linear or real object into cells/grids, effectively by chopping up simultaneously along horizontal and vertical slices according to Jones (1997). The maps identify the coordinates X and Y by having the same reading in each map; these points can be used for base-map window as references. The map row and column are determined by equation (1) and (2).

$$\text{Row} = \text{Max Y} - \text{Min Y}/\text{Resolution} \text{ ----- (1)}$$

$$\text{Column} = \text{Max X} - \text{Min X}/\text{Resolution} \text{ ----- (2)}$$

Since the digital data maps have different management; the standardization process must be performed. Eastman 1999 defined standardization as a procedure to ensure that the

criterion maps are comparable in MCE process. Thus, without the standardization process the proposed GIS/IDRIS³² software cannot be run. FUZZY representation module allows a map to identify the suitability at each pixel (Zadeh, 1965). In order to achieve MCE, AHP is used to determine the weights of each criterion and to achieve operational economy application in the evaluation of land suitability. According to Weerakoon 2002, AHP is a mathematical method to determine priority of the criteria in the decision making process.

The matrix conversion of AHP (1-9) scales for “proximity to” criterion is prepared. Tables 1, 2, and 3 show the judgments made by experts’ opinion. After running several calculations in IDRIS³², the numeric value did not satisfy the requirement of weighted summation must equal to one. Thus, some modifications are made whereby the value of each judgment is made based on the hierarchy told by the experts. The final value that equals to 1.0 is shown in table 4. The weighted value for each criterion is calculated using the MCE module. The AHP matrix is presented as eigenvector values. It has ability to calculate weights for multiple criteria with pairwise comparisons method. Pair wise comparison has nine levels of important (1-9) scales as shown in Table 5. The important intensity levels 4, 6 and 8 are in between.

Table 1. AHP value by Expert [1]

Proximity to	Soil	Transportation	Topography	Utility	Geography	Land-use
Soil	1					
Transportation	3	1				
Topography	9	8	1			
Utility	3	8	8	1		
Geography	9	8	9	9	1	
Land-use	9	9	9	9	9	1

Table 2. AHP value by Expert [2]

Proximity to	Soil	Transportation	Topography	Utility	Geography	Land-use
Soil	1					
Transportation	1	1				
Topography	9	8	1			
Utility	1	3	1/5	1		
Geography	9	8	9	9	1	
Land-use	1	5	9	9	1	1

Table 3. AHP value by Expert [3]

Proximity to	Soil	Transportation	Topography	Utility	Geography	Land-use
Soil	1					
Transportation	7	1				
Topography	3	3	1			
Utility	7	7	5	1		
Geography	1	8	9	9	1	
Land-use	7	7	5	1	7	1

Table 4. Eigenvector Values Derived from AHP

Criterion	Weights
Geography	0.0835
Land Use	0.3813
Soil	0.1479
Roads	0.0565
Rivers	0.3308
Total	1.000
Consistency Ratio (CR)	0.10
Consistency result 0.10 is	Acceptable

3.2. Model Design

The general procedure for GIS analytical model applied in this research is presented in Figure 1 and the flowchart process described below.

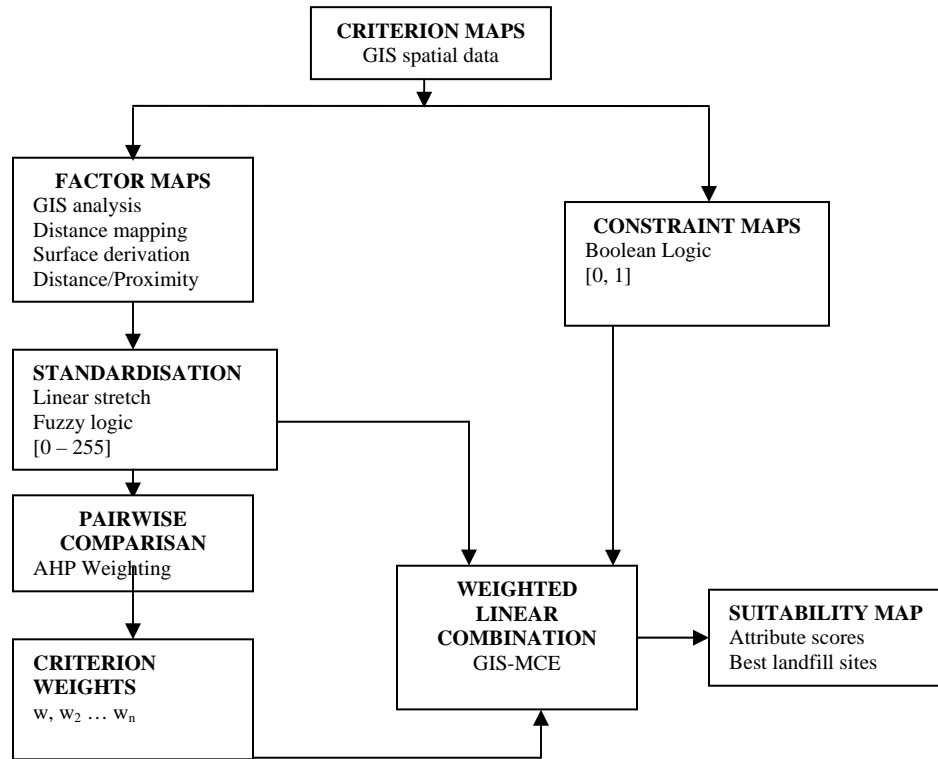


Fig. 1 Model Design Flowchart

Table 5. Saaty's Preferences Table

Definition	Importance Intensity
Equal important	1
Moderate important	3
Strong important	5
Very strong important	7
Extremely important	9

The model design shown in Figure 1 is a stage for spatial search and analysis. The criterion maps that are obtained from the previous section can be classified into two major groups; constraints and factors. The constraint is presented as Boolean images. Boolean Logical operators consist primarily of AND, OR, NOT and exclusively OR (XOR), produce results of either true or false (Jones, 1997). Boolean logic can be use to find combinations of layers that are defined by conjunctions of AND, OR, NOT and OR operators. Images in Boolean logic are always given the values of 0 and 1 only for the land suitability. The suitability is given a score of one (1) and the unsuitable as zero (0). In this regard, the constraints model should prohibit any development that fall in the areas with value 0. Furthermore, the general factor maps selected for this study are soil, roads system, surface water, forest reserved, environmental protected areas, urban, rural and residential areas as well as mines.

The creation of factor maps will involve some GIS analytical function. Buffer is described as a zone or area in GIS analysis. The surface analysis of digital elevation model (DEM) and slope are neglected. The DEM can be classified as constraint maps for Boolean Maps. The study area has a flat topography (horizontal slope) and the contour surfaces are very less. Buffer zone is described as the zone in terms of GIS functionality. The buffer zone has only three colors with values of 0, 1, and 2. In this analysis, the value for target area and buffer zone output will be recognized as 0.

4. Results and Discussion

The site selection model used in the methodology has produced an expected result in the selection of new landfill areas.

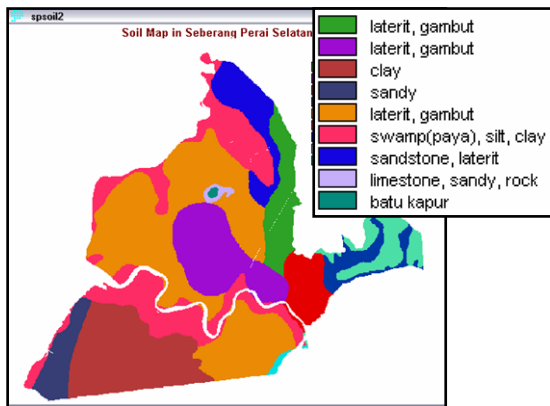


Fig. 2. (a) (26) Soil Types

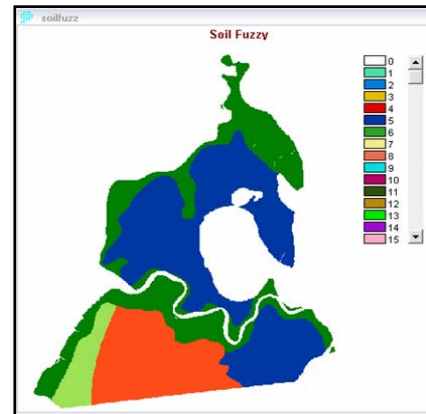


Fig. 2. (b) (9) Soil Types

Figure 2 (a) shows the various soil types available in the study area. There are about 26 soil attributes represented by each polygon. The database has identified only 9 major soil types in this region Figure 2 (b). The soil identification is not an absolute result because the exact category is not available. The soil types are only interpreted using the land cover map based on its agricultural activities. Around 5138.7 ha of the land covered with palm oil plantations. Consequently, it can be assumed that most of the land in SSP is comprised of Alluvium and Laterite soils.

For this landfill siting purpose, the land resources are very limited. The scarcity is because the land is used for agricultural activities and environmentally protected. Figure 2 (b) shows the soil map in the form of a standardized soil criterion. Only four soils are

considered for standardization. In Figure 2, the attribute value files for soil type selection. This is a value file to assign FUZZY Logic Set. A high score is given to sandy soil according to its importance and availability. The lowest score is given to the land used for agriculture. Clay is one of the best sites for landfill siting because clay can prevent leachate problems. Leachate migration from the landfill could be a potential source of surface and groundwater contaminations (Aziz et al., 2005). Moreover, clay area is less important for urban development once compared to other sand types because there are no residential areas on the clay land and it is mostly covered by mangrove and Nipah Swamp Lake. Furthermore, there are only a few land cleared by government for future development.

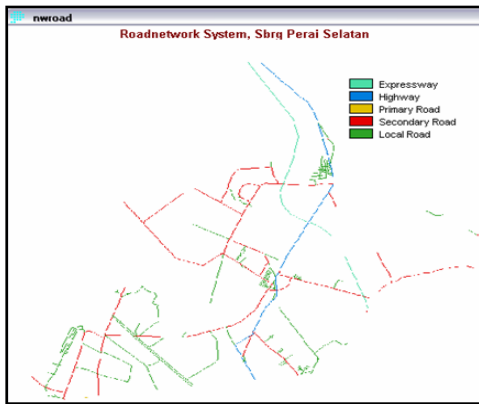


Fig. 3. (a) Roads Network without Buffer



Fig. 3. (b) Roads Network with Buffer

Road network is comprised of four main roads connected within this region. The highest hierarchy of road system is expressway and the lowest is local road. This region has a good network system and access to the landfill anywhere in this area is possible Figure 3 (a). According to international guidelines for landfill siting the criterion map has indicated that the suitable distance from road network is within 1000 m buffer (Cointreau, 1996). This is very important for the environmental requirement and property protection. Besides, it helps to reduce the pollution already caused by traffic on the road. Landfill must be within 3030 m (10,000 ft) away from any airport-railway, thus birds are attracted to landfill sites where different types of food are available (Agamendu, 1990). Figure 3 (b) shows the buffered distance for roads where no landfill site is suitable to be constructed in. Then, the IDRISI standardized function is used to stretch the buffer zone to a score ranging from 0 to 255 values. The Simpan Byram forest is one of the most protected areas in south of SSP, with a total land of 202.43 hectares. This forest, in Figure 4 (a) is preserved for birds' migration and for its sanctuary. In selecting a potential land sites, it is important to ensure that sufficient land area is available (Tchobanoglous et al., 1993). No landfill site is allowed to be built within this protected land at a buffer distance of 100 m Figure 4 (b). Therefore, before a full-scale investigation of a potential site is undertaken, all zoning ordinance of protected zone should be reviewed clearly or change to estimate any legalities (Samuel, 1974).

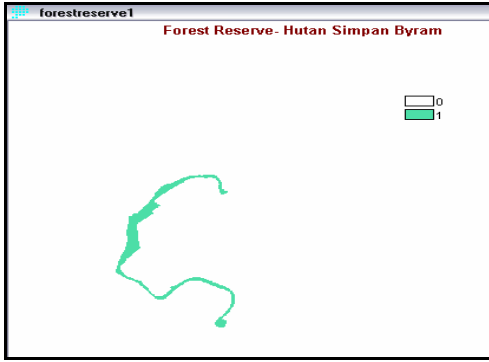


Fig. 4. (a) Forest without Buffer Zone



Fig. 4. (b) Forest with Buffer Zone

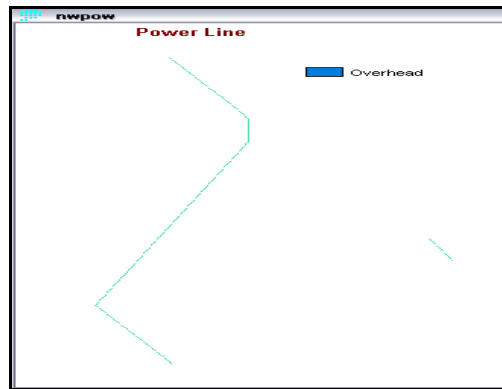


Fig. 5. Power Line (Electricity)

The main power line overhead is via North Perak State to North Penang State on a single cable line. No restriction is imposed for a power line in landfill location as long as it can be connected to the plant. In this assessment, the power line map is just converted into Boolean image format 0 indicate the power line and 1 for the rest of the areas as shown in Figure 5.

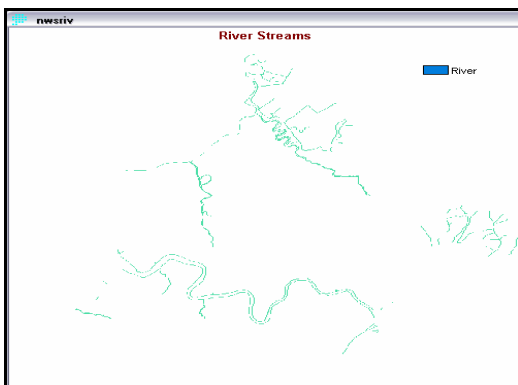


Fig. 6. (a) Rivers without Buffer Zone

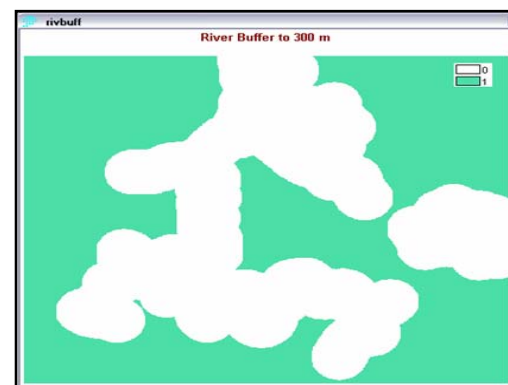


Fig. 6. (b) Rivers Buffer Zone

Surface water (rivers) is very important because of its ecological balance to all the human being activities and as a nature resource. Rivers can be endangered by the landfill because of leachate issue which is dangerous it can bring a great pollution to the river. Figure 6 (a) shows the river network in SSP. Based on World Bank guidelines to

encounter the leachate problem, a buffer distance of 300 m from the river is considered for landfill location Figure 6 (b). According to Samuel Weiss 1974 leachate may leave the landfill down at the ground surface as a spring or percolated through the soil and rock that surround the waste.

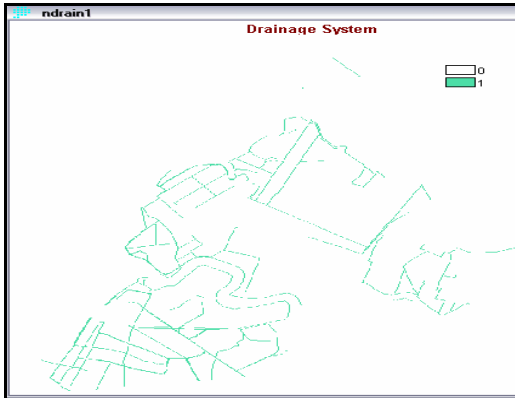


Fig. 7. (a) Drainage without Buffer Zone

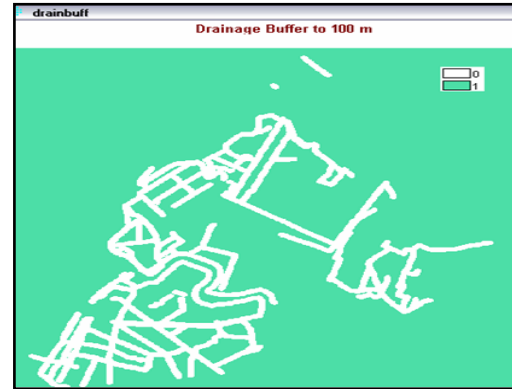


Fig. 7. (b) Drainage Buffer Zone

Drainage system is an important factor to be protected once landfill's survey is conducted. The sewage carried by the drainage system can be treated and then made to flow into rivers. The sewage must not contain any hazardous liquid such as chemicals or leachate. Landfill has its drainage system to avoid any leachate flow contaminations hence, still it is important to be aware of the impact of drainage system failure. Therefore, a buffer distance of 100 m from the drainage network is considered safe in this study. Figure 7 (a) shows the drainage network and its buffer distance Figure 7 (b). The geology properties of the study area are not considered as factor or constraints. There are limitations of geological data for this area, therefore the depth to the bedrock and groundwater is not taken into consideration that requires more expert interpretation and fieldwork to collect the data, which is beyond the scope of this study. Figure 8 shows the geological deposits of the study area.

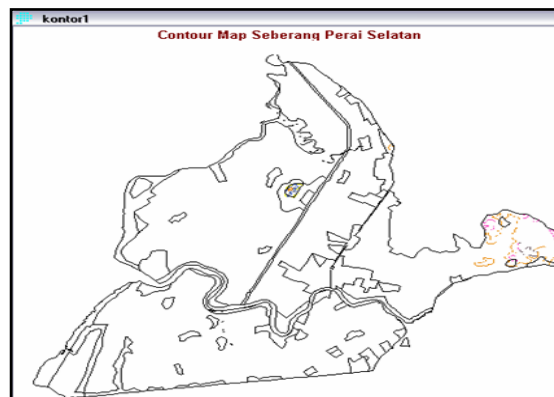


Fig. 8. Contour Map of SSP

The AHP method is based on the calculation of using the eigenvector methods. This method of a pairwise comparison matrix is graded by a decision maker and stored in the IDRISI³² pair wise comparison modules.

Criterion weighting is performed using expert judgments to compare each criterion to landfill siting based on experts' preferences. The criteria used in the landfill selection are comprised of road network, land use, river, geology, utility and topography (Ahamad et al., 2003). The AHP method combined complex criterion factors from several hierarchies. The IDRISI³² applies this methodology to their MCE problem in the format of hierarchical structure. The limitation of AHP is that it allows a maximum of nine-criterion factor for pair wise comparison in a single hierarchy. This is to ensure that the consistency of rating by decision making is acceptable and in accordance with the Saaty' scale (1-9) of AHP (Saaty, (1980) and Malczewski (1999)).

After the weights of each factor are determined the GIS functions are set out and now the model can be applied to find the optimal site. The weights values are not fixed during the process and it can always be altered if siting criteria or considerations are changed. Based on the weighted values, the degree of importance of each factor is increased for its suitability scores. Different decision makers may assign different weights. The weights obtained from several experts' opinion. Their judgments are based on environmental, political, economic and social conditions for the choice of site.

Figure 9 shows the map overlay processing that is done after the weights for every map is calculated. The overlay procedures play a central role in many GIS applications (O'Sullivan and Unwin, (2003) and Malczewski, (2004)). Two types of map layers are presented; constraint and factor. These maps standardized have value range from 0 to 255. Every factor maps has its weights values. These values will determine the importance of every map in the overlay process. This process gives the result as shown in Figure10 and Figure 11.

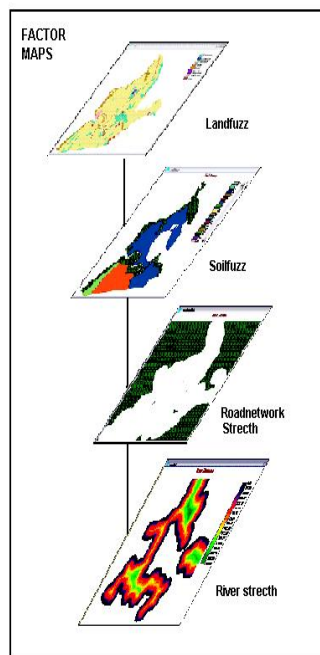


Fig. 9. (a) Factors Maps Overlay

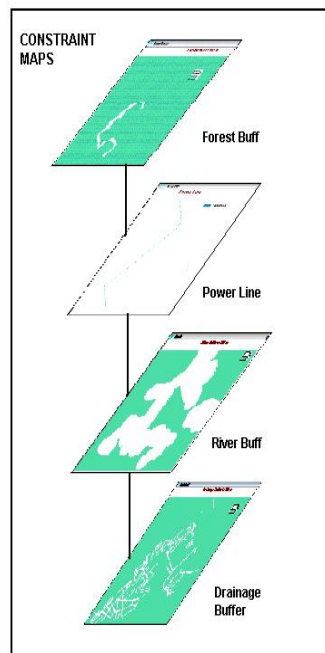


Fig. 9. (b) Constraints Maps Overlay

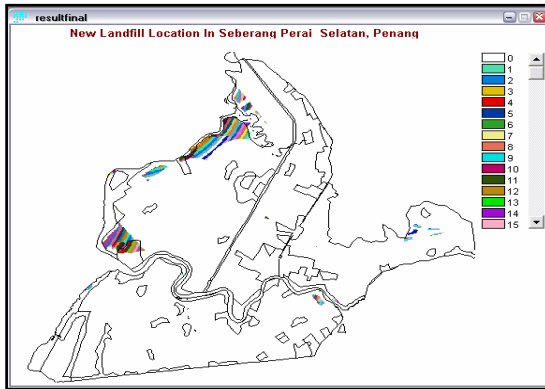


Fig. 10 Results of Overlaying Processing

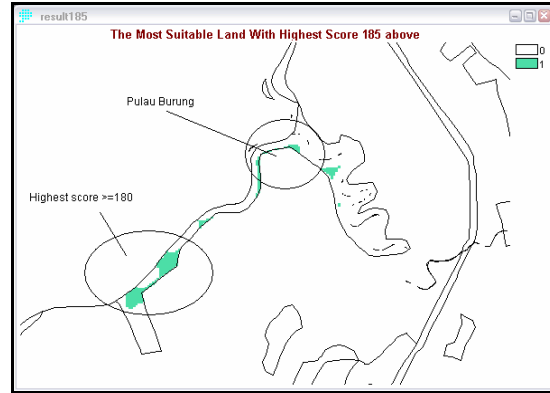


Fig. 11 The Accurate Landfills Location

5. Conclusion

The process of landfill siting presented here can be a rational process of optimal allocation of sanitary landfills. This site considered for future development. The result from the simulation model as applied to Pulau Burung in SSP indicates that the land availability for landfill siting is very few. There are only 18.35 ha of land left to be considered for the waste dump sites. The integrations of GIS with site selection model have proved its ability in searching land suitability. A landfill requirement needs a minimum of 20 ha for a new site. The proposed new landfill site is situated near the existing landfill at Pulau Burung. This new site can be considered as replacement for a new phase to supply the increasing demand of solid waste generation in the regions of Pulau Pinang, SSP. In terms of geographic condition, the new land is found to be similar with the previous landfill. It has identical topography situated on the west side where most of the land is of clay types. In fact, the new land is much better compared to Pulau Burung landfill because it is far from the main river streams. It has no residential areas nearby and the surrounding area is forest (Palm oil plantations). The access road to the site is not far from the main road networks in the region. The new landfill site may require a short distance road to be constructed and attached to the main road. The model has successfully determined the suitable area in short time and finally solved the multi-criteria problem by means of decision making preferences.

6. References

- [1]- Messineo A., D. Panno, (2008), *Municipal Waste Management in Sicily: Practices and Challenges*, **Waste Management** 28 1201–1208.
- [2]- Al-Salem, S. M. (2008), *Country Report: Establishing an Integrated Databank for Plastic Manufacturers and Converters in Kuwait*, **Waste Management (in press)** doi: doi:10.1016/j.wasman.2008.02.030.
- [3]- Karadimas V. N., Vassili G. Loumos (2008), *GIS-based Modeling for the Estimation of Municipal Solid Waste Generation and Collection*, **Waste Management and Research Journal** DOI: 10.1177/0734242X07081484.
- [4]- Alhumoud, J. M., 2005, *Municipal Solid Waste Recycling in the Gulf Co-operation Council States*. In: **Resources, Conservation and Recycling** 45 (2005) 142–158, (Elsevier) doi:10.1016/j.resconrec.2005.01.010

- [5]- Troschinetz, A. M., Mihelcic, J.R., (2008), *Sustainable Recycling of Municipal Solid Waste in Developing Countries*, *Waste Management* (in press) doi: doi. org/ 10. 1016/j. wasman.2008.06.004
- [6]- Environment Protection Agency (EPA), (1993), *Location Criteria Chapter 2 Sub-part B: In Solid Waste Disposal Facility Criteria: Technical Manual*, (USA-EPA 530-R-93).
- [7]- Haines, R. C., (1988), *A Study on the Safety Aspect Relate to the Handling, Monitoring of Hazardous Wastes: Consolidated report of studies undertaken for the European Federation for the Improvement of living and working*, Published by Shankill Company, Duplin, Ireland.
- [8]- Bolton, N. (1995). *The Handbook of Landfill Operations*, Bozeman, MO: published by Blue Ridge Services Blue Ridge Solid Waste Consulting, Atascadero, California.
- [9]- Christian, L., Stefanie, H., Samuel, S., 2003, *Municipal Solid Waste Management Strategies and Technologies for Sustainable Solutions*, published by Springer-Verlag Berlin Heidelberg, German
- [10]- Saeed, Mohamed Osman, Nasir M. H., and Mujeebu M. A., (2008), *Development of Municipal Solid Waste Generation and Recyclable Components Rate of Kuala Lumpur: Perspective Study. Paper presented in International Conference on Environment (ICENV 2008) Penang, Malaysia.*
- [11]- Syed R. Qasim and Walter Chiang, (1994), *Sanitary Landfill Planning Design and Operation*, published by Technomic publishing Company, Lancaster, Pennsylvania, USA.
- [12]- Ohman K. V. H. & J. P. A Hettiaratchi & J. Ruwanpura & J. Balakrishnan & G. Achari (2007), *Development of a Landfill Model to Prioritize Design and Operating Objectives*. *Environ Monit Assess* DOI 10.1007/s10661-007-9715-1
- [13]- Benítez, S. O., Lozano-Olvera, G., Morelos, R.A., Armijo de Vega, C. (2008), *Mathematical Modeling to Predict Residential Solid Waste Generation*, *Waste Management Journal* 28 S7–S13.
- [14]- Montserrat Z., Emilio Molero, Álvaro Hurtado, Alejandro Grindlay and Ángel Ramos (2008), *Evaluation of a Municipal Landfill Site in Southern Spain with GIS-Aided Methodology*, doi:10.1016/j.jhazmat.2008.03.023
- [15]- Yagoub, M. M. and Taher, B. (1998). *GIS Applications for Dumping Site Selection*, Presented at: The 18th Annual ESRI User Conference, 27-31 July 1998, San Diego, California, USA
- [16]- Sumathi, V. R., Usha Natesan and Chinmoy Sarkar (2007), *GIS-based Approach for Optimized Siting of Municipal Solid Waste Landfill*, doi: 10.1016/j. wasman.2007. 09.032.
- [17]- Katoch, S.S., Kumar, V., (2008), *Modeling Seasonal Variation in Biomedical Waste Generation at Healthcare Facilities*, *Waste Management & Research*, vol. 26.
- [18]- Saaty, T. L. (1980). *The Analytical Hierarchy Process*, New York: McGraw-Hill.
- [19]- Chang, Ni-Bin, G. Parvathinathanb, Jeff B. Breeden (2008), *Combining GIS with FUZZY Multi-Criteria Decision Making for Landfill Siting in A Fast-Growing Urban Region, Texas, USA*, . *Journal of Environmental Management* Volume 87, Issue 1, April 2008, Pages 139-153

- [20]- Lin, H.Y., Kao, J. J., (1998), *A Vector-Based Spatial Model for Landfill Siting*, **Journal of the Hazardous Materials**, Volume 58, Issues 1-3, February 1998, pp. 3-14.
- [21]- **Japan International Cooperation Agency (JICA) 1999, Solid Waste Management Study for Local Municipalities for Penang State, Malaysia: Master Plan Report.**
- [22]- Ahamad, M. S. ,W. Hussin, W.M.A., Ahmad, S., (2003), *Comparison of Normal AHP and Multiplicative AHP Criterion Weighting in GIS-based Land Suitability Analysis*, **International Symposium and Exhibition on Geo-information, Oct., 13-14, 2003, Shah Alam, Malaysia.**
- [23]- Eastman, J. R., (1999), *Idrisi32 tutorial Guides*, **Clark Labs, Clark University, USA.**
- [24]- Jones., B.C., (1997), *Geographical Information Systems and Computer Cartography*, **Wesley Longman, 1st Edition, Harlow, England.**
- [25]- Zadeh, L. H., (1965), *FUZZY sets Information and Control*, vol. 8, pp. 338–353.
- [26]- Weerakoon, K. G. P. K., (2002), *Integration of GIS Based Suitability analysis and Multi Criteria Evaluation for Urban Land Use Planning; Contribution from The Analytic Hierarchy Process*, **Proceedings of the 2002 Asian Conference on Remote Sensing, Kathmandu, Nepal.**
- [27]- Aziz, Abdul Hamidi, Mohd Suffian Yusoff , Mohd Nordin Adlan, Nurul Hidayah Adnan, Salina Alias, (2003), *Physica-Chmical Removal of Iron from s\ Semi Aerobic Landfill Leachate by Iimestone Filter*, **Journal Waste Management 24 ((2004) 353-358)**
- [28]- Cointreau Sandra (1996), *Sanitary Landfill Design and Siting Criteria*, **In: World Bank Guidance as an Urban Infrastructure Sanitary Landfill Siting and Design Guidance Note**, published in May 1996 and it was updated November, 2004.
- [29]- Agamuthu P., (2003), *Solid Waste: Principals and Management with Malaysian Case Studies*, **Published by UM press, Kuala Lumpur, Malaysia.**
- [30]- Tchobanoglous, G. and O’Leary P. R., (1993), *Landfilling In, Handbook of Solid Waste and Management*, **Kreith F. (Ed.). McGrae-Hill, New York, USA.**
- [31]- Samuel Weiss, (1974), *Sanitary Landfill Technology*, **Published in USA by Nyoes Data Cooperation, Nyoes Building, in Park Ridge, New Jersey 07656.**
- [32]- Malczewski J. (1999), *GIS and multi Criteria Analysis*, **Published by John Wiley and Sons Inc., USA.**
- [33]- O’Sullivan, D., Unwin, D.J., (2003), *Geographic Information Analysis*, **Wiley, Hoboken, NJ, USA.**
- [34]- Malczewski J., (2004), *GIS-based Land-Use Suitability Analysis: a Critical Overview*. **In: Progress in Planning 62 (2004) 3–65, Elsevier.**