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Environmental Planning Strategies for Optimum Solid Waste Landfill Siting

(Strategi Perancangan Alam Sekitar untuk Penempatan Optimum Tapak Pelupusan Sisa Pepejal)

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ABSTRACT

The use of environmental planning tools for optimum solid waste landfill siting taking into account all environmental implications was carried out by applying Life Cycle Analysis (LCA) to enhance the research information obtained from initial analysis using Geographical Information Systems (GIS). The objective of this study is to identify the most eco-friendly landfill site by conducting a LCA analysis upon 5 potential GIS generated sites which incorporated eleven important criteria related to the social, environmental, and economical factors. The LCA analysis utilized the daily distance covered by collection trucks among the 5 selected landfill sites to generate inventory data on total energy usage for each landfill sites. The planning and selection of the potential sites were facilitated after conducting environmental impact analysis upon the inventory data which showed the least environmental impact.

Keywords: Geographic information system; impact analysis; life cycle assessment; landfill siting

ABSTRAK

Penggunaan alat pengurusan alam sekitar untuk penempatan tapak pelupusan sampah yang optimum dijalankan dengan mengaplikasikan kaedah Analisis Kitaran Hayat (LCA) untuk menambahbaikan maklumat kajian yang telah dijanakan oleh Sistem Maklumat Geografi (GIS). Objektif kajian ini adalah untuk mengenalpasti tapak bahan buangan yang paling mesra alam dengan menjalankan satu analisis LCA di 5 kawasan potensi tapak yang dijana oleh GIS yang sudah pun menggabungkan 11 kepentingan kriteria berkaitan dengan kemasyarakatan, alam sekitar dan faktor-faktor ekonomi. Analisis LCA menggunakan jumlah jarak yang dilalui oleh lori kutipan setiap hari di antara 5 tapak bahan buangan terpilih untuk menjana inventori data ke atas jumlah penggunaan tenaga untuk setiap tapak bahan buangan. Perancangan dan pemilihan untuk tapak yang paling sesuai dipermudahkan setelah dijalankan satu analisis impak ke atas inventori data tersebut untuk menentukan tapak pelupusan sampah yang mana akan menghasilkan kesan yang minimum terhadap alam sekitar.

Kata kunci: Analisis kitaran hayat; penilaian impak; sistem maklumat geografi; tapak pelupusan sampah

INTRODUCTION

Currently, Malaysia is facing solid waste management issues as landfills are rapidly filling up, increasing amount of waste are generated, shortage of disposal land, resulting of serious environmental and human health impacts. These circumstances happened due to the growing amount and the variety types of waste generated in relation with the rapid population and industrial growth, and also due to the rising in the standard of living of the people.

Landfilling is the most widely used method for solid waste disposal because it is the most economical and environmentally acceptable method throughout the world. Historically, landfills have created various environmental problems and thus, the public have become more aware concerning landfill issues such as increasing concern on the groundwater contamination and potential release of toxic gases and odour. These impacts of associated problems could be minimized by implementing proper landfill siting technique that involves the interplay of engineering, science and politics. The engineering disciplines required include civil, environmental, geotechnical, hydrogeological, and transportation. The science disciplines required include archaeology, biology, geology, horticulture, hydrogeology, and wetlands. Due to this purpose, numerous criteria, factors, and regulations must be taken into account such as avoid any floodplain area, wetland, surface water, residential areas and etc. These siting factors must be carefully analyzed in order to come out with an appropriate site that could have minimum impact on environment, economic, accepted by public as well as comply with the regulations. Without fully considered all current the regulations and environmental, sociocultural, engineering, and economic factors, the decision maker might reach an improper conclusion (Kao & Lin 1996).

Since various input factors should be considered in landfill selection, by using conventional processing

approach the landfill siting analysis becomes difficult and complex. For instance, spatial data pertaining to the environmental, social, economic, and engineering factors have to be assessed. Therefore, a lot of time is needed to carry out the assessment. In addition, the siting process may need to be repeated for many times until the most suitable site is selected (Kao et al. 1999).

The Geographical Information Systems (GIS) are widely used in landfill site selection to achieve the combination of the identified criteria in order to generate the suitability maps (Leao et al. 2004). Presently, it is the most reliable tool as it has capability to store, retrieve, and analyze a large amount of data as well as outputs visualization. Furthermore, landfill siting analysis by using GIS gives a big save on time consume. GIS has been utilized to conduct an initial screening in order to find a suitable area for locating landfills. Several techniques that use GIS for landfill site selection have been found in the literature (Sener 2004; Basagaoglu et al. 1997; Kao et al. 1996; Kontos et al. 2003; Kao et al. 1999).

After the initial GIS screening, Life Cycle Assessment (LCA) analysis will be utilize to conduct in-depth analysis on the environmental impact of GIS suggested area to compare the full range of environmental damages, and to be able to choose the least burdensome one. LCA is a tool widely use for assessing the environmental impacts associated with a product, process or service throughout its life cycle, from the extraction of raw materials through to processing, transport, use, reuse, recycling or disposal (Sumiani 2004). LCA can also be a usefull tool for comparing the environmental attribute of similar products or services such as landfill location.

Lately LCA is becoming an important tool in evaluating solid waste management systems. Although, the waste management system has long been practised in major parts of the world since 1940s, but the outrageous amount of the waste types which contribute to the complexity of waste management has created the needs for more accurate and detail modelling of the waste management in order to assess the environmental emissions and resource conservation. The European Union has recommended life cycle thinking for decision making by utilization of LCA model that play an important role for more sustainable waste management strategies.

LCA models dedicated to waste management can be used as decision support and for a variety of issues within solid waste management. LCA models can be use for evaluating alternatives in a municipal master plan for waste management, identifying key areas to improve present waste management systems, assessing efficiency of new treatment technologies, setting optimum criteria for material recycling, and quantifying importance of waste minimization. In the market, there are numbers of LCA models have been used to provide quantitative environmental assessment of issues in waste management (Bahnder et al. 2007).

The purpose of this study is to develop a landfill siting methodology that integrates the multi criteria decision making method, which are the analytical hierarchy process (AHP) and weighted linear combination (WLC) method with the GIS environment and continue with LCA analysis in comparing the environmental burdens. The presented methodology is applied to the Klang District, as a case study area which aims to evaluate the potential areas for landfill siting on the entire study region and to find the most suitable area for locating landfills.

Study Area

Klang (or Kelang) is the royal capital of the state of Selangor, Malaysia. It is located about 32 km to the west of Kuala Lumpur and 6 km east of Port Klang. It was the civil capital of Selangor in an earlier era before the emergence of Kuala Lumpur and the current capital, Shah Alam. Port Klang is one of the world's busiest seaports. This territory area of approximately 573 km^2, and total population by 2007 at 1,004,194 with the density of 1,738/km^2, contains residential, commercial, industrial, agricultural and etc.

The increasing of population in Klang gives a greater impact towards the daily amount of generated municipal solid waste. According to the Klang Department of Environment, Teluk Gong waste disposal site which operated until year 2000 closed down because of the leachate produced contained significant high amount of contaminants which causes pollution to the surrounding water stream. In addition, the capacity of Teluk Gong site had reached the maximum level of height which is almost 30 meters. In 2001, a new waste disposal site in Teluk Kapas was opened to replace the Teluk Gong waste site. The overall area is almost 0.178 km^2 and its lifetime is between 3 to 5 years and should reach its maximum capacity by 2007. However, until today, this site is still operating as there is no suitable replacement area yet. Hence, due to the urgency of the situation, the Klang district is chosen as this research study area.

GIS has the capability to provide spatial analysis tools for sorting, retrieving, and manipulating georeferenced computerized maps (Kao et al. 1996). It is widely used in various research fields including landfill siting. Together with LCA methodology, the capability of further enhancing the GIS preliminary site selection could be improved further by quantifying the information of environmental burdens for each selected sites in order to choose the most suitable and optimum site.

Methodology

This research utilized the preliminary data from GIS selected potential landfill sites from previous conducted research. Further on, the LCA quantification was applied to determine the optimal selection site based on the environmental aspects due to the collection and siting of the proposed sites.The spatial analysis tools provided by the GIS have been utilized together with the multi criteria decision making procedure to facilitate landfill siting for

the entire study area in the initial stage (Mohd Din et al. 2008).

Before the spatial analysis was performed, limitation and factors criteria must be identified according to the local regulations, international practice as well as from the related literature that are suitable with the study area. Hence, they were outlined based on the evaluation on the environmental, social, and engineering-economic issues There were 11 importance criteria identified for siting a landfill at the study area namely historical site, swamp, flood prone, railway, residential, surface water, road accessibility, soil type, slope, land use and urban. These criteria were divided into the two categories namely constraint and factor criteria. Constraint criteria represent the unsuitable areas according to the regulations, which prohibit landfill site from being placed within these areas that may have conflict with the regulations and/or could harm the environment. While, Factors criteria were used to evaluate the potential areas for landfill based on its suitability (Mohd Din et al. 2008).

All the data pertaining to the criteria were obtained from several government agencies. Most of these data were in the GIS format except for archaeology, flood prone, and railway which were in hardcopy format. Therefore, manual digitizing was performed to convert hardcopy into GIS format (Mohd Din et al. 2008).

A number of candidate sites have been revealed through the initial study by considering 11 parameters as stated as above. In order to allocate the most suitable areas derived from the presented analysis, further study is needed on the predetermined collection routes of 5 candidate sites using LCA analysis. This could be carry out by considering the potential energy used by the collection truck through the distance of collection route. The details of the 5 candidate sites that were most suitable for further investigation are shown in table and figure below.

TABLE 1. Description of sites

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

RESULT AND DISCUSSION

From the results of GIS analysis, LCA was introduced to further investigation on the GIS recommended sites for impact assessment in term of collection route. The collection route and distance from collection point to 5 different GIS recommended landfill site are the baseline data used for the analysis.

This research utilized the LCA software of SimaPro 7 to analysis the average distance for each landfill sites from the collection point which is Bandar Klang. Klang Valley with the average of 1.5 kg of municipal solid waste

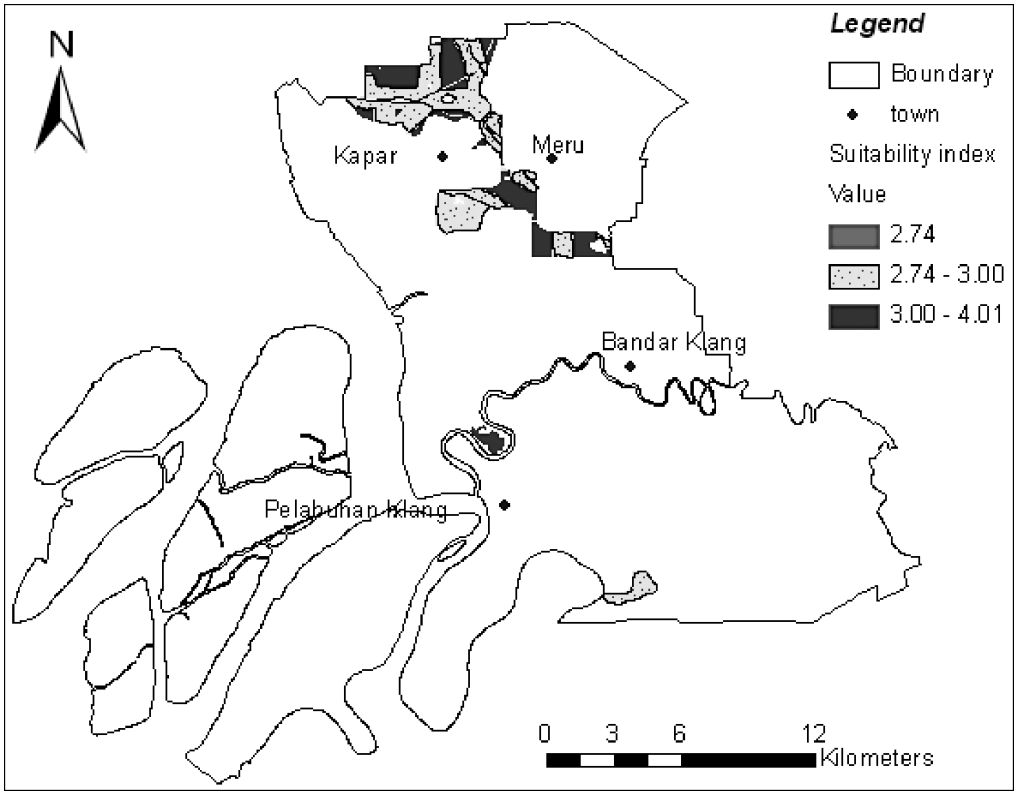

FIGURE 1. The most suitable locations for landfill sitting

generated every day per capita by 2005 (Sivapalan 2002) and with the approximate population of 809,400 by 2007 (Department of Statistics Malaysia, 2008) estimated to produce around 1506 tons of municipal solid waste per day to the landfill.

In the LCA analysis, specification of diesel powered truck with the capacity of 5 tons with the average load of 50% from total capacity was chosen to represent the waste collection truck for all the landfill sites. The LCIA analysis used Eco-indicator 99 (H) V2.04/Europe EI 99 H/H method in SimaPro 7 to assess the environmental impact for estimated distance among 5 GIS suggested sites and collection site as shown in Table 2. The results generated in Table 3 and Figures 2 show the total impact of each collection routes generated per day for collection of 1214 tons amount of municipal solid waste.

TABLE 2. Distance of sites

Site	Area (hectare)	Estimated average distance from Bandar Klang (km)
Area 1	207	19.83
Area 2	181	18.41
Area 3	215	14.16
Area 4	121	11.51
Area 5	126	10

From the results as shown in Table 4 and Figure 3, it is clear that landfill site of A5 which is located nearer to the collection site of Bandar Klang contributed the least environmental impacts compared to all the other landfill sites which are located further away. The longer the collection

TABLE 3. LCIA Results for each damage categories

Damage category	Unit	Area 5	Area 4	Area 3	Area 2	Area 1
Total	Pt	317.04	365.01	449.02	583.73	615.88
Human Health	Pt	124.17	142.95	175.86	228.61	241.20
Ecosystem Quality	Pt	14.90	17.16	21.11	27.44	28.95
Resources	Pt	177.97	204.90	252.06	327.68	345.73

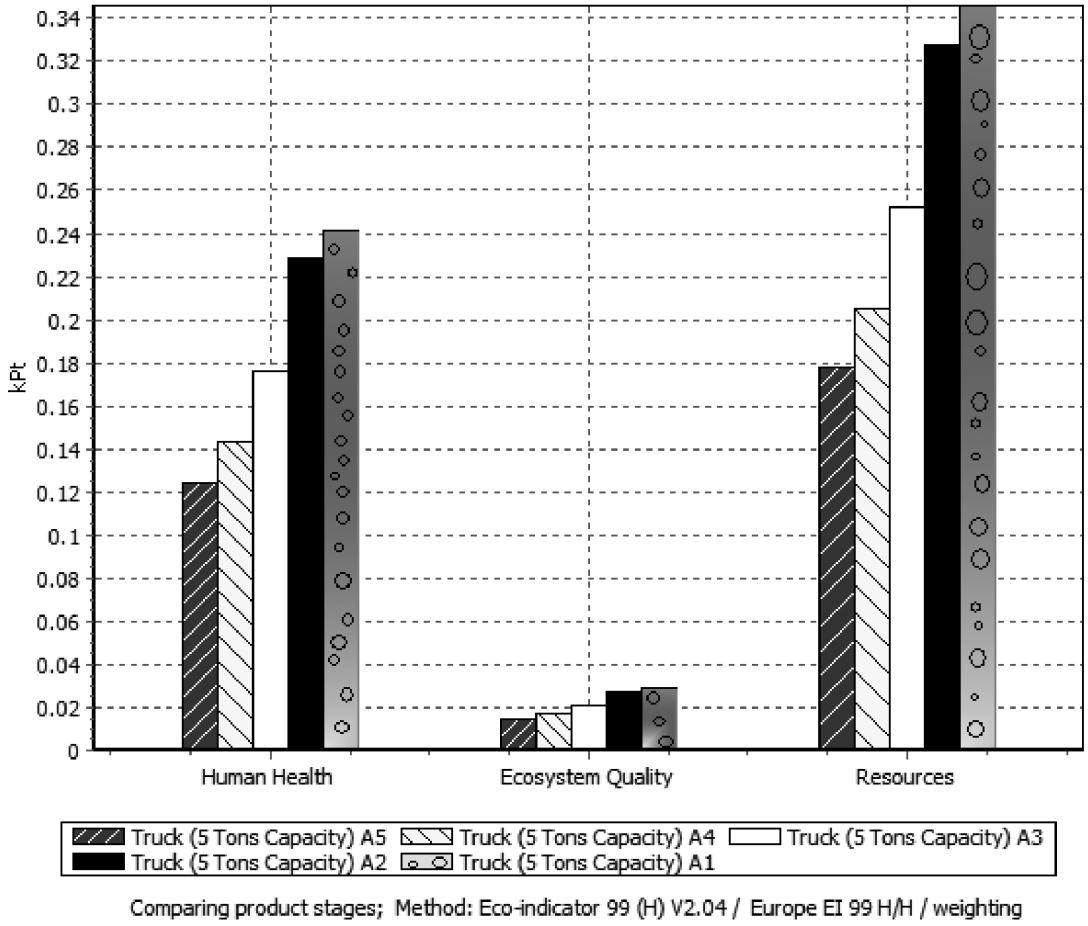

FIGURE 2. LCIA Results for each damage categories

TABLE 4. LCIA Results per impact category

Impact category	Unit	Area 5	Area 4	Area 3	Area 2	Area 1
Total	Pt	317.04	365.01	449.02	583.73	615.88
Carcinogens	Pt	0.23	0.27	0.33	0.43	0.46
Resp. organics	Pt	0.28	0.32	0.39	0.51	0.54
Resp. inorganics	Pt	113.04	130.14	160.10	208.13	219.59
Climate change	Pt	10.61	12.22	15.03	19.54	20.62
Ecotoxicity	Pt	0.12	0.14	0.17	0.22	0.23
Acidification/ Eutrophication	Pt	14.78	17.02	20.93	27.22	28.71
Fossil fuels	Pt	177.97	204.90	252.06	327.68	345.73

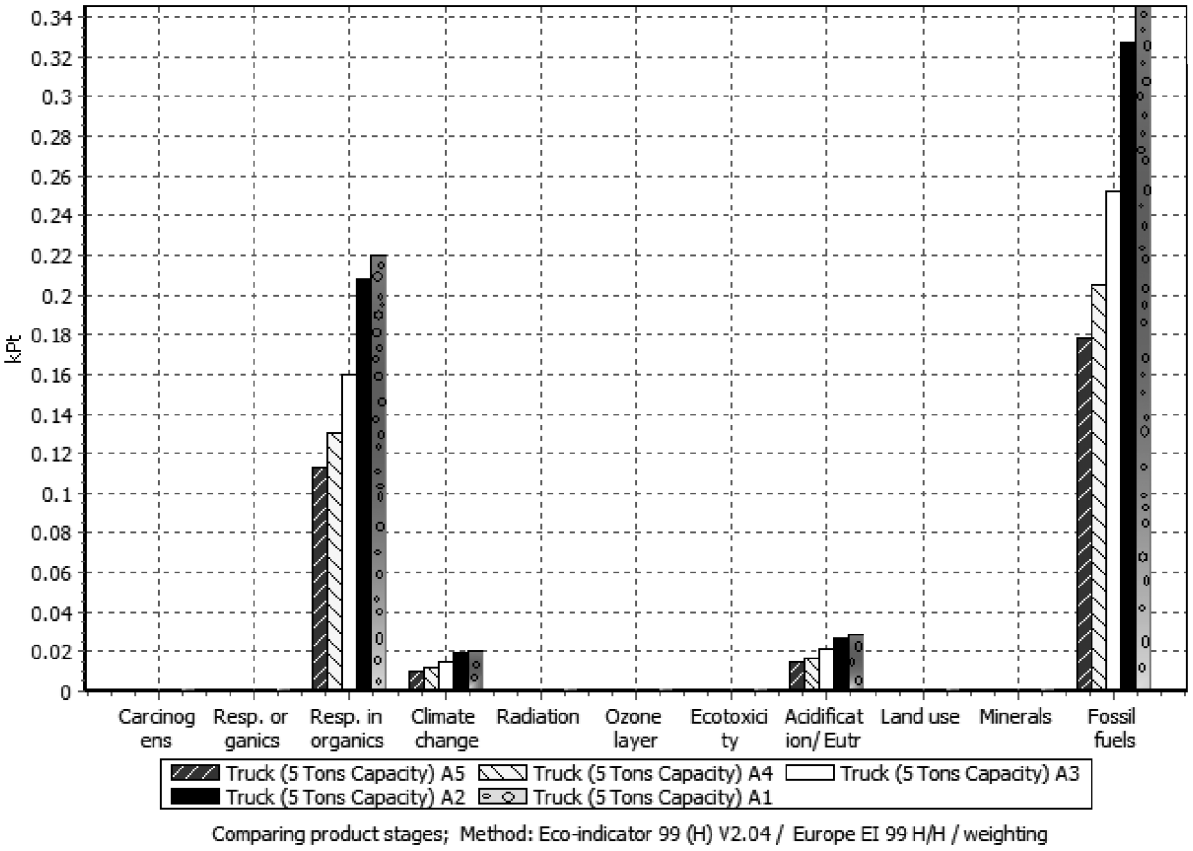

FIGURE 3. LCIA Results per impact category

distance and high diesel usage will contribute higher impact damage to human health, resource consumptions and ecosystem quality. Table 4 and Figure 3 show the results for per impact category showed that the damage anticipated largely contributed towards fossil fuels depletion and respiratory disease along with small contribution on climate change and eutrophication phenomenon.

CONCLUSION

The LCA analysis conducted on the 5 GIS recommended landfill sites quantified and showed that landfill site A5 which is located nearer to the collection sites contribute the least impact to the environment in term of diesel usage through the collection routes. However, the capacity of each potential landfill site should also be studied to incorporate the life span of each site for better decision making. Therefore, from the analysis of this study, landfill site of A5 should be selected for future planning of landfill sites since it produces the least impact to the environment from the application of LCA analysis on its collection routes.

In conclusion, the incorporation of the methodology used in the study to incorporate both environmental planning tools such as GIS and LCA, could further enhance the decision making process in terms of managing and properly siting landfill sites to ensure optimum environmental aspects are achieved.

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