IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Comprehensive Spatial Criteria and Parameters for Sustainable Landfill Site Selection

To cite this article: M S S Ahamad and S Z Ahmad 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **540** 012071

Comprehensive Spatial Criteria and Parameters for Sustainable Landfill Site Selection

M S S Ahamad[1,2*] and S Z Ahmad[1]

[1]School of Civil Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.

[2]Solid Waste Management Cluster, Science, and Engineering Research Centre, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.

Email*: cesanusi@usm.my (Corresponding author)

Abstract. A landfill site is an important facility that must be occasionally evaluated when its demand gets high with the increment of generated waste. The task of selecting new landfill sites becomes difficult when there is a shortage of land and time available. It requires tedious planning decision about identifying the suitable sites. The complication will proliferate when there are various criteria that need to be apprehended. In Malaysia, the procedures for landfill site selection (LSS) is provided in the National Strategic Plan for Solid Waste Management (NSPSWM). It specifies the mitigation measures to be followed, but the restrictions on the appropriateness of suitable new landfill sites were not comprehensively deliberated. The criteria for the site suitability problem was not distinctly characterized as prescribed by the local Environmental Impact Assessment (EIA) guidelines. The significance of selecting proper landfill sites must encompass the physical characteristics, environmental impact, economic and social acceptance for the necessity of the sustainability community life. From the works of literature, this study introduced seventeen (17) universally adopted spatial criteria categorized under the environmental, physical and socio-economic (EPSE) characteristics. They were successively assigned with the relative weights and standard parameters. The EPSE criteria can assist in improving the regulated LSS policy currently available in the local NSPSWM and EIA guidelines. This will ascertain that future landfill site will be sustainable, safeguard public health, ensuring minimal impact on the environment, and provide long term isolation of the solid waste deposited.

Keywords: landfill site selection; spatial criteria and standard parameters; GIS

1. Introduction

Waste management is an important environmental issue where there is a need to conserve the resources as well as preventing pollution of the environment. Landfill site selection (LSS) is part of the waste management practice that is subjected to certain guidelines and policies aimed at minimizing the risk of environmental issues as part of the transition to a sustainable future [1]. The aim is to ensure that the landfill site is developed in an environmentally and socially acceptable manner to protect the environment, public health and quality of life [2]. It must conform to the policies and regulations that are generally accepted by the public [3]. There are many criteria (or factors) that must be taken into consideration and carefully evaluated. A proper landfill site selection process must avoid and reduce short term or long-term impacts that may possibly emerge during the design and implementation [4;1]. The legislative restriction is one of the important criteria in landfill site selection. In Malaysia, the waste management practices are generally driven by several statutory regulations such as the National Solid Waste Management Policy (NSWMP), National Strategic Plan for Solid Waste Management (NSPSWM), Environmental Impact Assessment (EIA) Guidelines for Development of Solid Waste Sanitary Landfill, and Solid Waste and Public Cleansing Management Act 2007 (Act 672). Also, the Department of National Solid Waste Management (NSWMD) is responsible for undertaking site selection and decision making based on the criteria set from the technical guidelines for Sanitary Landfill Design and Operation developed by Japan International Cooperation Agency (JICA) [5].

In general, the identification and selection process of the landfill site in Malaysia are performed by the respective state governments, as the land is categorized as the state matter. Priority is given to the usage of the state land and sites identified within local or structure plans for landfill development. Provision of enough buffer zone between the proposed landfill sites and residential areas is of paramount importance. Land approval in Malaysia will generally include (but not limited to) State Economic Planning Unit, Public Works Department, Department of Environment, Department of Irrigation and Drainage, Department of National Solid Waste Management and Town and Country Planning Department. Nonetheless, the implementation of site selection processes is slightly different in Sabah and Sarawak.

Landfill site selection (LSS) is amongst the difficult tasks faced by most communities in implementing an integrated solid waste management program [6]. It is usually focused on the health and safety issues related to an attitude commonly referred to as "Not In My Back Yard" (NIMBY) [7;8]. Naturally, the public disapproval to landfills will be most intense when the landfill is to be constructed close to their home. Their opposition is mostly attributed to the undesirable developments such as additional traffic, noise, odour, and litter [9]. In addition, the siting of a landfill is alleged to reduce the property values and decreasing the quality of life. From this environmental perspective, the principal objective of site selection is to identify a suitable location of the landfill that will safeguard public health, ensuring minimal impact on the environment, and provide long term isolation of MSW deposited in the landfill site [10]. The selection of new landfill requires the assessments of criteria associated with the various factors governing the suitability of the site. It encompasses comprehensive evaluation processes in identifying the best available disposal sites to fulfil the governing regulations in view of the environmental, physical, and socio-economic impacts [11;12;13]

The local LSS practice in Malaysia does not inclusively consider the environmental, physical and socio-economic (EPSE) criteria in conserving and protecting the environment. Only explicit site selection and screening criteria categorized as environmental, economic, and technical or engineering criteria were stated by EIA guidelines [14]. Nonetheless, the NSPSWM has prescribed a checklist for landfill site selection which is very subjective, barely defined and no limits or standards to be followed in the selection criteria of a sustainable landfill site [15]. This paper provides the foundation for searching the sustainable and comprehensive environmental, physical and socio-economic (EPSE) criteria that can be benchmarked with the local guidelines in Malaysia. It is intended to assist the authorities introduced a complete description of the landfill site selection criteria and ensuring its selection procedures are strictly followed.

2. Review of the common LSS criteria

There are numerous criteria that must be considered in the LSS process, for example surface water, sensitive areas, urban areas, residential areas, slopes, etc. The environmental protection and public health considerations must be the principal concern, such that the selection of the appropriate site will minimize potential environmental impacts and provide a sound basis for effective management [16;17]. The processes must make maximum usage of the available data in representing LSS criteria and ensures that the outcomes of the process are acceptable [16]. However, in the current practice, only the right and appropriate LSS criteria have been considered by researchers for optimizing the results and avoiding redundant factors. From the works of literature [18], a total of 17 LSS criteria was universally and locally applied, namely surface water bodies, sensitive areas, land use, road access, residential area, urban area, aquifer potential (groundwater), slope, soil permeability, geological fault properties, airport location, haul distance, flooding area, wind potential, utilities, rainfall intensity (climate), and bedrocks/ lithology. The frequency summary is described in Figure 1.

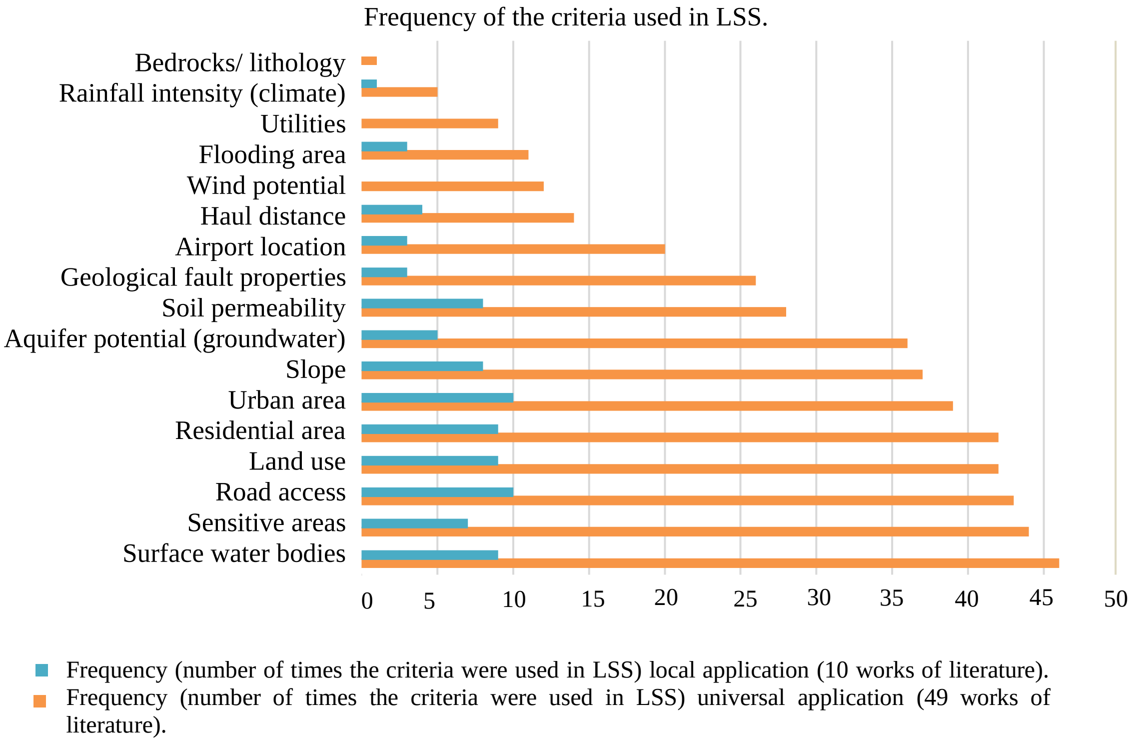

Figure 1. Frequency summary of common criteria applied in LSS study (source [18]).

The LSS criteria such as wind potential, utilities, and bedrock/lithology in the local LSS have not yet been considered. One reason for this is the lack of availability of the related data to represent the criteria [19]. Furthermore, the Malaysian Guidelines have not specifically described the exact data required for these criteria. Also, the dissimilarity of the LSS guidelines and policies of different states in Malaysia could lead to restrictions on the use of standard LSS criteria. It can be emphasized that most municipalities have their own location restriction (criteria) to meet the local environment conditions [20]. These differences cannot be taken lightly as the common LSS criteria must be uniform for the entire country as it may cause inconsistency in determining a sustainable landfill site. The uniformity will help in providing an efficient and effective solid waste management especially in terms of the site selection process.

The increasing awareness of the policymakers and public on the environmental, physical, and socio-economic (EPSE) problems that relate to the criteria of landfill location has increased complexity and pressure in the decision-making process. Therefore, the assurance given to the policymakers and the public that the selected landfill site is environmentally friendly and its EPSE impacts will be minimal is of utmost importance. The National Strategic Plan for Solid Waste Management (NSPSWM) is one effort made by the federal government to make solid waste management in Malaysia to be standard, well organized and systematic.

3. Methodology

3.1. Reclassifying the LSS criteria under EPSE category.

It is essential that the NSPSWM and the EIA guidelines set out the EPSE criteria relevant to the LSS. For this reason, this paper reclassifies the 17 common criteria to the relevant EPSE subcategory. The environmental criteria (E) have been identified as the parameters that restrict the outcome to specific geographic areas for the protection of sensitive habitats, as well as human health and safety. Physical Criteria (P) describes parameters that may affect the construction and operation of landfill sites, including technical and operational criteria. Socio-economic criteria (SE) are parameters that relate to landfill sites with social aspects (i.e. settlement areas, urban areas, cultural areas and visibility) and economic aspects (i.e. waste disposal costs, land costs and construction costs) [14; 21]. A clear description of each sub-category (or sub-criteria) is provided in Table 1. NSPSWM has set specific limits to some criteria, while others do not have any legal restrictions [22].

Table 1. EPSE criteria and sub-criteria [14; 22].

Sub-criteria	Description	unit
Main criteria: Environmental (E)		
1. surface water bodies	criteria that avoids landfill to be situated close to water bodies including rivers, lakes, and ponds in protecting water bodies ecosystem and avoiding flood plains.	meter (m)
2. sensitive areas	criteria that avoid landfill to be situated close to sensitive areas (i.e. forest reserves, tourism areas, wetlands).	meter (m)
3. aquifer potential (groundwater)	criteria that considers the aquifer potentials (i.e. high, medium, and low) around the landfill sites to prevent groundwater pollution.	n/a
4. rainfall intensity (climate)	criteria that define the rainfall intensity to avoid side effects of drainage and erosion.	n/a
5. flooding area	criteria that opposed landfill sites to be situated nearby flood protection embankments.	meter (m)
Main criteria: Physical (P)		
6. road access	criteria that considers transportation issues and management of landfill to optimize traveling time and costs.	meter (m)
7. soil permeability	criteria that determine the soil permeability classes (i.e. rapid, moderate, and slow) to prevent groundwater pollution from landfill leachates.	n/a
8. haul distance	criteria that considers the distances of town centers (collection points) to avoid high transportation costs.	kilometer (km)
9. wind potential	criteria that opposed landfill sites to be exposed to wind to control litter and dust and prevent damages to the landfill infrastructures due to strong wind.	n/a
10. slope	criteria that selects appropriate terrain conditions that are suitable for construction of landfill sites.	percent (%)
11. geological fault properties	criteria that avoids locating landfill sites near existing faults to prevent the ground motion effects.	meter (m)
12. airport location	criteria that determine the landfill sites not to be located near to airport areas to prevent the birds' disturbance and rising dust from landfills	km
13. bedrock/ lithology	criteria that determine the landfill sites to be situated on the solid un-weathered rock that lies beneath the loose surface deposits of soil, alluvium, etc. to avoid a natural disaster such as the earthquake.	n/a

Main criteria: Socio-economic (SE)		
Sub-criteria	Description	unit
14. residential area	criteria that opposed landfill sites to be situated nearby residential areas (nimby syndrome).	meter (m)
15. urban area	criteria that opposed landfill sites to be situated nearby urbanized areas (i.e. townships, administrative centers, commercial centers, schools, hospitals, and other institutions.)	meter (m)
16. land use	criteria that determine the land use that is suitable for LSS.	n/a
17. utilities	criteria that considers the infrastructures or utilities (i.e. electricity and water supply systems) to minimize the installation costs.	meter (m)

3.2. Setting the standard parameters of the EPSE criteria.

NSPSWM guidelines have provided guidance and advisory framework to federal, state and local governments on the immediate and long-term management of solid waste. However, the guidelines just set out a checklist of the criteria (preferred conditions) in the LSS process. There is no separate standard (limits) to be specified. It is therefore important for the EPSE criteria to be published with specified limits (standard parameters) for future sustainable landfill sites.

This paper introduces newly defined sets of limits (parameters) and EPSE criteria attributes for refining the LSS process in Malaysia. Suggested parameters and attributes were allocated based on information gathered from the EIA [2], the NSPSWM [22] and the World Bank Guidelines [23]. Table 2 described the proposed standard parameters that can assist the local authorities in evaluating the site selection criteria and procedures in Malaysia.

Table 2. Proposed standard parameters for LSS criteria [source: 2; 22; 23].

Environmental (E)	NSPSWM	Proposed standard limits
1. surface water bodies	100 meter (m)	500 meter (m)
2. sensitive areas	500 meter (m)	500 meter (m)
3. aquifer potential (groundwater)	no indication of excessive water table rises, springs, or vadose water passages	low aquifer potential
4. rainfall intensity (climate)	minimal rain and rain intensity	low intensity (1-10 mm/hr)
5. flooding area	avoid floodplains	100 meter (m)
Physical (P)	**NSPSWM**	**Proposed standard limits**
6. road access	500 meter (m)	500 meter (m)
7. soil permeability	heavy poor draining	slow/very slow permeability
8. haul distance	close to center of the potential service area	25 kilometer (km)
9. wind potential	good air mixing and predominantly downstream of human activities	calm to light air (0 -1.5 m/s)
10. slope	<10%	<10%
11. geological fault properties	100 meter (m)	500* meter (m)
12. airport location	3 kilometer (km)	3 kilometer (km)
13. bedrock/ lithology	avoid fissured avoid and fractured rocks	intrusive rocks
Socio-economic (SE)	**NSPSWM**	**Proposed standard limits**
14. residential area	1000 meter (m)	1000 meter (m)
15. urban area	1000 meter (m)	1000 meter (m)

16. land use	avoid areas planned for high value development	agricultural land area, clear land, pasture, and scrub. avoid commercial and administrative areas, livestock, transportations, human settlements, infrastructures, industrials, reserved, forests, paddy fields, and water bodies.
17. utilities	avoid sensitive sites	300 meter (m)

3.3. Ranking and weighting the preference of the EPSE criteria

In articulating how frequent that specific criterion being used in dealing with LSS problems, each criterion is ranked accordingly. Then, the normalized weight was determined as shown in Table 3. Surface water bodies (E-criteria), Road access (P-Criteria), and Land use (SE-criteria) were the most frequent criteria found in the works of literature. On the contrary, bedrocks (lithology), rainfalls, and utilities were the least applied criteria in the LSS.

Table 3. Normalized weight and rank of EPSE criteria.

Rank	Normalize weight	Sub-criteria	Rank	Normalize weight	Sub-criteria
		Environmental			Physical
1	0.321	surface water bodies	1	0.241	road access
2	0.305	sensitive area	2	0.204	slope
3	0.252	aquifer	3	0.160	soil
4	0.084	flooding area	4	0.142	geological fault
5	0.038	rainfall	5	0.117	airport
			6	0.068	haul distance
			7	0.062	wind
			8	0.006	bedrocks

Rank	Normalize weight	Sub-criteria
		Socio-economic
1	0.320	land use
2	0.311	residential area
3	0.295	urban area
4	0.074	utilities

Goal		
1	0.390	Physical
2	0.316	Environmental
3	0.294	Socio-Economic

Figure 2 is the graphical structure describing the frequency weights of the main EPSE criteria in achieving the goals of sustainable landfill site selection. The “Physical criteria” has the highest preferences with the assigned weight of 0.390 (39%), followed by the "Environmental criteria" 0.316 (32%) and "Socio-Economic criteria" 0.294 (29%), respectively. The "Physical criteria" was dominance (highest weights) as forty-five selected works of literature have used these criteria in their research study. This indicates that past researches have given greater emphasis to the physical aspects (P), such as road access, slope, soil, geological fault, airport, haul distance, wind, and bedrocks. These aspects measure the stability of the area and the safety of the site to be selected as a landfill site and indirectly, to avoid nuisance to the people and other creatures. However, the importance of the environmental aspects (E), such as surface water, sensitive areas, aquifers, flooding areas, and rainfall must be evident since those parameters protect the sensitive ecosystem, and human health and safety. Likewise, the socio-economic aspects (SE), such as land use, residential areas, urban areas, and utilities are equally important in the future LSS study. Nevertheless, the (SE) criteria are significant particularly in the cost planning and it indirectly ensures safety to the settlements and population. The relevance of weightage for EPSE criteria is that it quantifies the degree of preferences of the criteria in modeling landfill site suitability problem.

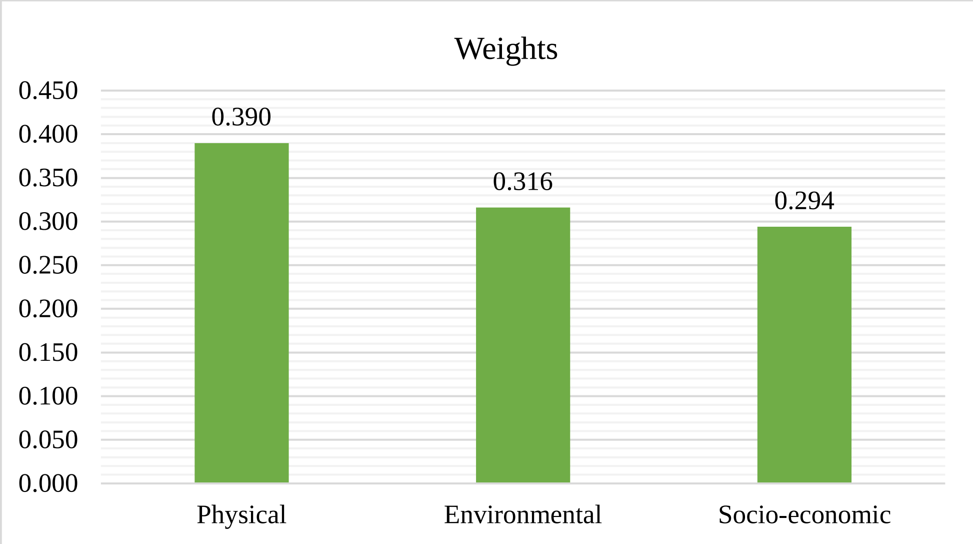

Figure 2. Frequency analyses of the main criteria weights.

4. Results and Discussion

4.1. *The comprehensive spatial EPSE criteria*

The comprehensive EPSE criteria can be spatially represented as factor and constraint maps and used for preliminary landfill site screening process. It helps the decision makers in the to select the potential landfill sites using a spatial analytical tool such as Geographic Information System (GIS). The EPSE criteria in spatial form can be numerically represented by geographic location, where derived maps can be produced using the standard parameters assigned to the respective criteria. These maps were formed using spatial analysis tools and contained additional information such as buffer zones from surface water bodies, or areas showing low permeability soils. The parameters listed in Table 4 can be spatially presented by derived maps and later re-classed as factors and constraint map layers required by the landfill site suitability model.

The derived map layers will act as a limit to the site selection process so that the best sites can be screened and evaluated to produce the potentially feasible sites. The current application of GIS in the LSS permits large geographical data covering large geographic regions to be quickly and efficiently quantified, weighted, screened and, spatially presented [24; 25; 26; 27; 28; 29; 30; 31].

Goal		Criteria	Parameters	Relative Weights
Sustainable landfill site selection (LSS)	Environmental (E)	1. surface water bodies	500 m	0.321
		2. sensitive areas	500 m	0.305
		3. groundwater/aquifer potential	low aquifer	0.252
		4. climate/ rainfall density	low/very low intensity	0.084
		5. flooding area	100 m	0.038
	Physical (P)	6. road access	500 m	0.241
		7. soil permeability	slow/very slow permeability	0.204
		8. haul distance	25-30 km	0.160
		9. wind potential	calm-light air	0.142
		10. slope	<10 %	0.117
		11. geological fault properties	500 m	0.068
		12. airport location	3 km	0.062
		13. bedrocks/lithology	intrusive rocks	0.006
	Socio-economic (SE)	14. residential area	1000 m	0.320
		15. urban area	1000 m	0.311
		16. land use	agricultural land area, clear land, pasture, and scrub. avoid commercial and administrative area, livestock, transportation, human settlement, infrastructure, industrial, reserved forest, paddy field, and water bodies.	0.295
		17. infrastructure/ utilities	300 m	0.074

5. Conclusion

This paper has introduced very comprehensive criteria applicable to the selection of new landfill sites in Malaysia. It covers all aspects of the environmental, physical, and socio-economic (EPSE) requirements that were selected based on the universal applications and local guidelines available in Malaysia. It helps local authorities to apply spatial quantitative measurement in the site selection procedures in Malaysia which directly leads to the sustainable LSS that is comprehensive, reduces cost and time. Likewise, the EPSE criteria can act as the standard parameters in the local guidelines such as the NSPSWM, and EIA Guidelines for Development of Solid Waste Sanitary Landfill.

Acknowledgements

The authors would like to thank Universiti Sains Malaysia for the Research University Bridging Incentive Grant assigned (304/PAWAM/6316439) on the research associated with effective solid waste management in Malaysia.

References

[1] Kjellstrom, T., Lodh, M., McMichael, T., Ranmuthugala, G., Shrestha, R. & Kingsland, S., (2006). 'Air and water pollution: burden and strategies for control', 2nd edition. Washington (DC): World Bank; 2006. Chapter 43.

[2] EIA, (2012). 'Environmental Impact Assessment Guidelines for Development of Solid Waste Sanitary Landfill', First Edition, Department of Environment Malaysia, Ministry of Natural Resources and Environment Malaysia.

[3] Ahmad, S. Z. (2018). 'Fuzzy logic-ordered weighted average model for effective municipal solid waste landfill site selection using comprehensive spatial environmental, physical and socio-economic criteria'. (Unpublished Ph.D. Theses). Universiti Sains Malaysia.
[4] Samsudin, M.D.M. & Don, M.M., (2013). 'Municipal solid waste management in Malaysia: Current practices, challenges and prospect', *Jurnal Teknologi,* 62(1):95–101.
[5] JICA (2004). 'The Study on the Safe Closure and Rehabilitation of Landfill sites in Malaysia', Final Report: Technical Guideline for Sanitary Landfill, Design, and Operation, Revised Draft, Volume 5.
[6] Tchobanoglous, G., Theisen, H., & Vigil, S. A., (1993). 'Integrated Solid Waste Management: Engineering Principles and Management Issues', McGraw-Hill International Editions: Civil Engineering Series, McGraw-Hill Publication.
[7] Rogoff, M. J. & Screve, F., (2011).'Waste-to-Energy (2nd Ed.)', William Andrew Publishing,
[8] Twardowska I., Allen H.E., Kettrup A.A.F. & Lacy W.J., (2004), 'Solid waste: assessment, monitoring, and remediation', Waste Management Series 4, Elsevier.
[9] Worrell, W. A., & Vesilind, P. A., (2012). 'Solid waste engineering', 2nd Edition, SI. Cengage Learning Publisher, United State of America.
[10] British Columbia, (2016). 'Landfill Criteria', British Columbia Ministry of Environment. Available at: www2.gov.bc.ca/assets/gov/environment/waste.../garbage/land fill_criteria.pdf
[11] Al Sabbagh, M.K., Velis, C.A., Wilson, D.C. & Cheeseman, C.R., (2012). 'Resource management performance in Bahrain: a systematic analysis of municipal waste management, secondary material flows, and organizational aspects. *Waste Management & Research,* 30(8):813-824.
[12] Brunner P.H., (2013). 'Cycles, spirals and linear flows. *Waste Management and Research,* 31(10): 1–2.
[13] Wilson, D.C., Smith, N.A., Blakey, N.C. & Shaxson, L., (2007). 'Using research-based knowledge to underpin waste and resources policy'. *Waste Management & Research,* 25(3):247-256.
[14] EIA, (2007). 'Environmental Impact Assessment Guidelines for Municipal Solid Waste and Sewage Treatment and Disposal Projects', Second Edition, Department of Environment Malaysia.
[15] Sin, T.J., Chen, G.K. & Hwang, G.H., (2016). 'Challenges in Selecting a Sustainable Landfill Site in Malaysia', *In MATEC Web of Conferences* (Vol. 47). EDP Sciences.
[16] Ersoy, H., & Bulut, F., (2009). 'Spatial and Multi-criteria Decision Analysis-based methodology for landfill site selection in growing urban regions', *Waste Management & Research,* 27(5):489-500
[17] Aderemi, A.O. & Falade, T.C., (2012). 'Environmental and health concerns associated with the open dumping of municipal solid waste: A Lagos, Nigeria experience'. *American Journal of Environmental Engineering,* 2(6):160-165.
[18] Ahmad, S. Z., Ahamad, M. S. S., & Yusoff, M. S. (2014). Spatial effect of new municipal solid waste landfill siting using different guidelines. Waste Management & Research, 32(1), 24-33.
[19] Saeed, M. O., Ahamad, M.S.S, Aziz, H. A., Ahmad, S. Z., (2012). 'An integrated AHP-GIS technique for landfill siting: A case study in Malaysia', *Kuwait Journal of Science and Engineering*. 39 (2B):23-46
[20] Manaf, L.A., Samah, M.A.A. & Zukki, N.I.M., (2009). 'Municipal solid waste management in Malaysia: Practices and challenges. *Waste Management*. 29(11):2902–2906.
[21] Afzali, A., Samani, J.M. V & Rashid, M., (2011). 'Municipal landfill site selection for Isfahan city by use of fuzzy logic and analytic hierarchy process'. *Iranian Journal of Environmental Health Science and Engineering,* 8(3):273–284.