ASSESSMENT OF HYBRID MODEL FOR SUSTAINABLE SANITARY LANDFILL SITING USING GEOSPATIAL AND GEOTECHNICAL TECHNIQUES

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DEDICATION

This thesis is dedicated to my late father Alhaji Ibrahim Mohammed who taught me how to strive for success, self-sufficient and never give up. Also, to my late step mother Hajia Amina Yerima and my late darling sister Safiya Makarfi. May Allah (Azza Wa Jaal) grant them the highest place in Aljannah Firdaus. Amin!!!

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ABSTRACT

One of the major challenges in waste management is the issue of selecting an appropriate site for sustainable sanitary landfilling for the disposal of municipal solid waste (MSW) due to the complexity of various factors that must be considered such as environmental, economic, and social. Therefore, this research developed an innovative hybrid model based on the integration of geographic information systems (GIS), multi-criteria decision analysis (MCDA) and geotechnical technique following landfill siting guidelines and regulations. Therefore, in order to have a sustainable sanitary landfill site selection model, there is a need to evaluate geospatial and geotechnical properties of the area where the potential landfill is to be constructed. The research included identification criteria of siting sanitary landfill such as water bodies, geology, soils, elevation, slope, residential areas, archeological sites, airports, population, roads, railways, infrastructures, and land use. Due to the large volume of spatial data, GIS was used to manage, evaluate, and process these data. In addition, analytical hierarchy process (AHP) was applied to solve decision making problems where multiple alternatives and competing objectives are involved. Criteria maps obtained for this research were prepared in the GIS environment followed by the criteria weights obtained from AHP pairwise comparison matrix and normalization. Next, the weighted criteria were evaluated and overlaid through GIS software ArcGIS 10.3. Then, map production of the most suitable sites for sanitary landfill was carried out using QGIS. Finally, a hybrid model was developed by integrating geospatial and geotechnical techniques. The results from the GIS and AHP revealed the three most suitable sites for sustainable sanitary landfill site selection. This was further examined using geotechnical criteria, namely permeability, volumetric shrinkage and shear strength to obtain the best site. Additionally, computer modeling through digital image technique (using Surfer and Matlab software) was used to validate the model. The model developed from the results of this research can be used as a guide for sustainable sanitary landfilling in developed and developing countries.

ABSTRAK

Salah satu cabaran utama dalam pengurusan sisa adalah isu pemilihan tapak yang sesuai untuk pembuangan sampah sanitari yang mampan bagi pelupusan sisa pepejal perbandaran (MSW) kerana kerumitan pelbagai faktor yang perlu dipertimbangkan seperti alam sekitar, ekonomi dan sosial. Oleh itu, kajian ini membangunkan model hibrid inovatif berasaskan penyepaduan sistem maklumat geografi (GIS), analisis keputusan pelbagai kriteria (MCDA) dan teknik geoteknik mengikut garis panduan dan peraturan tapak pelupusan sampah. Oleh itu, untuk mempunyai model pemilihan tapak tambah sanitari sampah yang mampan, terdapat keperluan untuk menilai sifat-sifat geospatial dan geoteknik kawasan di mana potensi tambak pelupusan akan dibina. Kajian ini termasuk kriteria pengenalan tapak pelupusan sanitari seperti badan air, geologi, tanah, ketinggian, cerun, kawasan perumahan, tapak arkeologi, lapangan terbang, penduduk, jalan raya, kereta api, infrastruktur, dan penggunaan tanah. Oleh kerana jumlah besar data spatial, GIS digunakan untuk mengurus, menilai, dan memproses data ini. Di samping itu, proses hierarki analitik (AHP) telah digunakan untuk menyelesaikan masalah membuat keputusan di mana pelbagai pilihan dan objektif bersaing terlibat. Peta kriteria yang diperoleh untuk kajian ini disediakan dalam persekitaran GIS diikuti dengan kriteria berat yang diperoleh dari matriks perbandingan pasangan yang sepadan dengan AHP dan penormalan. Seterusnya, kriteria pemberat telah dinilai dan ditindih melalui perisian GIS ArcGIS 10.3. Kemudian, pengeluaran peta yang paling sesuai untuk tapak pelupusan sanitari telah dilakukan menggunakan QGIS. Akhirnya, model hibrid telah dibangunkan dengan mengintegrasikan teknik geospatial dan geoteknik. Hasil daripada GIS dan AHP menunjukkan tiga tapak paling sesuai untuk pemilihan tapak pelupusan sampah sanitari yang mampan. Kajian ini diperluaskan lagi dengan menggunakan kriteria geoteknik, iaitu kebolehtelapan, pengecutan isipadu dan kekuatan ricih untuk mendapatkan tapak terbaik. Di samping itu, pemodelan komputer melalui teknik imej berdigit (menggunakan perisian Surfer dan Matlab) digunakan untuk mengesahkan model. Model yang dibangunkan dari hasil kajian ini dapat digunakan sebagai panduan untuk pembuangan sampah sanitari yang mampan di negara maju dan berkembang.

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LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
ANP	-	Analytical Network Process
ASTER	-	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BSCS	-	British Standard Classification System
BSL	-	British Standard Light
DEM	-	Digital Elevation Model
DIT	-	Digital Image Technique
FL	-	Fuzzy Logic
GDEM	-	Global Digital Elevation Map
GIS	-	Geographic Information Systems
GLOVIS	-	Global Visualization Viewer
KML	-	Keyhole Mark-up Language
MCDA	-	Multi-Criteria Decision Analysis
MDD	-	Maximum Dry Density
MSWDS	-	Municipal Solid Waste Disposal Sites
NA	-	Natural Attenuation
OMC	-	Optimum Moisture Content
OWA	-	Ordered Weighted Averaging
PI	-	Plasticity Index
PL	-	Plastic Limit
QGIS	-	Quantum Geographic Information Systems
RSO	-	Rectified Skewed Orthomorphic
SAW	-	Simple Additive Weighting
SWM	-	Solid Waste Management
TOPSIS	-	Technique for Order of Preference by Similarity to Ideal Solution
UCS	-	Unconfined Compressive Strength
UKEA	-	United Kingdom Environment Agency

USEPA	-	United States Environmental Protection Agency
USGS	-	United States Geological Survey
VSS	-	Volumetric Shrinkage Strain

LIST OF SYMBOLS

λ	-	Maximum Eigen Value
a	-	Area of the standpipe
G_s	-	Specific gravity
k	-	Hydraulic conductivity
kr	-	Relative hydraulic conductivity
ks	-	Saturated hydraulic conductivity
L	-	Length of sample
S_i	-	Free swell index
t	-	Time
ψ	-	Suction
v	-	Velocity
v_s	-	Volume of soil
v_w	-	Volume of water

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The most significant part of urban planning is identifying a desirable location for municipal solid waste disposal landfill (Bahrani *et al.*, 2016). However, serious environmental problems or hazards to inhabitants can arise from landfill locations as well as the methods with which the solid waste at a site is disposed (Sharholy *et al.*, 2008). The greatest concerns associated with landfill environmental impacts are linked to its effects on ground water, surface water, air, soil, odor emission, and issues occurring as a result of solid waste transportation (Chabuk *et al.*, 2017a). The most common approach used in municipal solid waste management techniques is a landfill (Jeswani and Azapagic, 2016). Other methods are composting and incineration, but the landfill has become the oldest and most common technique as a result of its convenience and affordability. Due to landfills, there are lots of problem that have risen in the waste management sector (Nas *et al.*, 2010). There is a need for effective and efficient solid waste management to prevent public health hazards, which will have a negative environmental impact.

Increase in the world population and the industrialization of more cities means an increase in the volume of waste, and managing the waste produced by cities have become more complex (Tahir *et al.*, 2011). Getting rid of waste using landfills has become an unavoidable component of the entire solid waste management framework. Regardless of reduction, reuse, and recycling activities and practices, there will always be a need for the transfer of the remaining generated waste into the landfill. In majority of developed and some developing countries, the most common techniques adopted for the disposal of solid waste are the sanitary landfills (Alavi *et al.*, 2013).

Presently, solid waste disposal sites are not properly monitored in many regions of the world, especially those that do not adhere strict terms for solid waste management. This has given rise to a combination of commercial, industrial, household waste as well as construction and hazardous waste into the same landfill (Chabuk *et al.*, 2017a; Scott *et al.*, 2005; Stanton and Schrader, 2001)**.** As generally considered, open dumps or unsanitary solid waste landfill sites are the most disposal problem because of their irregularity and threat to the environment. Also, they are often used without sufficient hydrogeological, geological, and environmental assessments (Önal *et al.*, 2013). This threatens the environment due to bad odor, air pollution, the risk of fire, surface water pollution, as well as groundwater pollution. Therefore, undesired visual pollution can easily be traced in these categories of sites.

Planned sites for sanitary landfills must be first evaluated and measured in detail to determine its social, environmental, economic, and geotechnical attributes in term of subsoil and geological formations, which consist of rock types, tectonic properties, groundwater level depth, etc. (Önal *et al.*, 2013). The most problematic aspects of the disposal process of municipal solid waste is the site selection issue (Kemal Korucu and Erdagi, 2012). Due to the many factors required when identifying landfills, this makes it become a very complex process (Önüt and Soner, 2008). These factors can be referred to as social, environmental, geomorphological, economic, geological, hydrological, and geotechnical. In many developing countries, the required data is collected via traditional methods, which are tedious and time consuming, or old existing data is used (Mohamed and Plante, 2002). According to Chabuk *et al.* (2016), there is a need for waste disposal sites in the surrounding area to preserve the biophysical environment and ecology. Similarly, other factors that must also be considered are the factors associated with the economy, which comprise the cost of acquiring the land together with both developmental and operational costs (Yesilnacar and Cetin, 2008). Likewise, when protecting the environment as well as public health while making sure the need for better sustainability features in term of quality of life, the selection of landfill sites is seen as a fundamental step when it comes to ultimate waste disposal practices. In terms of the preliminary landfill process, the required successive steps are determined by proper landfill site selection. To ensure undesirable long-term effects are avoided, it is necessary to implement landfill siting. Therefore, landfill sites should be carefully selected through the recommendations provided by environmental agencies (Ahmad *et al.*, 2011).

The United State is one of the countries that saw the earliest changes in the development of sanitary landfills in the 20th century through the process of depositing solid waste in layers, compacting, as well as making sure it is often covered with soil. Several countries (e.g. Canada, United States, United Kingdom, Sweden, Australia, and Malaysia) have adopted governmental regulations involving the selection, design, and monitoring of modern landfills to avoid negative social and environmental impacts (Scott *et al.*, 2005). Landfill site selection operation can involve the advantages of geospatial technology, namely remote sensing, Geographical Information Systems (GIS), and Multi-Criteria Decision-Making Methods (MCDM). Hence, they serve as powerful tools for addressing problems arising from landfill site selection. Remote sensing has a great potential to extract earth surface features such as roads, rivers, and vegetation, as well as providing a detailed land cover and land use map from satellite images (Wasige *et al.*, 2013). GIS allows the analyst to efficiently utilize data from various sources to produce detailed models to identify potential places. Multi-Criteria Decision-Making Analysis (MCDA) is often used to handle complex information in very large quantities, especially in this area of research where criteria maps weightings are used together with GIS to recognize the most suitable landfill site.

In order to select a sanitary landfill site, it is significant to conduct geotechnical analysis, which is referred to as soil investigation for the purpose of acquiring the necessary data to study a variety of layers of soil at selected sites as well as to unveil the groundwater depth at these sites (Bagchi, 2004). The investigation of soil at each site is usually based on knowing the properties associated with the subsoil. Similarly, other features of the soil such as the Atterberg limits of fine grained soils or thickness of each stratum are required to estimate both the quantities of solid waste that can be put at each site, and the groundwater depth for each site (Chabuk *et al.*, 2017a).

Many researchers have assessed potential landfill sites using GIS and MCDA methods. This research presents an up-to-date overview on improvements made to landfill site selection evaluation criteria and the methodology used for locating landfills that combines GIS and MCDA. A hybrid model was developed for the selection of sustainable sanitary landfill sites that consider geotechnical criteria as a basic requirement of the landfill sites selection process to ensure the best sites are underlain by an impermeable layer possessing desirable geotechnical characteristics that is also environmentally friendly, economically affordable, and socially acceptable. Geotechnical properties comprise hydraulic conductivity or permeability, shear strength, and volumetric shrinkage. No research is currently available to fill in the missing research gap regarding geotechnical criteria as an important criterion in landfill site selection. As leachate is the main groundwater contaminant, landfill sites must have soil with excellent geotechnical properties capable of retaining these leachates. Therefore, the soil must have a good retention capacity for leachate in terms of permeability and an adequate shear strength to carry the load of waste and trafficability of vehicles that disposes the waste. Equally, minimal volumetric shrinkage is required to negate seasonal variations due to wetting and drying seasonal variation. This study will help decision-makers, stakeholders, and solid waste management agencies to identify the most optimal and sustainable locations for municipal solid waste disposal.

1.2 Problem Statement

To curtail environmental and health hazard, assessments of major factors such as geotechnical, hydrogeological, seismicity, geological and environmental are required for sanitary solid waste disposal sites to be sustainably constructed (Şener *et al.*, 2011; Önal *et al.*, 2013). Thus, to plan and construct suitable municipal solid waste landfills that have attributes in relation to environmental, social, and economic factors in today's society, the problem of site selection and location is inevitable (Eskandari *et al.*, 2012a). This required the application of integrated specialty that involves professionalism from geospatial and geotechnical which was judiciously deploy in this research.

Malaysia daily disposes up to 28,500 tons of municipal solid waste into landfills (Agamuthu and Fauziah, 2011). Considering this fact enforces sustainable landfilling to curtail danger to the people and the environment. Furthermore, the main waste disposal technique in Malaysia up-to-date is landfilling, which accounts for more than 80% of the collected MSW (Manaf *et al.*, 2009). Though, the present landfill sites are attaining their maximum limits of containment which means that new sites need to be constructed (Manaf *et al.*, 2009).

Johor is among the states in Malaysia developing at a speedy pace. This means that an increase in the solid waste generation is expected. Unfortunately, record shows that by 2010, Johor had terminated 21 landfills, and 15 are still operating with only 1 among them being sanitary landfill, and the rest are either open or controlled landfills (Samsudina and Dona, 2013). This is causing great concerns as one sanitary landfill cannot accommodate the waste generation for long, except with an alternative for expansion. These uncontrolled landfills have repercussion leading to unpleasant views, leachate generation, water contamination and costlier waste management. These challenges could be overcome by creating new sanitary landfill sites.

Existing methods for landfill site selection regards many objectives and criteria, however, an integrated method that inculcates all policies for optimum landfill site is lacking. Regarding this, a hybrid model is required which simultaneously considers important criteria as environmental, economic, social, and geotechnical. The use of geospatial technology such as remote sensing with GIS to prepare the required input data in GIS-based site selection for improved decision-making was used in this study. Indeed, researchers constantly attempt to improve the techniques to mapping the best sites for waste disposal and resolve the problems associated with the current mapping techniques. In this respect, an innovative approach based on Geotechnical criteria was developed in this study to improve the accuracy of the landfill sites selection process. This is because when environmental measures were not put in place with respect to the construction, problems are expected to occur (Önal *et al.*, 2013; Depountis *et al.*, 2009; Bruno, 2007). Therefore, for a sustainable sanitary landfill site selection model, the geotechnical, environmental, economic, and social factors need to be evaluated and assessed in detail.

Furthermore, it can be observed that landfill siting analysis typically requires evaluating various rules, factors, constraints, and numerous spatial data which modern

GIS, although capable of rapidly processing a massive amount of spatial data, lacks the ability to locate an optimal site when compactness and other factors are simultaneously evaluated. Previously developed GIS-based model could not be applied to resolve this inability for irregularly shaped spatial data. Therefore, an enhanced spatial siting model is developed herein for general spatial data with the integration of both GIS, remote sensing, and multi-criteria evaluation methods. Thereafter, the geotechnical criteria are applied to ensure the integrity of selected sites. The study area (Johor Bahru) was used to demonstrate the applicability of the developed model.

1.3 Aim and Objectives

The aim of this study is to develop a hybrid model for siting a sustainable sanitary landfill site using geospatial and geotechnical techniques. To achieve the aim, the following objectives had been formulated:

1. To identify the most important criteria that conform with sanitary landfill siting guidelines, rules, and regulations.

2. To produce and validate map of potential sites for sanitary landfills according to the identified criteria.

3. To develop a hybrid model for siting suitable and sustainable sanitary landfill sites using an integration of geospatial and geotechnical techniques.

4. To evaluate and validate the developed hybrid model using digital image technique (DIT).

1.4 Research Questions

S/No	Objectives	Research Questions
1	Objective 1	1. What are the important criteria used in sanitary landfill siting? 2. What are the rules and regulations governing these criteria?
2	Objective 2	1. What are the methods used in producing the potential map sites for sanitary landfill based on the identified criteria? 2. How do you validate the potential map sites produced?
3	Objective 3	1. How can the model be developed? 2. What is the impact of the geotechnical criteria in sanitary landfill siting model?
4	Objective 4	1. Which method is used to validate the developed model? 2. Where are the most suitable sites based on the integration of geotechnical suitability criteria?

1.5 Scope of the Study

The efficiency of solid waste disposal depends upon selection of proper site and there are several issues that have impacts for site selection. One of the reasons for undertaking the present study is the rapid growth in population which is leading to an increase in the amount of waste generated in the study area.

The applications of GIS and MCDA are numerous in different fields of Sciences and Engineering. In this research, GIS and MCDA were integrated with geotechnics to develop a hybrid model for identifying the most suitable site for sustainable sanitary landfill to meet the future waste disposal site demand. Additionally, the Analytical Hierarchy Process (AHP) was adopted as a prevalent

MCDA method for deriving the importance of one criterion over the other. Equally, its flexibility, efficiency, and accuracy when it comes to solving issues related to conflicting objectives. AHP gives range of location from least suitable to most suitable location according to criteria ranking and expert judgement. Therefore, this is important to users especially for the decision makers to decide the most suitable areas to be considered for landfilling.

The various criterion considered for this research are water bodies, geology, soils, elevation, slope, residential area, archeological sites, airport, population, roads, railways, infrastructures, land use, soil permeability, soil volumetric shrinkage, and soil shear strength.

This research work has implemented the use of latest geospatial techniques to select a sustainable sanitary landfill site in the study area focusing on geotechnical criteria as a key factor in siting sanitary landfill. This is to ensure that the soil beneath the ground surface can support the threats of varying climatic conditions of wet and dry season, loads bearing capacities, and conditions posed on it by transportation facilities before any further construction process begins. Also, the goal of the geotechnical investigation was to preserve the safety of the public and the facility constructed, as well as to preserve the economic investment by the government or stakeholders. Figure 1 shows the map of the study area. This study covers Johor Bahru (JB). JB was chosen in this study as it is one of the rapid developing area in Johor state, this has contributed to the increasing amount of solid waste generated. Therefore, selecting sustainable sanitary landfill site in this area is needed because the existing sanitary landfill cannot accommodate the waste produced.

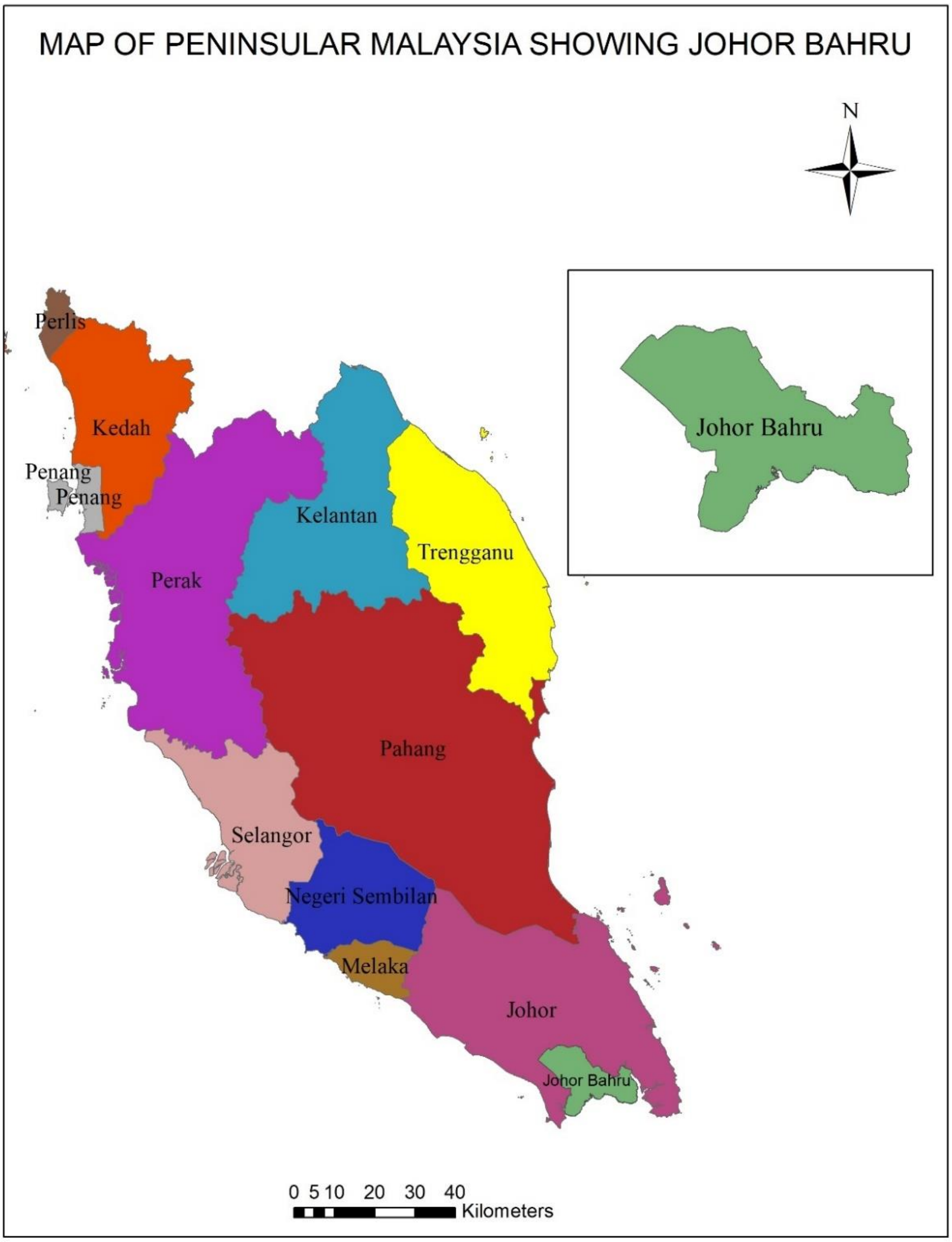

Figure 1.1 Map of the study area

1.6 Significance of the Study

Proper Protection of public health and the environment should be a priority and serve as a right to quality of life. Fundamentally, landfill site selection is frontier in waste disposal techniques used in achieving a cleaner and safe environment. It governs various of the successive stages in the landfill process, and when appropriately employed, would safeguard against nuisances and negative long-term effects. A well-selected sanitary landfill site will generally facilitate an uncomplicated design and provide ample cover material, which would facilitate an environmentally and publicly acceptable operation at a reasonable cost.

By applying this developed hybrid model, the landfill siting process can be done comprehensively knowing that the safety measure for construction of quality criteria is adopted through geotechnics. All the different organizations involved i.e. solid waste management authorities, policy and decision makers, stakeholders from various fields can implement the use of the latest up to date model for the construction of a well and sustainable sanitary landfill site for the disposal of municipal solid waste. Similarly, this will reduce the cost of construction as it impedes the money paid for site investigation. In addition, it will also help the project managers to cut down the time spent debating location-based problems as well as reduce costs.

Most importantly, the results of the best potential sites obtained in this study will be useful especially to the Johor Bahru solid waste management authority. They can directly use these areas to construct a new sanitary landfill site. This is because the sites have met all the necessary requirements related to landfill siting standards, rules and regulations. Moreover, this newly selected sites, if constructed can serve as a way of reducing illegal waste dumping sites because the waste generated can be transported easily within the municipality.

1.7 Contribution of the Study

In terms of contributions to the frontier of knowledge, this research stretches over the following fields: GIS, MCDA, and Geotechnics. This study contributes to the frontier of knowledge by developing a hybrid model linking Geospatial and Geotechnical techniques for sustainable sanitary landfill siting. Although GIS and MCDA has been widely used for landfill site selection models (Santhosh and Babu, 2018; Khodaparast *et al.*, 2018; Eskandari *et al.*, 2013; Şener *et al.*, 2005;), yet no models have considered geotechnical criteria as a basic requirement analysis. Only few studies (Mornya *et al.*, 2010; Babalola and Busu, 2011) have linked their site selection model with soil permeability as a criterion for landfill site selection. However, they have failed to employ other engineering and physical properties examination of the soil in their models for landfill site selection. To the author's knowledge, this is the first study that integrates Geospatial and Geotechnical approach to select not just a landfill but a sustainable sanitary landfill site.

Furthermore, all the different organizations involved i.e. solid waste management authorities, policy and decision makers, stakeholders from various fields can implement the use of the latest up to date model for the construction of a well and sustainable sanitary landfill site for the disposal of municipal solid waste.

This research is also the first formal study on sanitary landfill site selection to the Johor Bahru municipality of Johor, Malaysia which rigorously evaluated the process of landfill siting in terms of selection criteria and methodology used in the past and present researches. This developed hybrid model helps to evaluate and illustrate the process of sustainable sanitary landfill siting.

1.8 Thesis Outlines

This thesis is organized in five chapters; introduction, literature review, methodology, results and discussion, and conclusion.

Chapter 1 (**Introduction):** This chapter covers the introduction which briefly explained an overview of the whole research, which includes background of the study, problem statement, aim and objectives, scope of study, the significance and contributions of the study.

Chapter 2 (Literature Review): This chapter is based on literature review of previous studies and describes the fundamental part of the research which provides appropriate knowledge including the theories and applications employed in this study.

Chapter 3 (Methodology): In this chapter, the whole work flow is explained and addresses each of the objectives outlined in Chapter 1 by adopting the appropriate research methods. In this chapter, the research methodology discusses from the initial study until the model development as well as the model validation technique.

Chapter 4 (Results, Analysis and Discussion): This chapter presents the results, analysis and discussion achieved according to the implementation of the methods adopted in the research. The results and relevant analysis were illustrated and elaborated in various forms such as tables, graphs and figures in this chapter.

Chapter 5 (**Conclusions and Recommendations):** Finally, this chapter delivers the conclusions drawn from this research and recommendations for future researches related to this study.

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