

GIS modelling for new landfill sites: critical review of employed criteria and methods of selection criteria

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Abstract. Policy makers and the public are increasingly concerned with the determination of landfill-siting input criteria (DLSIC) in landfill modelling procedures as an area of research. Thus, its procedures are complicated and decision makers are increasingly pressured. These procedures can be considerably develop in order to reduce the negative effect of landfill locations on the environment, economy, and society. In this review article, literature related to the developments of 64 models and their procedures in the past 18 years (from 1997 to 2014) were comprehensively survey. DLSIC are determined through a conventional method. The frequency of criterion usage reflects the limitation of Conventional method for DLSIC. Moreover, some of these studies utilize unrelated criteria that are time-consuming, costly, arduous, and fruitless. Potential improvement in Geographic information systems GIS modelling parameter for landfill sites via utilizing multivariate analysis (MVA) instead of Conventional method (CM) through for DLSIC (e.g., Input variables, Accuracy, objectivity, reliability of criteria, time consumption, cost and comprehensiveness) were emphasize. It can be conclude that expenses can be reduce by implementing MVA in DLSIC for landfill modelling using geographic information systems (GIS) based on the corresponding significant level. Moreover, the determined criteria can be accurate, satisfying, sufficient, and free of bias from experts and human error.

1. Introduction

The process of searching for a new municipal waste disposal site is time-consuming [1]. The related procedures are extremely complex because its involve combination of several knowledge from diverse interesting areas, and numerous gatherings are in charge of or influenced by the outcomes [2][3–5]. To properly identify and select appropriate landfill sites, systematic procedures must be adopted and followed carefully [6]. [7] stated that the determination of suitable landfill locations is a decision that requires extensive land evaluation. Therefore, the process of landfill siting considers environmental, ecological, and technical parameters [8,9]. The selected locations must also fulfil the necessities of existing legislative guidelines and reduce health and environmental expenses in the meantime [10]. Furthermore, design considerations, area availability and prospects of development. Similarly, [11]



concluded that Geographic information systems (GIS) modelling for new landfill sites must take operational and economic issues into account. In addition; insurance and social considerations and political opposition explained through the phenomenon “not in my back yard (NIMBY)” [12–15]. On the other hand, GIS modelling aims to find suitable spatial patterns for upcoming landuse based on exact constraints, preferences or predictions of some activity. The spatial nature of modelling of new landfill sites problem involves the usage of GIS to expand the traditional frameworks in order to concern equally spatial and attributes data. According to McHarg’s map layering theory [16], these frameworks constructed to reinforced performance and managing geographic data to improve their part in landfill GIS modeling. Additionally, the synergy between multiple criteria decision analysis (MCDA) techniques and previous frameworks come from the improvement of multicriteria spatial decision support systems (MC-SDSS). The aim of synergizing is to rating the suitable sites based on their significance in sustaining modelling goals. The research of MC-SDSS concentrations on improving software packages and decision techniques, which lead to facilitate the assessment process to select the new landfill sites.

Recent last two decades, a noteworthy number of articles conducting for landfill GIS modelling. It demonstrates the benefits resulting through the synergy of MCDA and GIS. Development of framework is mutual practice between these publications, which intention to modelling the landfill sites. These frameworks delivers consistent stages for handling conflicting objectives among the diverse involved crowds that react with decision making procedure, as well as in the meantime to deliver compromises between the conflicting aims. In addition, it permits the analyzer to consider the stakeholders preferences. These frameworks contain coherent sequence of stages. It can be discriminate through four stages. First, determining objective trees and identifying maps of constraint and factor criterion. Second, execute standardization procedures on the maps. Third, in choice stage, specific decision rule implemented to the set of the criteria in order to generated map of suitability index and classify it. Forth, to define the robustness of the modelling result, sensitivity analysis were implemented [17]. Consequently, in implementation stage, trustiness evaluated for the new sites through assessment of public opposition. On the off chance that the chosen site does not fulfil the expectations, then all prior four stage require to recurrence till ensures minimizes environmental consequences and achieving public acceptance.

In addition, policy makers and the public are increasingly aware and concerned with the environmental problem related to landfill-siting criteria. Thus, landfilling procedures must consider numerous of the different related criteria and variables [18] involved in the selection of a proper site for healthy urban landfills [19]. Consequently, GIS modelling framework for landfill site are complicated and decision-makers are increasingly pressured [2,5]. However, the number of considered criteria for landfill modelling increases, which may result in the adoption of unnecessary criteria that will be high cost, time-consuming, and wasting resources without reaping any benefit. In contrast; it potential to disregarded some significant criteria, or consider some criteria as more important than it’s real important due to vague and subjective estimates. Consequently decision-makers may make poor siting decisions and inappropriate landfill sites might be selected [18]. Moreover, these problems can have negative and far-reaching effects on the environment, economy and ecology situations.

Recently, various methods have been widely employed to determine a list of related criteria for landfill GIS modelling framework without testing their suitability. Conventional method (CM) to selecting the significant criteria such as guidelines, regulation requirements, previous literature and expert interviews were used recently.

This article aim to review the employed criteria and methods of selection criteria concerning landfill GIS modelling to clarifying its problems in this filed and propose guidelines for future research. In this paper, (1) an extensive survey of GIS modelling scientific published literature and critically reviews to determine the list of the used criteria and criterion usage scores. (2) demonstration and evaluation for the employed methods for selecting GIS criteria which implemented formerly in past 18 years for landfill GIS modelling were performed, and (3) investigate the potential improvement of the

implementing spatial multivariate analysis SMVA method over the covenantal method CM to determine the landfill siting input criteria (DLSIC).

2. Methodology

A numerous number of publications consider the application of MCDA for landfill GIS modelling issue [2–4,6,14,15,20–35]. This is owing to the necessity for developing new frameworks as well as, the fast development in computer science, dramatically contributed to the enlargement of MCDA application. Published articles related to frameworks have been reviewed over the years from 1997 to 2004. An exploration to select the relevant articles was executed via variety of scientific journals publishers such as; ScienceDirect (www.sciencedirect.com), SpringerLink (link.springer.com), ASCE (www.asce.org), SAGE (online.sagepub.com), Taylor and Francis (www.tandfonline.com), as well as Scopus database (www.scopus.com). The seeking was made through the following terms; multi criteria and GIS, landfill modeling, landfill siting, mapping and analysis, selection of Municipal Solid Waste (MSW) landfill, suitability analysis, landfilling, and MCDA. Additionally, their references list were explored hastily to select further related papers in the same scope. An extensive survey was conducted to extract the common criteria employed for GIS modelling for landfill sites as highlighted earlier in the literature. Moreover, statistical summary was performed to determine the criterion usage scores alongside all the selected articles. In addition, another literature survey was accompanied to summarize the considered method adopted for selection criteria for landfill siting.

3. Results and discussion

3.1. Articles analysis

From the literature, 75 published studies have been selected; these studies and models commonly focus on developing and improving the frameworks that can identify the most suitable location for landfill sites. It summarizes the progress of main published research, concerning landfill GIS modelling documented in literature since 1997. Nearly 85% of articles being released after 2008, (data extracted from Scopus and existing articles), which reflecting the growing interest and awareness. [7] concerning the benefits of GIS in this research scope as shown in **Figure 1** and the increasing interest of Asian countries in this kind of research as demonstrated in **Figure 2**.

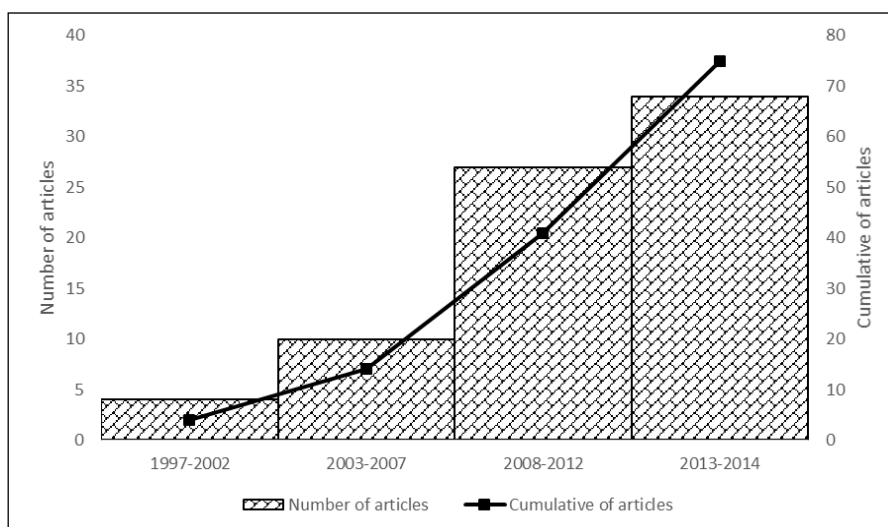


Figure 1. Recent published works concerning the development of landfill GIS modelling.

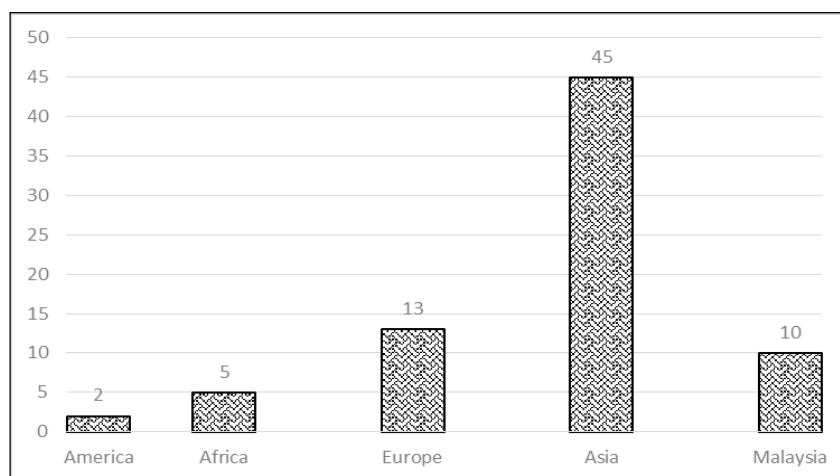


Figure 2. Published article based on different location.

3.2. Input criteria of landfill GIS modelling

Even though the effectual of landfill GIS modelling mainly influenced by the adequacy of evaluation criteria through the entire framework, huge amount of criteria were implemented via legislation and decision makers [17]. Decision makers have been accomplished wide work to reach to this amount of criteria, which targeting to minimize the social, environmental, and economic expenses. Additionally fulfil government regulations requirements as well as public acceptance [2]. Under the heading ‘Input criteria of landfill GIS modelling’, Table 1, 2 and 3 summarizes the number of criteria that have been implemented to evaluate appropriate sites via GIS modelling. The wide investigation of the literature released that 80 criterion have been executed until present to improving landfill GIS modelling frameworks. The number of criteria is maximized as a result of the stress and the pressure from increased awareness of researchers, the public opposition, decision makers, and the government regulations with regard to landfill modelling [3,7].

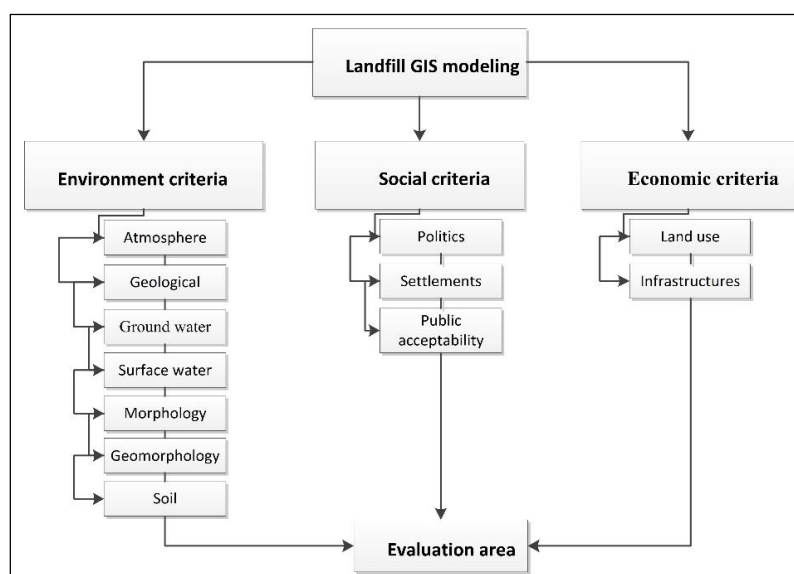


Figure 3. Objective and sub-objectives decision tree for Landfill GIS modelling.

To deliver a coherent discussion concerning the applied criteria, it have been gathered into three major groups **Figure 3**, which establishing a three-level decision tree, which reflect the sustainable objectives (environment, economy and social) and for further and easier understanding of the massive number of criteria. These groups explained more general considerations (objectives) than that should

be satisfied through the GIS modelling. In addition, twelve sub-groups that deliver additional definitions in evaluation process were conduct (atmosphere, geological, ground water, surface water, morphology, soil, geomorphology, politics, settlements, public acceptability, land use, and infrastructures). **Figure 4** shows the classification of the decision objectives and sub-objectives used in the previous work.

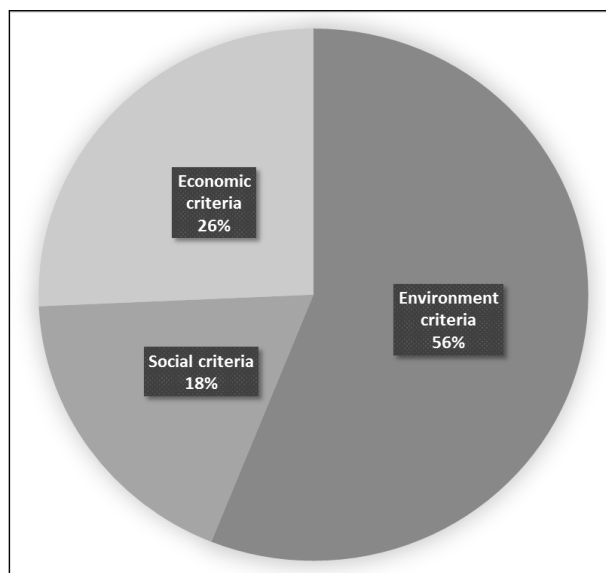


Figure 4. Percentage of criteria frequency in landfill modelling.

On the other hand, the sub-criteria were statistically accounted the usage score (based on 75 reviewed articles) to generate primary knowledge regarding the used criteria and its usage frequency, which is presented in **Figure 4**. The percentage for the frequency of sustainable criteria application is considerably high. The sub-criteria were group into three categories as per this percentage. **Figure 4** indicates that the environmental criteria constitute 56% of the total criteria. This proportion reflects the stress related to environmental issues during landfill modelling operation. The economic and social aspects accounted for 26% and 18%, respectively. These percentages emphasize that many articles focused on environmental criteria in general and either ignored or barely considered the social and economic aspects and vice versa [9,36–39]. These criteria reflect the limitation of CM for DLSIC, and it is not necessary to be appropriate for landfill modelling. On the other hand, all the adopted 80th sub-decision criteria through the three sections were discussed briefly and separately in three sections, as well as the criterion score of usage in the previous articles, In the following sections;

3.2.1. *Environment criteria*

Matters relevant to environment safeguard were exemplified in evaluation via verity necessary criteria, (Meteorology, Geological, Ground water, Surface water, morphology, soil, Geomorphology and Sensitive zones criteria) according to Malaysian guideline [40]. The environment criteria represent the first part in the sustainable development and planning, it embodied the analysis via implementing variety of criteria, these criteria play substantial roll to select the landfill sites. The goal of environment criteria is to protect the surrounding environment against any water, soil, air pollution resource [2]. Moreover, avoiding any degradation and minimize the risk in the desire area. These sensitive sites should exclude from the evaluation zone and placing the landfills a sufficient distance far away from the sensitive areas. By providing the attention to environmental criteria, it is easily to explain the consideration of the exacting guidelines through local and universal regulation. **Table 1** illustrates the summary of employment criterion in the environment section. The fact that 39 criteria implemented in the literature were relate to environmental section.

Table 1. Summary of the employment criterion in the Environment section.

Objective	Criteria	Sub-criteria	Reference
Environment	Meteorology/ Atmosphere	Evaporation	[12]
		Climatic regimes	[4]
		Humidity	[41]
		Precipitation	[42]
		Temperature	[43]
		Air pollution	[44]
	Geological	Landslides	[45]
		Geological formation/lithology	[46]
		Earthquake zones	[34]
		Faults	[11]
	Ground water	Aquifers	[2]
		Groundwater quality	[47]
		Groundwater direction	[12]
		Hydraulic conductivity of groundwater	[1]
		Groundwater depth	[39]
	Surface water	Lakes/ponds	[48]
		Rivers/streams	[7]
		Springs	[28]
		Flood plains	[21]
		Wetlands	[22]
		Dam	[8]
	Morphology	Elevation	[42]
		Land aspects	[49]
		Slope	[10]
	Soil	Soil depth	[28]
		Soil type	[38]
		Soil permeability	[50]
		Mining and land resources	[51]
		Land contamination	[48]
	Geomorphology	Geomorphology (karst, erosion)	[51]
		Snow and glacial period	[10]
		Drillings	[20]
		Geothermal fields	[2]
		Gorges and caves	[13]
	Sensitive zones	Petrochemical storage plants	[11]
		Protected forest	[52]
		Protected areas	[15]
		Cultivation and natural cover	[19]
		Sensitive ecosystems	[13]

Figure 5. Frequency of criterion usage score in environment section clearly shown the criterion importance score of usage, were the five most significant landfill modelling criteria are distance from rivers, which referred to 54 articles in the literature, while distance from lakes (45 articles), slope (41 articles), elevation (30 articles) and soil (25 articles), which is imposed from the national/international guidelines [40]. In these studies, 10 out of 39 criteria were applied only once, including humidity, landslides, groundwater directions, the hydraulic conductivity of groundwater, snow and glacial periods, drillings, land contamination, geothermal fields, gorges and caves, petrochemical storage plants, climatic regimes, and air pollution [40]. And it is not enforced by national/international regulations [42], While the remained criteria referees frequently in 2 to 24 articles and it varied in existing in the guidelines or not. The small score does not essentially mean the criterion is insignificant. Moreover, the restricted usage can be possibly due to the some responsible causes such as deficiency of infrastructure, data availability or natural feature).

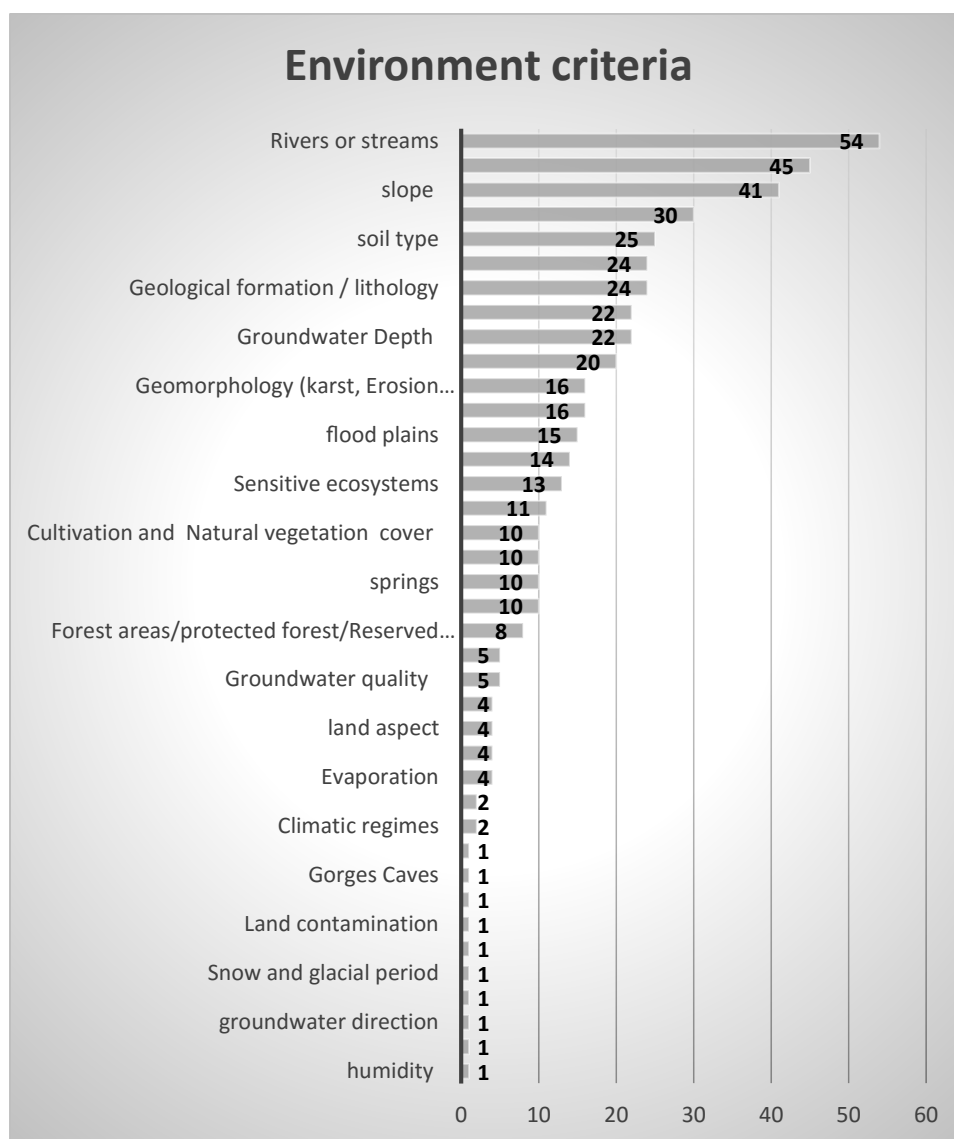


Figure 5. Frequency of criterion usage score in environment section.

3.2.2. Social criteria

The significance of the social criteria lies in the public acceptability or social consensus and political opposition that can arise from establishment of a new landfill site. The population do not want landfill sites to be located near their residential areas because it consider as obnoxious locations. this fact expressed through the phenomenon “not in my back yard (NIMBY)” [12–15], which in another term call locally unacceptable land uses (LULUs), particularly in heavily inhabited zones. During the past, NIMBY phenomenon has been mightily relevant to GIS modelling plans and landfill planning. These NIMBY controversies need the involvement of individuals personify different competence areas, social values and political agendas to handle the geographic decision issues [2]. The different preferences participants (technical experts, Decision makers and stakeholders) improved the understanding of the spatial issues (evaluate situations, needs assessment, clarifying goals, define criteria). As a result, the difficulty were decrease and the decisions made further thoughtful, precede to an efficient landfill GIS modelling and hence reducing the danger of occur public opposition. Thus, several criteria used in the literature such as; Sufficient distance from danger of odor and insects were taken from (residential areas, Archaeological, tourism, and cultural sites, sports sites, education, historical sites, recreational sites, Natural parks, theaters, Hospital, schools, universities, military areas, airports. Furthermore, dense population areas, Villages/rural areas, Visible travel distance from roads, Visibility from residential areas, Wind direction, Wind speed, District boundaries and National borders) to get over resident conflict. **Table 2** delivers a summary of employment criterion in current survey from collected works.

Table 2. Summary of the employment criterion in the Social section.

Objective	Criteria	Sub-criteria	Reference
Social	Politics	District boundaries	[38]
		National borders	[41]
	Settlements	Proximity to dense population	[53]
		Villages/rural areas	[14]
		Population of urban centers	[14]
	Public acceptability	Visible travel distance from roads	[24]
		Visibility from residential areas	[10]
		Wind direction	[28]
		Wind speed	[42]
		Urban/residential areas	[54]
		Archaeological, tourism, and cultural sites	[6]
		Sports education	[55]
		Tourism services	
		Natural parks	[45]
		Theaters	[32]
		Hospital/public health safety	[2]
		Schools/universities	[32]
		Military areas	[56]
		Airport/helipad/airfield	[57]

This social section referred to 19 criteria in the literature. **Figure 6.** Frequency of criterion usage score in social section obviously displayed the criterion importance score of usage. The five most significant landfill modelling criteria are distance from residential areas, which referred to 32 articles

in the literature. While distance from urban centers population and airports (27 articles), distance from villages/Rural areas (20 articles), distance from archaeological/tourism/cultural sites (18 articles), and Wind direction (14 articles). which is forced by national/international guidelines [40]. In these studies, 7 of the total 19 criteria were applied only once or twice, including Proximity to dense population, distant from theaters, distant from schools/ university, distant from district boundary, wind speed, distant from sports-Education sites and distant from services for Tourism sites [2]. And it is not enforced by national/international regulations [40]. While the remained criteria referees frequently in 5 to 1 articles and it varied in existing in the guidelines or not.

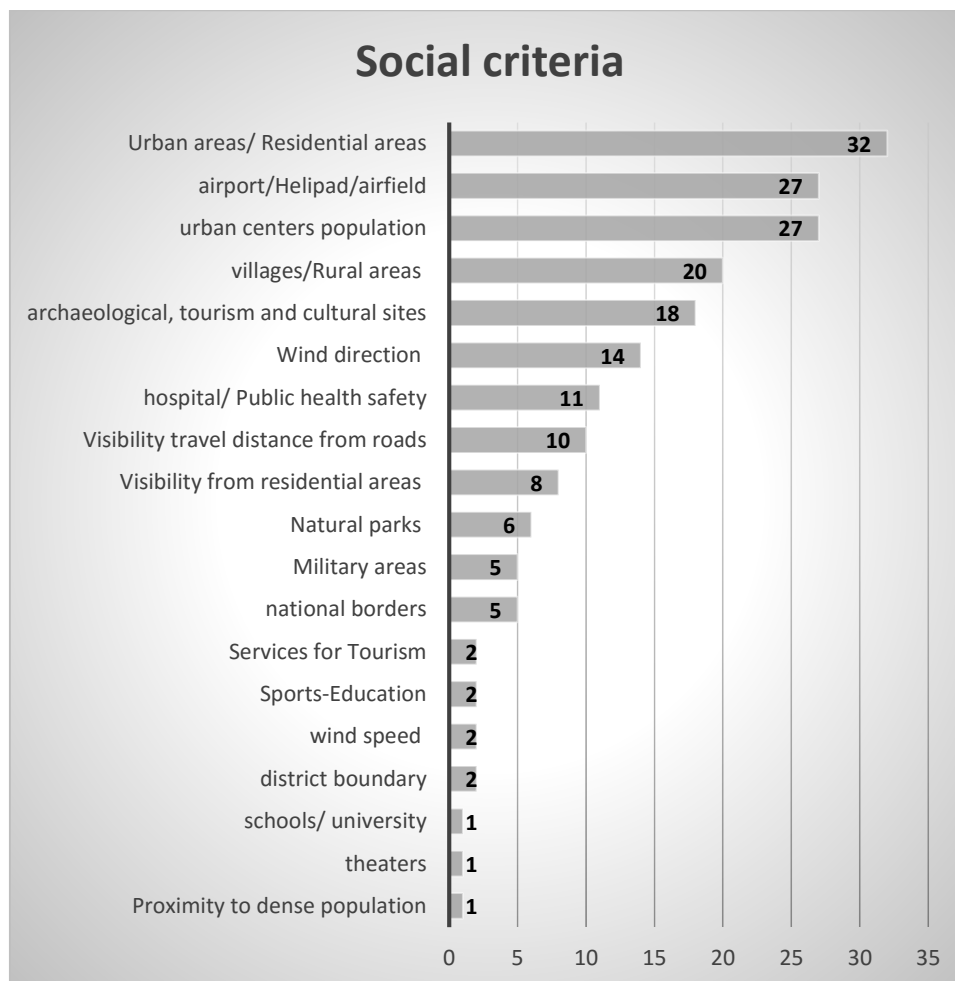


Figure 6. Frequency of criterion usage score in social section.

3.2.3. Economic criteria

The aim of economic criteria is to minimize the final cost of modelling landfill sites and to guarantee suitability of landfill sites as well as effective services process. Furthermore, targeting to sidestep in value deterioration of property, tourism industry, future use of the land and industrial areas. Therefore, landfills must take a least space from the private properties or some land use type. The accessibility of landfill locations is a factor that essential to assessed throughout the GIS modelling process to guarantee garbage trucks sufficient accessibility to landfill locations to reduce waste transference and collection expenses from the origin source to landfill sites, which mean in another way minimization of travel cost, in addition to reduce the complementary infrastructure building

requirements [58]. The nearness of the landfill sites to the local and federal streets networks wanted, although landfill sites preferable to be place far away from the major transportation network. Additionally; an fitting planning procedure must guarantee the conservation of infrastructures, water facilities and public utilities, thus should take an exclusion zones from it [58]. Moreover, to ensure the compliance with current landfills to avoid of services area conflicting. As shown in Table 3, there are 22 criteria were implemented in landfill GIS modelling in the previous work.

Table 3. Summary of the employment criterion in the economic section provides the criterion importance score of usage, were the five most significant landfill modelling criteria are road accessibility, which referred to 52 articles in the previous works, while Land use (43 articles), Ground infrastructures (18 articles), Industrial areas (16 articles), and Municipal and local wells (12 articles), which is forced by national/international guidelines [40]. In these articles, 5 of the total 19 criteria were utilized just one time communication infrastructures, ownership, salinization zones, grazing and public utilities. Furthermore, it is unenforced by any national/international regulations [40]. While the remained criteria referees frequently in 12 to 3 articles and it varied in existing in the guidelines or not.

Table 3. Summary of the employment criterion in the economic section.

Objective	Criteria	Sub-criteria	Reference
Economic	Land use	Land use/cover	[59]
		Coastlines	[48]
		Ownership	[48]
		Salinization zones	[58]
		Industrial areas	[60]
		Compliance with current landfills	[36]
		land cost	[37]
		Future use of the land	[54]
		Special disposal location (Abandoned mines, quarries)	[10]
		Deserted fields	[13]
		Grazing	[55]
		Availability of cover materials	[51]
		Recycling/ferrous exploitation	[15]
	Infrastructures	Public utilities	[2]
		Ground infrastructures	[61]
		Communication infrastructures	[11]
		Railways	[14]
		Road accessibility to the site	[62]
		Water facilities	[58]
		Municipal and local wells	[63]
		Waste production centres (transfer station)	[39]
		Capacity of landfill sites	[25]

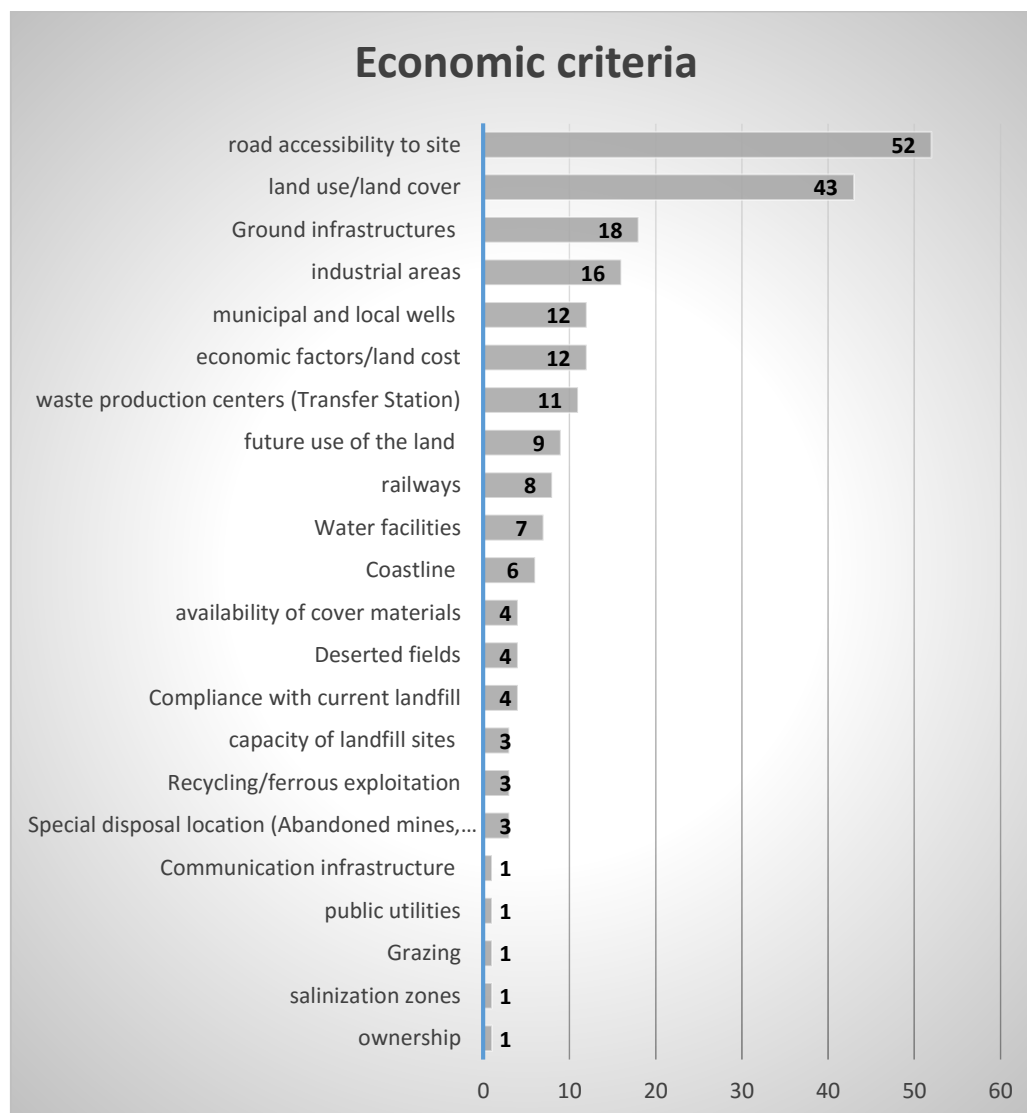


Figure 7. Frequency of criterion usage score in economic section.

3.3. Use of CM to determine the input criteria

The survey results of adopted method for selection criteria for landfill-siting are depicted in Fig. 8 based on the survey of literature review above, the most common method of landfill-siting criteria selection is to follow guideline and regulation requirements. **Figure 8** suggests that 46 studies selected criteria according to this method; 26 extracted criteria from previous literature; 11 conducted expert interviews; and 6 statistically analyzed survey questionnaires. The significant level was determined as per the weighting of the criteria extracted from these questionnaires. However, four studies did not describe the criteria selection processes they used, and other works justify their disregard of some criteria based on data availability.

Some studies [2,10,12,28,42] apply various comprehensive models that consist of many criteria determined without testing (either attribute or spatial testing) or pre-processing. This orientation complicates landfill modelling procedures and renders them time-consuming because of the high amount of spatial data that must be purchased, collected, prepared, and processed for landfill location selection [12,24,47,59,62,64]. The weighting process is challenging, because face-to-face interviews

must be conducted [59], and all of the criteria must be explained to each expert or specialist. Nonetheless, ignoring any of these criteria may result in the selection of inappropriate landfill locations and in miscalculations. These outcomes can negatively affect the environment, the economy, and ecology [18]. Unfortunately, some studies discarded some important criteria [1,14,55], which may result in poor siting decisions. Instead, these studies utilize unrelated criteria that are time-consuming, costly, arduous, and fruitless. In addition, some criteria (variables) may be accompanied by other criteria, for instance, modelling land use can satisfy the objective and can act as an alternative to many criteria, such as schools and utilities, especially within the constructed area. Thus, the limited data do not affect the accuracy of the result, thereby minimizing the expense attributed to additional unnecessary data.

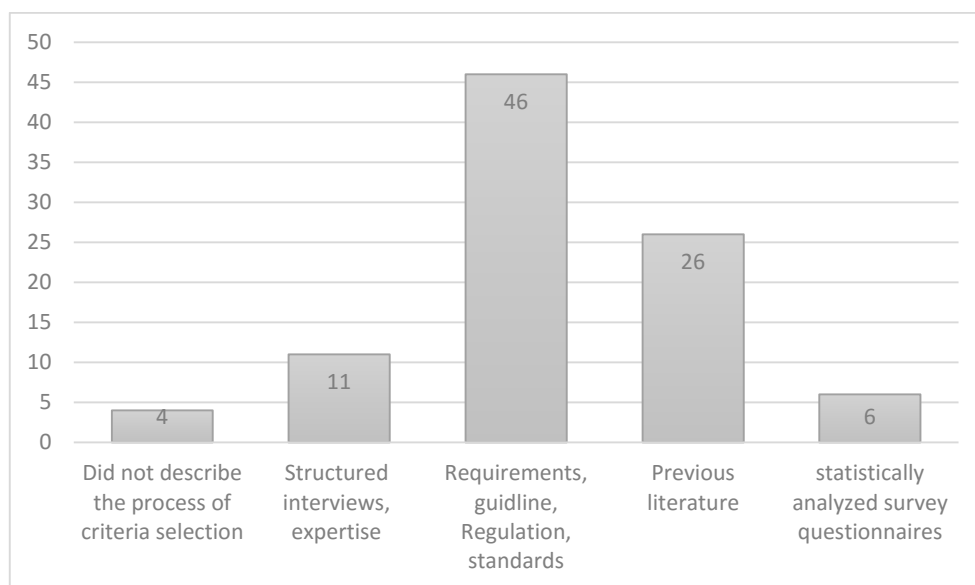


Figure 8. Popular method adopted for landfill-siting criteria selection.

Aforementioned, the conventional method for selection landfill siting criteria are inaccurate, unsatisfactory, insufficient, time-consuming, and unacceptable. Therefore, there is an urgent need for a new method that can avoid the previous limitation and guarantee reasonable result, and reduce environmental influences as well as at meantime rise probability to override opposition of public.

The methods can improved through multivariate analysis (MVA) to determine the landfill siting input criteria (DLSIC). It select the criteria according to their significant levels for each criterion based on the spatial measurements extracted from the input maps of existing landfills [28], which lead to enhances the accuracy and efficiency [65–69]. This method helps to manage the budget for GIS projects, which are short on fund support given the high cost of project operation and design. The collection and manipulation of unnecessary data waste budgeted resources because these data are unrelated to either projects or models.

3.4. Potential improvement through MVA determination

To investigate the potential improvement of MVA method for DLSIC instead of CM, these two methods were compare. **Table 4** summarizes their effect on results of the model in different aspects, such as input variables (data collection, processing, and modeling), accuracy, reliability of criteria validation, and the comprehensiveness of the criteria.

Table 4. Potential improvement in GIS modelling parameter for landfill sites via utilizing MVA instead of CM through for DLSIC.

Parameter	CM determination	MVA determination	Reference
Input variables (Data collection, processing and modelling)	Both related and unrelated criteria are inputted; as a result, landfill modelling is particularly time-consuming, arduous, and costly.	Significant spatial criteria alone are inputted, thereby reducing modelling time considerably. In the process, costs are typically lower as well.	[1,10,24,31,49,70]
Accuracy and objectivity	- CM determines criteria based on expert knowledge. - Simple determination based on either public or expert opinion. - Subject to bias from experts and human error.	MVA is a scientific and statistic determination method that shifts based on the spatial measurements obtained from the real Geo-database. It is also highly objective.	[6,7,37,48,71]
Reliability of criteria validation	The level of validation reliability of the landfill modelling model criteria is low.	Confidence can be enhance to high level by adapting significant criteria.	[6] [38][34]
Comprehensiveness of the criteria	Comprehensiveness levels vary intermittently among the different models.	Comprehensiveness can be improve by testing most of the criteria prior to determining the significant ones.	[2,28,42]

4. Conclusions

A comprehensively surveys literature conduct related to the developments of 75 landfill modelling models and their procedures in the past 18 years (from 1997 to 2014) reflects the growing awareness of this research scope. Approximately 80 criteria used in previous works to evaluate land for landfill modelling given different importance levels. In addition, the different criteria lists derived from previous models are justified by data availability, which are relate to the application area and are suitable for landfill policies. The varied frequency in the input criteria of previous models reflects an imbalance in determination of criteria in landfill modelling and limitation. This imbalance induces miscalculations and various problems. Moreover, this result signifies that dissimilarities in the input criteria increase the cost of search procedures for new landfill sites. The DLSIC methods in landfill modelling were develop based on previous literature, expert interviews, guidelines and regulation requirements, and questionnaires. The use of MVA determination instead of conventional determination in landfill modelling could be progressed from a costly, less scientific, and less efficient approach to a highly scientific technique that is very beneficial. These benefits are induce by the different DLSIC procedures and are as follows: (1) time-scale reduction, which implicitly lowers cost in most cases; (2) a decline in the number of steps of overall procedures to eliminate the need for expert interviews and data collection, manipulation, modeling, and weighting; and (3) the increased effectiveness of overall procedures. These benefits suggest that the final models obtained from MVA for DLSIC procedures may be more economically competitive than those generated using conventional techniques. MVA determination technology recently has been applies for DLSIC in landfill modelling. Nonetheless, no research has been conduct on the DLSIC in landfill modelling

using GIS based on spatial measurements obtained through MVA. Based on this review and to the best of our knowledge. The same is true with respect to research on site selection for GIS spatial modelling and planning fields. Thus, future studies should aim to understand the procedures of low-cost DLSIC in landfill modelling using GIS and to demonstrate MVA effectively. Furthermore, none of the previous studies tested the significant levels of landfill modelling criteria using MVA techniques, to the best of our knowledge.

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