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The challenge of future landfill: A case study of Malaysia

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Landfilling is the most frequent waste disposal method worldwide. It is recognised as being an important option both now and in the near future, especially in low- and middle-income countries, since it is the easiest and the cheapest technology available. Owing to financial constraints, landfills usually lack of environmental abatement measures, such as leachate collection systems and lining materials. As a result, a lot of contamination is inflicted upon the environment. Importantly, even with proper abatement measures in landfills, there is no guarantee that contamination will be prevented. Another major concern is the appropriate location for landfills to ensure the impact towards the environment are minimised. This paper highlights the challenge to find suitable place for future landfill in Malaysia. There is a tendency of landfill to be built on unsuitable area such as near to residential area or on agricultural land where most of the land are grading as high prospect value to be developed as business or industrial area that are more profitable.

Key words: Municipal solid waste, disposal methods, landfilling, developing countries, Malaysia.

INTRODUCTION

Municipal solid waste (MSW) is a category of diverse waste, generated from different sources (that is, residential, commercial, municipal services, agriculture), each of which is itself heterogeneous. Significant concerns over the environmental impacts of MSW have emerged, the nature of which depends upon the waste amount and composition, as well as the disposal methods. An effective waste disposal methods is closely related to the waste composition, the operational cost and also technology available (Lau, 2004).

Waste generation continues to increase with the economy and population growth. This suggests that the greatest challenge is to provide more waste disposal facilities such as landfill to treat the waste (Hassan et al., 2001). Despite the complexity of waste produced, the standards of landfills in most developing countries are still poor; these include inadequate waste treatment facilities, inefficient collection and storage systems, co-disposal of municipal waste with hazardous waste, inefficient utilisation of disposal space, lack of environmental abatement measures and poor documentation (Hassan et al., 2000). As a consequence, a great deal of contamination, especially to surface water, soil and ground water, occurs, threatening the health of exposed populations and ecosystems (Zhang et al., 2010).

Malaysia is a South East Asia country where landfill is important and where the standard of waste management needs to be improved. It comprises thirteen states and three federal territories, with a total surface area of 329,700 km^2 (Figure 1). The capital city of Malaysia is Kuala Lumpur, with Putrajaya the seat of the federal government. Known as one of the rapidly developing

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economies in Asia, MSW generation is projected to increase from 292 kg/capita in 2000 to 511 kg/capita in 2025 (Lau, 2004). At present, landfilling is the main waste disposal method (80% usage) and it is still expected to account for 65% of waste in 2020 (Waste Management Policy of Malaysia 10th Plan, 2010 to 2020). By comparison, recycling and intermediate processing are projected to take 20 and 15% of the waste in 2020. Most landfills in the country are in a bad condition (Latifah et al., 2009), operated without proper protective measures, such as lining systems, leachate treatment and gas venting.

Since landfilling is the main waste disposal method in near future, this paper highlights the challenge to find suitable place for future landfill in Malaysia. Carrying out a landfill siting assessment is a complicated process involving many factors, that is, environmental, socio-cultural, technical and economic. Planners face great difficulties in establishing the most suitable locations for landfilling, owing to shortages of space and increasing quantities of solid waste, due to a rapid urbanisation process. To illustrate the significant of this argument, a case study in highly developed state of Malaysia, that is, Selangor was highlighted in this paper. The case study provides a suitably varied context to address the issue in the country.

MUNICIPAL SOLID WASTE GENERATION

MSW increases rapidly with economic activities and population growth. For example, the growth of MSW in the Organization for Economic Co-operation and Development (OECD) countries has closely followed the increases in the gross domestic production (GDP) and population (Figure 2) (United Nations Environment Programme (UNEP), 2004; OECD, 2000; Lau, 2004).

The rates of waste generation between world regions are notably different. For example, the average rate of urban waste generation amongst the high income countries such as Denmark, Japan, Korea and United Kingdom was 2.13 kg/capita/day (Table 1). In the upper middle income countries such as Malaysia, Myanmar and Mexico, the rate was slightly lower than the high income countries (1.16 kg/cap/day).

On the other hand, the lower middle income countries (that is, China, India, Thailand, Sri Lanka) and the lower income countries (that is, Ghana, Lao, Tanzania) had less generation rate between 0.60 to 0.78 kg/capita/day. The waste generation rate is expected to increase from 1.2 to 1.4 kg/capita/day in 2025, with the total increase of three million tons/day (Hoornweg et al., 2012). This was influenced by economic development, the degree of industrialization, public habits and local climate. Generally, the higher the economic development and urbanization, the greater the amount of solid waste produced.

WASTE COMPOSITION

In many parts of the world, the main component of MSW is an organic waste (especially food waste). For example, the organic waste tends to be very high in low income countries (64%) compared to the high income countries which have high percentage of paper waste (31%) (Table 2).

Considering the MSW generated in general, its main constituents are similar throughout the world, but the quantity generated, the density and the proportion of streams vary widely between regions. This was influenced by many factors, such as level of economic development, urbanization level, lifestyle, cultural norms, geographical location, energy sources and weather conditions (Hoornweg et al., 2012; Khatib, 2011; Nasir et al., 1995). For example, high consumption of fresh and unprocessed food as well as preparation of meals in low income countries generates significant quantities of organic waste in this region. This is the opposite of high income countries where the lifestyle favours fewer homes cooking, relying mainly on the readymade backed food (Khatib, 2011).

Waste composition is an important factor that determines the suitability of different waste disposal methods. For example, high percentage of organic material from 48 to 68% in the municipal waste has encouraged the use of landfilling in Malaysia (Nasir et al., 1995). The failure of an incineration trial in Malaysia was attributed to high moisture content from the organic compounds in MSW, which incurred additional operation costs to cover the auxiliary fuel in burning processes (Agamuthu, 2001).

LANDFILLING PRACTICE IN DEVELOPED AND DEVELOPING REGIONS

Landflling is the most frequent MSW disposal method worldwide, recognised as being an important option both now and in the near future, especially in low- and middle-income countries. For example, 338 million tonnes of waste were landfilled in most of the countries (Table 3). In the middle and lower income countries, they have poorly operated landfill that are likely classified as controlled dumping and 71.5 million tonnes waste were disposed through open dumping (Hoornweg et al., 2012).
Among developing Asian (that is, Malaysia, Vietnam, India, Thailand and Indonesia), 70 to 90% of the MSW are being disposed in landfill (Figure 3). In contrast, the main waste disposal treatment in most developed Asian (that is, Japan and Korea) is incineration. Landfilling has become the least preferable option in most European countries. For example, the main waste disposal in Germany and Denmark are now incineration and recycling owing to the fact that these countries have imposed restrictions on the landfill of certain waste

Table 1. Waste generation by region (Hoornweg et al., 2012).

Region	Current available data			Projections for 2025			
	Total urban population (millions)	Urban waste generation		Projected population		Projected urban waste	
		Per capita (kg/capita/day)	Total (tons/day)	Total populations (millions)	Urban population (millions)	Per capita (kg/capita/day)	Total (tons/day)
High income	774	2.13	1,649,547	1,112	912	2.1	1,879,590
Upper middle income	572	1.16	665,586	888	619	1.6	987,039
Lower middle income	1,293	0.78	1,012,321	4,010	2,080	1.3	2,618,804
Lower income	343	0.60	204,802	1,637	676	0.86	584,272
Total	2,982	1.19	3,532,256	7,647	4,287	1.4	6,069,705

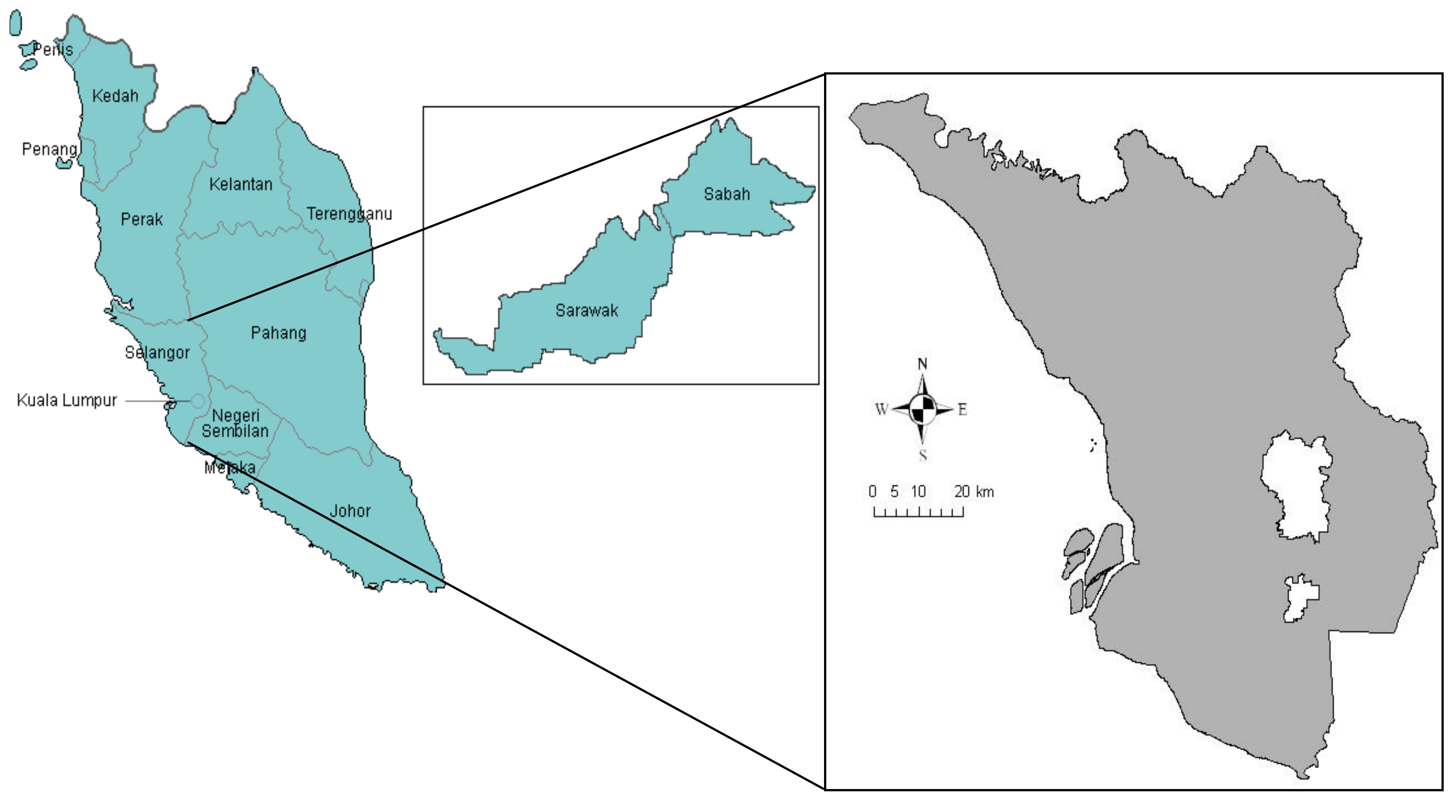


Figure 1. The location of Selangor in Peninsular Malaysia.

Table 2. Type of waste composition by income level countries (Hoornweg et al., 2012).

	Current estimates					
Income level	**Organic (%)**	**Paper (%)**	**Plastic (%)**	**Glass (%)**	**Metal (%)**	**Other (%)**
Low income	64	5	8	3	3	17
Lower middle income	59	9	12	3	2	15
Upper middle income	54	14	11	5	3	13
High income	28	31	11	7	6	17

Table 3. MSW disposal by income (million tonnes) (Hoornweg et al., 2012).

Parameter	MSW disposal by income (million tonnes)			
	High income	**Upper middle income**	**Lower middle income**	**Lower income**
Landfills	250	80	2.2	6.1
Dumps	0.05	44	0.47	27*
Compost	66	1.3	0.05	1.2
Recycled	129	1.9	0.02	2.9
Incineration	122	0.18	0.05	0.12
Other	21	8.4	0.97	18

*This value is relatively high due to the inclusion of China

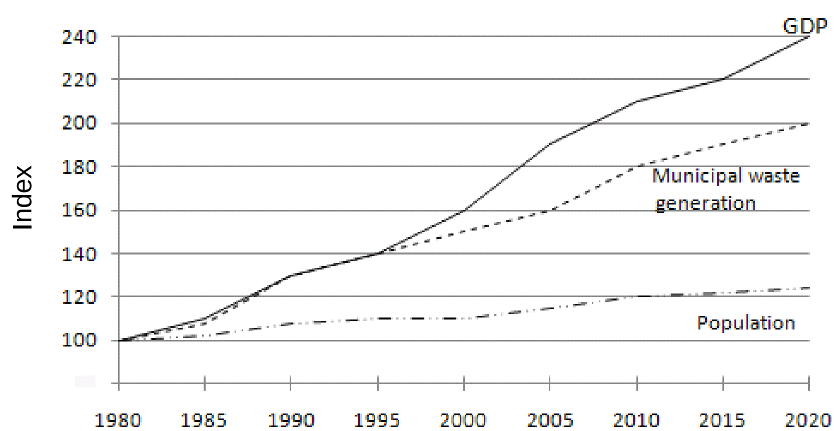


Figure 2. Municipal waste generation in OECD countries compared with trends in GDP and population (UNEP, 2004).

streams and have further emphasised policies on recycling and recovery for most of their waste stream. In the European Environment State and Outlook (SOER) (2010), it was reported that only 40% of municipal waste in the EU-27 was landfilled in 2008, while other proportions were recycled (22%), incinerated (20%) and composted (18%).

MSW landfilling practice is different between developed and developing regions, a key contrast being varying emphasis on particular stages of the waste management hierarchy. For example, incineration and recycling are the main waste disposal methods in European Union (EU) countries such as Germany and Denmark (SOER, 2010). This is owing to the fact that these countries have imposed restrictions on the landfill of certain waste streams and have further strengthened policies on recycling and recovery for most of their waste stream.

Furthermore, in European countries (Germany), only waste that cannot be considered for recycling will be disposed of in landfill. MSW is pre-treated to render it suitability for landfilling; this is one of the possible solutions when seeking to solve environmental problems from a degradation process. The biodegradable, organic waste components are first removed, which means that the waste masses and volumes going to landfill are decreasing continuously, therefore leading to steady reductions in the number of operated landfills (Hassan et al., 2006). This has not been applied in majority of the developing countries (Idris et al., 2004).

In developed Asian countries such as South Korea, the

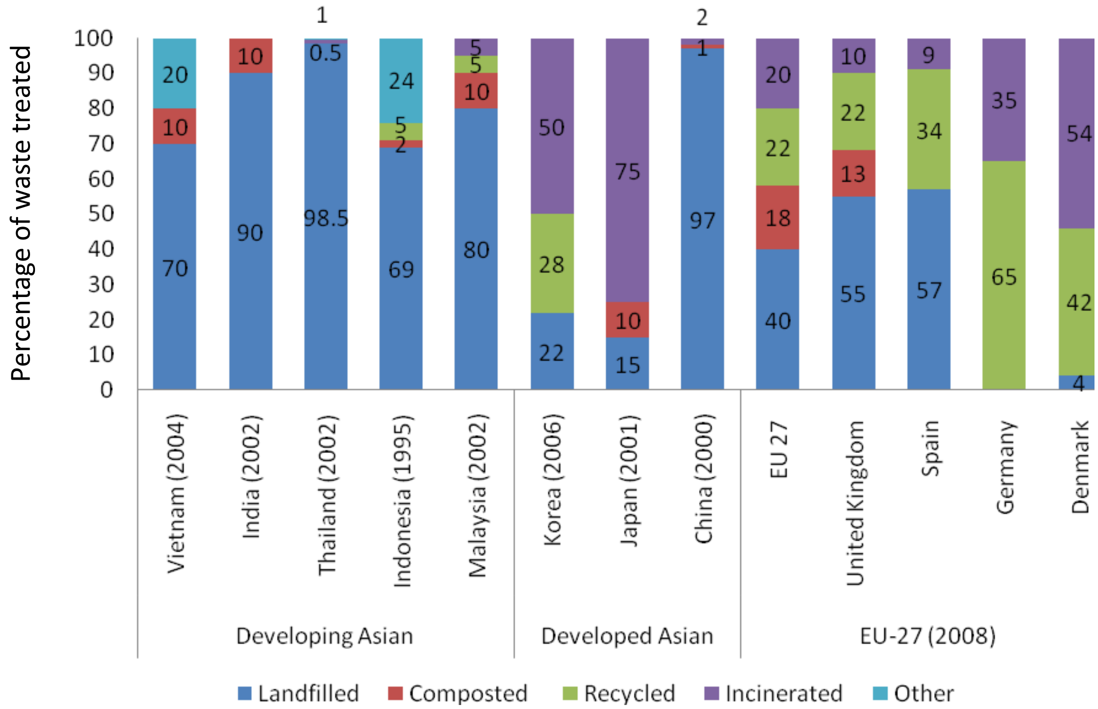


Figure 3. Municipal waste treatment (% of waste treated) (Visvanathan et al., 2005; Ryu, 2010; SOER, 2010).

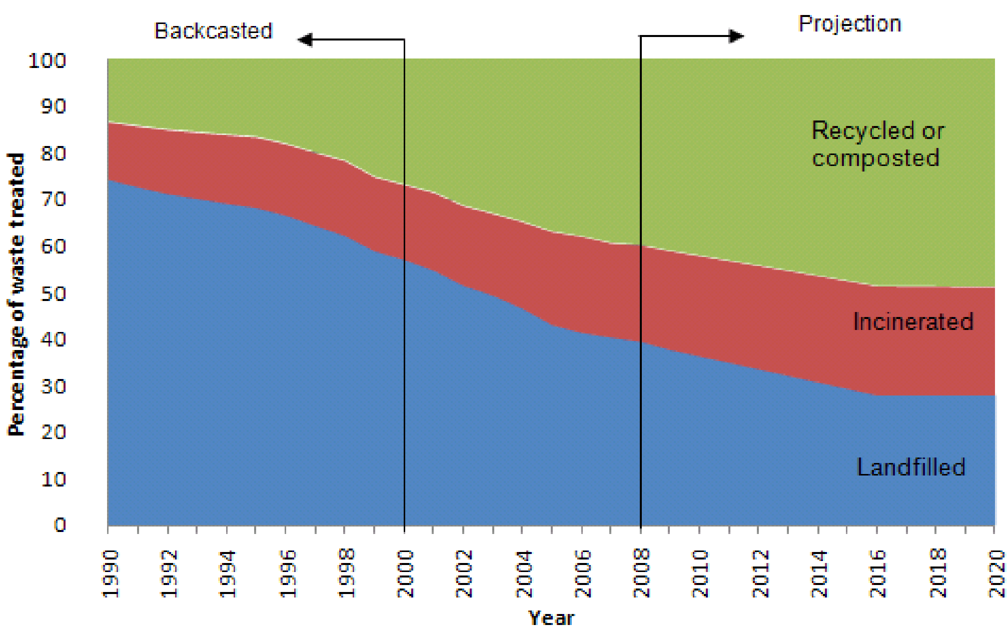


Figure 4. Trends and outlook for management of municipal waste in the EU-27 (SOER, 2010).

recycling has increased and reduce the use of landfilling from 62% in 1997 to 28% in 2006, with the successful introduction of obligatory schemes for a volume based waste fee and segregation of food waste system (Ryu, 2010).

Furthermore, in European countries, only waste that cannot be considered for recycling will be disposed of in landfill, whereas in many of developing Asian countries such as Malaysia, Thailand, Vietnam, India and Indonesia, all type of wastes (e.g. municipal waste, industrial waste, construction waste) are disposed in landfills without being pre-treated (Hassan et al., 2006; Visvanathan et al., 2005). Non-sanitary landfills and open dumping dominate in these countries (Idris et al., 2004; Latifah et al., 2009).

The landfilling of mixed wastes is the worst solution of all as biological, chemical and physical degradation processes in such sites can lead to harmful emissions of gas and leachate. With this in mind, it is therefore not guaranteed that the harmful emissions of leachate and landfill gas can be contained via technical barriers or liners in a landfill (Hassan et al., 2006). Accordingly, extensive remedial, monitoring and repair work can be required to prevent negative environmental impacts. For example, in Germany, MSW is pre-treated to render it suitability for landfilling; this is one of the possible solutions when seeking to solve environmental problems from a degradation process. The biodegradable, organic waste components are first removed, which means that the waste masses and volumes going to landfill are decreasing continuously, therefore leading to steady reductions in the number of operated landfills (Hassan et al., 2006). This has not been applied in majority of the developing countries (Idris et al., 2004).

Importantly, if the question is posed to whether landfills will continue to be an option for waste disposal globally in the future, the answer is an affirmative. For example, the projection of landfills in Europe, further decrease in the future, fell from 74% in 1990 to 40% in 2008 (Figure 4) (SOER, 2010). The percentage of recycled waste increased from 13% in 1990 to 40% in 2008, and incineration also slightly increased from12 to 21%. By 2020, landfilling is projected to fall further to 28%, with increases in recycling and composting. To some extent, this indicates that the Waste Directive Framework (75/442/EEC) (revised 2008/98/EC) has been a success in changing the waste management system in the Europe.

The Waste Directive Framework (revised 2008/98/EC) sets out a general framework for waste management in Europe together with the Packaging and Packaging Waste Directive (94/62/EC), which deals with a specific priority waste stream; and the Landfill Directive (99/31/EC), which sets standards for a method of disposal. These directives aim to move up the waste hierarchy by significantly reducing reliance on landfill, increasing recycling, reuse, composting and recovery, and ultimately waste reduction (DEFRA UK, 2009).

Several other directives, also detailed in EU waste policy, include the Directive on Batteries and Accumulators (91/86/EEC) which focuses on specific priority waste streams, and the Directive on Incineration of Hazardous Waste (94/67/EEC), which focuses on the impacts of treatment and disposal on the environment by setting up common technical standards. Furthermore, the commission has also drawn up a list of wastes, known as the European Waste Catalogue, in an attempt to standardise waste classification and reporting (Hansen et al., 2002). These all aim to attain the sustainable management of waste in the EU regions.

In OECD countries (that is, Germany, UK, Korea), landfilling shows an increasing trend but at a slow rate, and by 2020, landfilling is expected to be replaced by incineration and recycling (Figure 5). However, in non-OECD countries landfill is continuing to increase rapidly and is still the most preferred option. Other methods of waste disposal incineration and recycling have also increased; but they have not replaced landfilling (UNEP, 2004). This suggests that, more landfills are needed to dispose wastes as an economy develops in these countries and more space is needed to locate this landfill in future. Therefore, the siting process should aim to locate landfills in areas which can help to minimise hazards to public health, as well as to the environment, yet are also financially efficient (McBean et al., 1995). Financial constraint is one of the reason of poor landfill management especially in these countries. For example, the cost of converting to sanitary landfill is too high for the Jordan government to bear, thus the challenge for the government in this stage is to improve the current fee system to cover at least the operation and maintenance costs. On the other hand they had to concentrate on encouraging residence to minimize waste through recycling, starting from the source (Aljaradin and Persson, 2010).

FUTURE DEMAND AND CHALLENGE TO LOCATE FUTURE LANDFILL: A CASE STUDY OF SELANGOR

Selangor has a total area of 8,104 km2 with 5.4 million inhabitants in 2010. This is approximately 20% of Malaysia's total population (Department of Statistic Malaysia, 2010). It is a state with a diversified economy including agriculture, industry, commerce and tourism. The state has recorded the highest GDP per capita in recent years (RM 27.6 million in 2009) and makes the highest contribution to the national GDP (22.1% in 2010) (Department of Statistic Malaysia, 2010). Selangor (including Federal Territory of Putrajaya) and Federal Territory of Kuala Lumpur are the major waste producers, responsible for one third of the total waste of the country (Tarmudi et al., 2009). The state facing a serious crisis of waste disposal as it receives waste from Kuala Lumpur (100% urbanised and high waste) as the city has no landfills owing to limited space. Based on the average waste growth rate of Selangor (3.0%) and Kuala Lumpur (1.1%), the volume of waste in the state is projected to increase from 2.9 million tonnes in 2010 to 3.6 million tonnes in 2020 (Sharifah Norkhadijah, 2011). It is apparent that the existing seven landfills in the state could only receive half of this waste per year (1.6 million tonnes per year). The accumulated amount of waste left to be disposed of in the next 15 years (2010 to 2025) in the new landfills is consequently 27.86 million tonnes. There is consequently an indication that the establishment of a systematic waste management is highly necessary in the state.

In order to identify new sites for landfilling, the country used constraint mapping techniques (CMT) (Department of Environment, 1997). This method excluded unsuitable areas according to the constraint criteria, so that potential sites could simply be selected in the remaining areas. The potential sites were subject to rapid preliminary screening in order to narrow down the search to the most desirable sites, which would then require detailed studies. However, this technique is not comprehensive, owing to the fact that the evaluation was carried out based only on the exclusionary criteria, which ultimately produced weak evidence or arguments to support the selection. Therefore, an integration method of geographic information system (GIS) and Multi Criteria Decision Analysis (MCDA) was used to site for future landfill in this case study. A combination of GIS and MCDA has been recommended as a powerful tool to solve landfill site selection issues (Sener et al., 2006) as it divides the process into smaller understandable parts, analyses them separately, and then integrates them in a logical manner (Malczewski, 2000).

The methodology comprises the following steps:

(1) The development of constraint and factor maps. A constraint serves to limit the alternatives under consideration, typically by classifying the area into two classes, unsuitable (value 0) and suitable (value 1), while factors are criteria which enhance or detract from the suitability of a specific alternative for the activity under consideration.
(2) The implementation of the Analytical Hierarchy Process (AHP) method through a questionnaire to calculate the importance weights for evaluation criteria according to expert opinion.
(3) The implementation of Weighted Linear Combination (WLC) to calculate the suitability indexes
(4) The calculation of a mean suitability index across respondents to reveal the most suitable areas for future landfill. The suitability index map divided the value into five classes from very low suitability (1 to 50) to very high suitability (200 to 255).

After taking into consideration the haulage distance, protected areas, transportation routes, groundwater vulnerability, surface water and slope, only 7% of the Selangor state is suitable for landfill development in future which is labelled as C1 to C13. The mean suitability index was divided into very low suitability (1 to 50), low suitability (50 to 100), moderate (100 to 150), high suitability (150 to 200) and very high suitability (200 to 255) as shown in Figure 6 (Sharifah Norkhadijah, 2011). These areas are mainly located on agricultural land, which was the only option left.

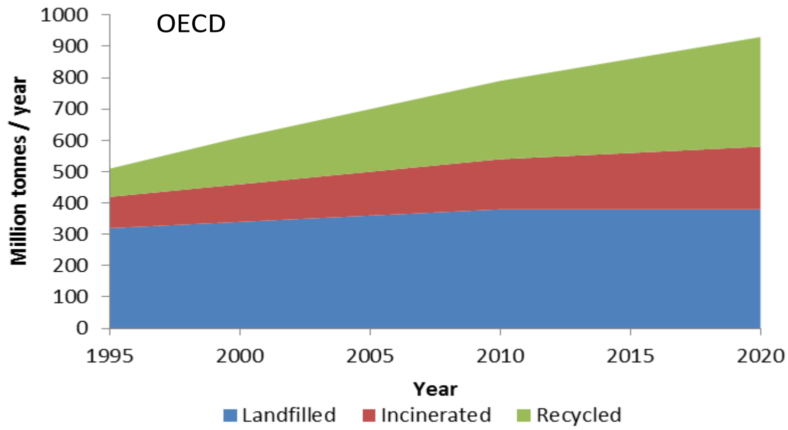
However, owing to the fact that these areas are generally far away from where waste is generated, there is a possibility of landfills being built on unsuitable areas. A comparison of the existing landfill sites in the state with the suitability map developed in the case study shows that most landfills (either still operating or closed) are located on unsuitable areas which is highlighted as white (Figure 7). This suggests that the current landfill site was not located in accordance to the CMT guidelines (Department of Environment, 1997) or possibly because of limited land available. This scenario would bring with them a major threat to the environment, especially to soil, surface water and groundwater. It may also produce adverse impact on agricultural industries such as food chain poisoning which leave negative impact on their contribution to the economy of the state.

The National Solid Waste Management (NSWM) agency recognised this issue but only recently and implementation is still limited. The policy statements of waste management implementation by the government indicates awareness that landfills cannot be the ultimate option any longer, and they have started to adopt new technologies to improve treatment and disposal processes for solid waste. There is also commitment to support environmental friendly activities such as recycling in promoting waste reduction as a key aim in the waste management policy. However, these policies were only promulgated recently, starting in 2006.

ENVIRONMENTAL POLLUTION

Another challenge in landfilling practice is environmental pollution from leachate (Adeolu et al., 2011; McDougall et al., 2001). Leachate from MSW landfills frequently exceeds standards for drinking water and surface water. The leachate often has significant potential to pollute groundwater and surface water. The common pathway for leachate to the environment is from the bottom of the landfill through the unsaturated soil layers to the groundwater and from groundwater through hydraulic connections to surface water. It may also result from the discharge of leachate through treatment plant or from untreated leachate (Johannessen, 1999).

The main factors influencing the pollution from leachate are the concentration and flux, the landfill siting, that is, the hydrogeological setting and the basic quality volume and sensitivity of the receiving groundwater and surface water (Johannessen, 1999). Leachate is produced over time, and with the percolation of rain water, the degradable fractions of the waste decompose and the resulting products are diluted and dispersed into the underlying soil if a site is not contained. Leachate production begins shortly after the process of landfilling possibly thousands of years. On a small scale, this



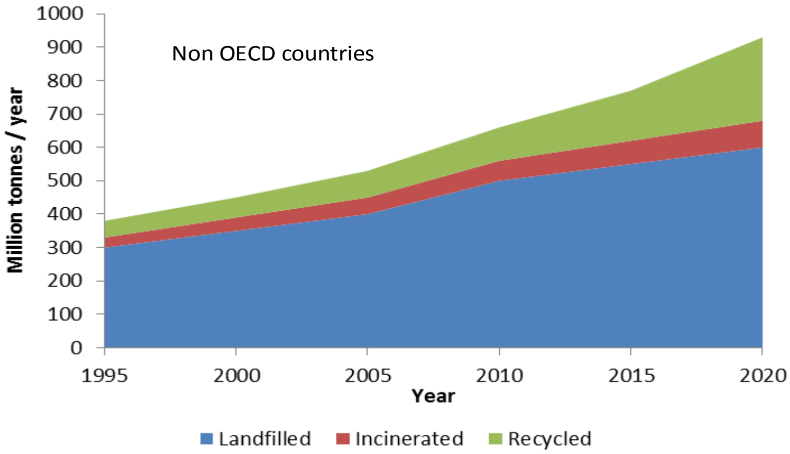


Figure 5. Projection of waste disposal methods in the world in Million tonnes/year (EU, 2010).

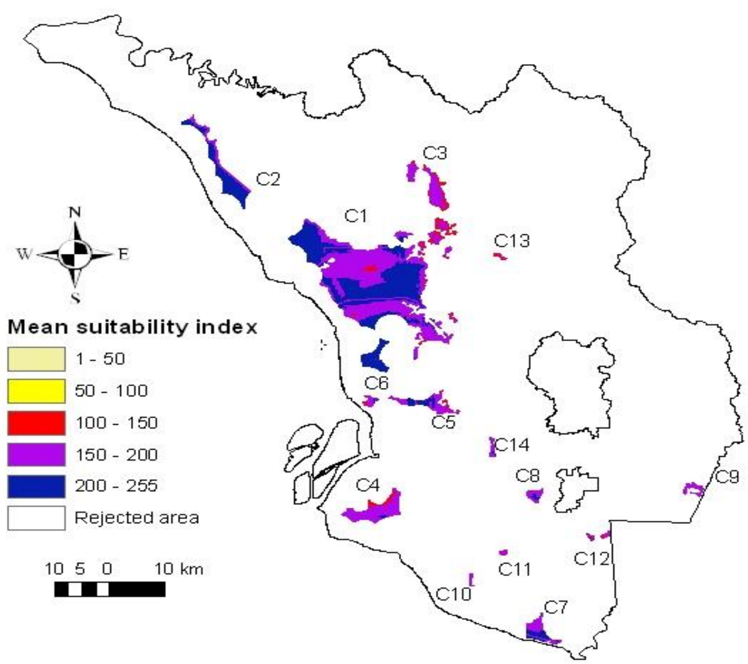


Figure 6. The mean suitability index map (Sharifah Norkhadijah, 2011).

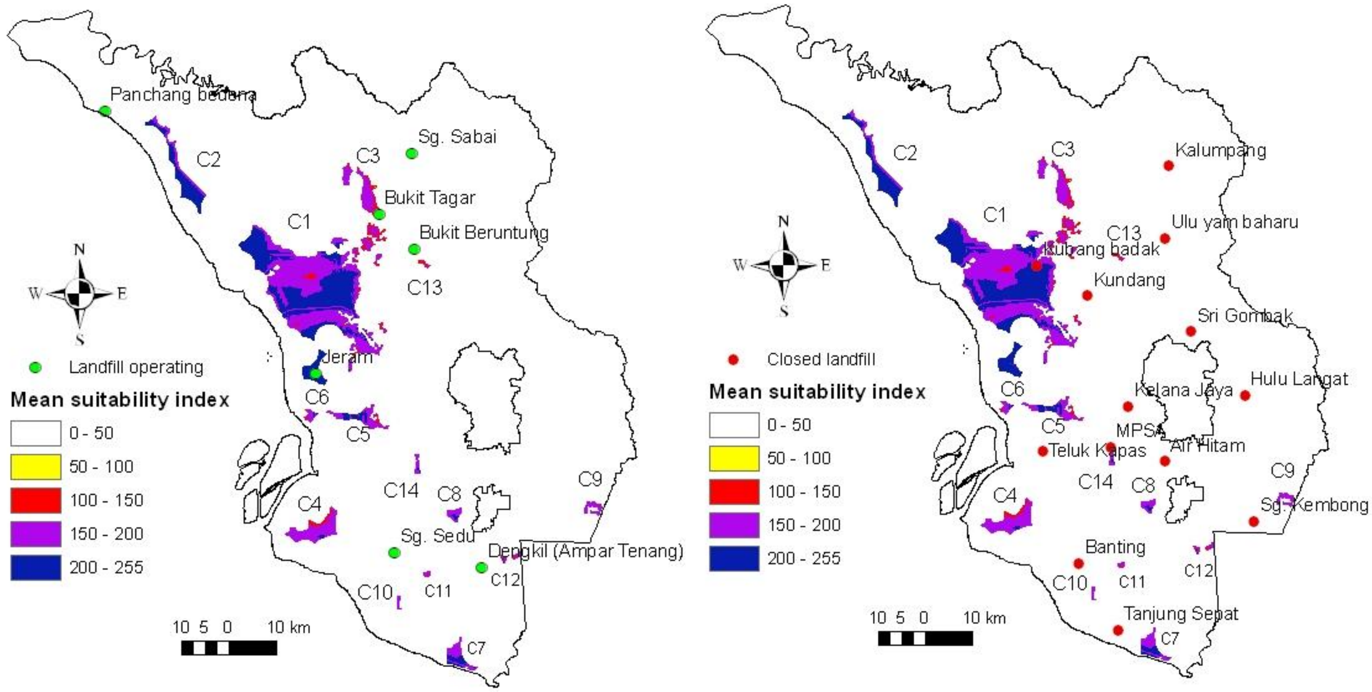


Figure 7. The location of current and closed landfills on the suitability index map (Sharifah Norkhadijah, 2011).

process (dilute and disperse) is effective, as soils have a natural capacity to further decompose organic material and to adsorb many inorganic residues. However, with the general increase in landfill size over time, and also when considering the high volume of waste, dilution and dispersion are no longer considered to be effective ways of dealing with landfill site emissions (McDougall et al., 2001).

Leachate is usually retained in the vicinity of the landfill unless it reaches the surface, thereby leading to runoff. In recharge areas, groundwater moves down and away from the site, and can potentially carry leachate contaminants from a landfill (Ahmed and Sulaiman, 2001). The area of pollutant migration may therefore be increased (Papadopoulou et al., 2007; Reyes-López et al., 2008; Singh et al., 2008; Jun et al., 2009). Leachate is also squeezed out of refuse through the compression and compaction occurring at landfills. These processes, in addition to precipitation percolating through landfills, eventually causes the refuse to reach field capacity and therefore leads to leachate percolation, which contaminates underground water sources below. Notably, the greater the refuse compacted, the greater the volume of leachate (Zanoni, 1972). Furthermore, the volume of leachate produced is influenced by climate. In comparatively warm climates, leachate production is usually higher than in colder climates (Visvanathan et al., 2003). Contaminated aquifers are not readily cleansed naturally, and economic methods for their decontamination do not exist (Quevauviller, 2005).

As water percolates downward through landfills, organic and inorganic constituents are dissolved together. Leachate may contain many different toxic elements (Lema et al., 1988; Agamuthu, 1999; Fauziah and Agamuthu, 2005; Deng and Englehardt, 2007). The composition of leachate depends on the nature of landfill, waste composition (Visvanathan et al., 2003), and the landfill age (Kulikowska and Klimiuk, 2008). If the permeability of the earth material is low, leachate may collect in the bottom of the refuse and may eventually discharge laterally to the surface and contaminate the soil (Lisk, 1991). In developed countries, public concern surrounding the location of landfills is based largely on the effects on human health of notorious cases of poor management of industrial waste, for example, Love Canal in the USA in the 1970s. There is also fear surrounding the possible adverse effects in the general population residing near relatively modern landfills (Giusti, 2009).

CONCLUSION

MSW landfill is in demand with the increase of waste generation, economy and population growth especially amongst developing countries. Based on the fact that limited space is available for landfill development and also the environmental pollution it may create, landfill cannot be the ultimate option for much longer. Adopting possibly thousands of years. On a small scale, this new technologies to improve treatment and disposal processes for solid waste is important. The commitment to support environmental friendly activities such as recycling in promoting waste reduction as a key aim in waste management policy also needs to be encouraged without excuse.

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