

University of Bahrain

College of Engineering



**Department of
Mechanical Engineering**

Municipal Waste Landfill Site Selection Model for Bahrain

Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Engineering Management

Prepared by:

Mariam Aamer Khalil Ebrahim

20061077

Supervised by:

Prof. Saad Suliman

(Professor)

University of Bahrain

Kingdom of Bahrain

December 2017

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University of Bahrain
Deanship of Graduate Studies

Thesis Discussion Committee Decision

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Thesis Title: <u>Municipal Waste Landfill Site Selection</u> <u>Model for Bahrain</u>	
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The Discussion Committee met on wednesday 27/12/2017 in Hall no. 14_162 (hall/room no.) _____. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student awarded grade A In the thesis subject MEM 598

- ☒ Without making any changes to the thesis
☐ After making the modifications attached with this decision

Discussion Committee Members Approval:

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Abstract

Municipal waste in the Kingdom of Bahrain is one of priority issue that needs to be resolved. Landfilling is the current technology used for ending up all types of waste, where Askar landfill is the main and only one used for landfilling all municipal wastes in Bahrain. Askar landfill reached its end use capacity by 2016, however it's still operating and receiving municipal wastes. This research aims to find out an alternative site for the existing landfill to be used at the current period and for near future, while Ministry of Works and Municipalities Affairs, and Supreme Council for Environment in Bahrain are thinking seriously to find a proper solution and sustainable technology rather than Landfilling. Five landfill alternatives located in the blue zone, next to Askar, of the land use map of Bahrain Vision for year 2030, and eleven decision criteria have been proposed. The study applies two analytical approaches to establish the best landfill. The adopted approaches are Fuzzy Set analysis and Analytical Hierarchal Process analysis. Both approaches are based on multi-criteria decision, Analytical Hierarchal Process simply links the alternatives with the ranges of distances for each criterion, while Fuzzy Set relies on the distances of these criteria with respect to the five alternatives and their inter relationship among the criteria and the alternatives. The results for both methodologies are almost the same as the ranking of the five alternatives for both methodologies are similar with slight difference in landfill positions 3 and 4, where the best alternative is found to be landfill no. (3), which is located in the middle of the blue zone below the existing landfill at Askar.

Dedication

I dedicate my thesis to my beloved husband for his support and giving me the hope to realize my dream. A special dedication to my mother for her prayers and my father for pushing my ambition further. I extend the dedication to my brothers, sister, and all family for their kind wishes.

Acknowledgement

I thank Allah firstly for generous giving during all my life.

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List of Abbreviations

AHP	Analytical Hierarchical Process
BIA	Bahrain International Airport
CPO	Central Planning Office
ERA	Environmental Risk Assessment
FMHP	Fuzzy Multi-criteria Hierarchy Process
FST	Fuzzy Set Theory
GDUP	General Directorate of Urban Planning
GIS	Global Information System
JOD	Jenning's O'Donovan and Partners, Consultant Engineers
MCDA	Multi-Criteria Decision Analysis
MMA&UP	Ministry of Municipalities Affairs and Urban Planning (Previous name)
MOW	Ministry of Works
MOWUP	Ministry of Works and Urban Planning (current name)
MSW	Municipal Solid waste
SAW	Simple Additive Weighing
SCE	Supreme Council of Environment
UP	Urban Planning

List of Notations

α -cut	Confidence level
λ	Degree of optimism
$\lambda_{\max}$	Maximum degree of optimism
PV	Priority Vector
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
n	No. of criteria
m	No. of alternatives
i	Landfill alternative index (i = 1, 2, ... 5)
j	Governorates index (j = 1, 2, ... 5)
d_i	Average path taken to a specific landfill i
k	Criteria index (k = 1, 2, ... 11)
ω_j	The population average weight of governorate j
d_{ij}	The average distance from governorate j to landfill i

Chapter 1: Introduction to the Study

- 1.1 Introduction
- 1.2 Research Problem
- 1.3 Research Questions
- 1.4 Research Objectives
- 1.5 Research Significance
- 1.6 The Study's Setting
- 1.7 Research Terminology

Chapter 1: Introduction to the Study

1.1 Introduction

Municipal Solid Waste (MSW) in the Kingdom of Bahrain is being a priority issue that needs sustainable solution, where the Ministry of Municipality and Agriculture Affairs and Supreme Council of Environment (SCE) in Bahrain are working seriously to manage these wastes and control the risks that may arise.

The municipal waste is the outcome of the useless and unnecessary items and the garbage of used items. MSW includes domestic and residential waste, building, construction and demolition waste, commercial and institutional waste, street sweepings, garden waste, non-hazardous and inert industrial waste. The generated amounts of municipal wastes are increasing rapidly. The huge developments in the Kingdom of Bahrain take part in the problem of disposal all these kinds of wastes, especially for the space required to landfill these magnitudes of wastes with concern to the public health. Thus, the MSW landfill becomes a significant issue.

Most of the municipal waste is collected and transported from many locations around the country and is being disposed at the Askar Municipal Landfill Site, which is operational since 1985 (Environmental Health Directorate, 1988). Askar Landfill has been the primary dumping site for all municipal wastes, agricultural waste, commercial waste, and non-hazardous industrial waste in Bahrain. The Census Register of 2001 shows that around 94% of municipal waste generated is being disposed of at Asker Landfill (JOD, 2013). The study done by JOD (2013) expected that Askar landfill to be reached the end of its operational life by 2016

based on the huge waste quantities generated and the space consumed each day. However, it's still operating and receiving municipal wastes.

In addition to the limited space, it's necessary to consider health and environmental effects of landfilling the municipal wastes on surrounding area, air, and groundwater. Therefore, disposing these wastes must find a sustainable solution in the Kingdom of Bahrain. The sustainable solutions for this problem may come in different ways. One of these ways concerns with the infrastructure development. Another way may deal with solid waste management especially with waste dumping and mode of transport for their removal. A further way is to utilize these wastes as construction materials in civil engineering projects.

Other extensive studies try to find aesthetic and environmentally friendly solutions by using the areas of landfill through gardening and agriculture. These kinds of solutions give positive indicators to the different sectors, helping environment by disposing of these wastes, aesthetic landscaping by gardening the landfill areas, and commercial as the benefits that will come from agricultural crop.

Over the world, it is shown that municipal wastes are critical problem that become growing over the time. Whenever, the increase in these wastes are generated from human activities or industrial processes; it causes significant environmental problems. Therefore, the present world trends deal with these wastes by designing processes that are known as low and non-waste technologies or attempts to recycle and reuse the waste generated.

Thus, Bahrain should find sustainable solutions for the 1.5 million tons of municipal wastes that generated annually (Central Informatics Organisation, 2011). These quantities are considered large for a small

island like Bahrain with an area of 934.57 km² (as per national detail land use map for 2030, issued by General Directorate of Urban Planning).

The problem of these large quantities of municipal wastes will be intensified soon due to development projects and due to the generated wastes that end up in landfill. These two factors as they applied continuously without appropriate management might have adverse impacts on human health and the environment.

Based on the previous studies, disposal of MSW by landfilling is the most used technology around the world. These studies mainly focused on selecting the optimum or most suitable landfill, taking on consideration the impact of the landfill on the ambient conditions.

Therefore, wastes disposal strategy in Bahrain is facing a real problem that needs an urgent solution in the near future. Thus, a study is needed to provide a professional solution for disposing the huge quantities of the municipal wastes, and a prevention management scheme of future environmental risks. The study will assist the environmental sectors (Ministry of Municipality Affairs, and Supreme Council for Environment) in the Kingdom of Bahrain to achieve their ambitions of making our country green, healthy and environmentally friendly.

1.2 Research Problem

The main problem of the study focuses on the wastes disposal; where the huge quantities of the municipal wastes that generated annually in Bahrain is an alarm to the public health and the space required for disposing these wastes.

Right now, most of municipal wastes are disposed by landfilling in Askar. The government land in Askar are almost used up and fully

occupied since 2016, however it's still receiving municipal wastes every day.

Therefore, finding an alternative space in the very few coming years is becoming an essential issue as the expectations and the analysis studies showed that Askar landfill is reached its end life.

In this situation, municipal wastes in Bahrain require full management program to find a proper solution, which deals with:

- Finding lands alternatives for disposing municipal wastes.
- Criteria for selection new landfill's location.

1.3 Research Questions

The questions which the study is going to answer are:

- What are the major criteria that need to be considered in order to select a location for landfilling the municipal wastes in Bahrain?
- Where are the alternative locations for landfilling municipal wastes in Bahrain for the next 15 years?
- What is the best location among these alternatives?

1.4 Research Objectives

The main objective of the study is to find out the most suitable land to be used as a municipal waste landfill. Furthermore, the study aims to develop a model for selection of landfill's location subject to the economic, social, and environmental constraints. It is also constrained by the possible transportation routes to deliver the wastes from Bahrain governorates to the proposed landfill.

1.5 Research Significance

The research study has significant issue in dealing with the huge quantities of municipal wastes in Bahrain. The main concern of the research is to find out a suitable MSW landfill with enough space and considerable capacity. The outcome will propose an alternative landfill to the mostly occupied one at Askar.

As landfilling is the only technology used for the waste management in Bahrain, and the main MSW landfill at Askar is reached its full capacity and still receiving MSW, thus, this research study is highly important and necessary for the near future.

1.6 The Study's Setting

Based on the current situation of Askar Landfill and on earlier studies during the last five years, it is fully occupied and reached its end life capacity by 2016. Adding to that, the current daily generated MSW are still disposed at Askar at an increasing rate due to increasing rate of population.

Therefore, Ministry of Municipalities Affairs and Urban Planning (MMA&UP) need an extensive study to sort out the environmental and social issues in relation to the wastes generated and its disposal. It requires a proper management for the waste collection which ends up at Askar landfill. As well, further sustainability study is required for managing the waste at Askar landfill and reducing the rate of disposal waste.

Currently, the main issue that requires to be resolved is finding an adequate capacity for landfilling in the coming years.

1.7 Research Terminology

Municipal wastes: Several kinds of wastes that include domestic and residential waste, building, construction and demolition waste, commercial and institutional waste, street sweepings, litter, garden waste, non-hazardous and inert industrial waste, and wastes/ rejects from small and medium enterprises.

Landfill: The disposal of waste material by burying it, especially as a method of filling in and reclaiming excavated pits.

Disposal: Processes that do not lead to the possibility of retrieving the resources or the recycling or re-extracting or the reuse thereof in direct or substitute uses.

Environment: the natural world, or in a geographical area, especially as affected by human activity.

Environmental Risk Assessment (ERA): provides a systematic procedure for predicting potential risks to human health or the environment.

Supreme Council for Environment (SCE): an entity in Kingdom of Bahrain aims to manage and protect the environment and all natural and marine resources, wildlife, and biodiversity.

Ministry of Municipalities Affairs and Urban Planning (MMA&UP): one of Kingdom of Bahrain's ministries aims to provide extensive services with direct bearing on every home, commercial outlets, and facilities to all Bahrainis.

Chapter 2: Literature Review

2.1 Introduction

2.2 Landfill in Literatures

Chapter 2: Literature Review

2.1 Introduction

Municipal Waste Management is a complex issue that require to concern with several aspects. It is not just an environmental problem; it has interacted with the social, economic, commercial, and even the political issues in any country. Therefore, municipal waste management needs extensive study to fulfill all aspects that it may affect.

There are many researches done in the field of MSW, solid waste management, sorting municipal waste, landfill site selection for municipal waste, etc. Back to the main topic of this study “Selection model for Municipal Waste landfill”, several researches had been carried out in several regions that concern with this issue. Most of these researches have used Multi-Criteria Decision Analysis (MCDA) and Global Information System (GIS). Few studies have used Statistical Data Analysis and other techniques.

For this study, a collection of waste management and selection of landfill articles have been studied to enhance the output of this study. Following are summaries of these articles.

2.2 Landfill in Literature

There are many researches on landfill and how to manage it, how to select optimal landfill location, and other issues related to waste management such as recycling, reusing and controlling environmental risk, which are not related to the study.

Melo et al. (2006) prepared a research on strategic decision analysis for selection of landfill sites. It aimed to relocate the landfill in the city of Cachoeiro de Itapemirim, Brazil by selecting suitable site using multi-criteria analysis and Geological Information Systems (GIS) by establishing pairwise analysis. To reduce the subjectivity in the decision, they developed an algorithm using final weights in pairwise comparisons to establish the relative importance of the variables. Multi-criteria analysis was classified into constraints and factors. Constraints were restrictive criteria based on boolean rate (true or false) that surround or limit the analysis of geographic regions. Factors were scale criteria that define some degree of suitability for all the geographic regions. Both associated to the environmental, operational, social, and economic dimensions of the study. The results revealed that there are 15 suitable sites with area between 20 and 200 hectare that scored greater than the score limit. The weakness of this study was not giving the optimal site; it presented the most suitable sites to be subjected to further analysis for future selection.

Charusiri and Ladachart (2008) prepared a study on GIS application for the determination of geological barriers; a case study of landfill site selection in Songkhia Province of Thailand. It aimed at classifying types of geological barriers for solid and hazardous waste disposal, and searching for appropriate waste disposal sites using GIS. The study was based on GIS model as a standard tool to search for high quality geological barriers suitable for landfill areas in the Songkhla region. It was mainly concerned in minimizing the environmental impact of planned waste disposal sites. The results of the study identified three maps for three barriers; lithological, clay and geological. At the end the

three maps were combined in one map to select the ideal waste disposal sites.

Bah and Tsiko (2011) prepared a study in Africa, entitled "landfill site selection by integrating geographical information systems and multi-criteria decision analysis; a case study of Freetown, Sierra Leone". In their study the decision making moved in two major stages. In the first stage GIS model was used, and then study area excluded some locations due to the physical and environmental restrictions within the rules of the constraints. The constraints were: reservation of drinking water sources; coastlines; forest reserves; sensitive ecosystems; and avoidance of unsuitable soil areas. In the second stage the study area was examined with concern of four factors: built-up areas; roads; water bodies; and degree of slope. In this stage, multi criteria analysis was used. The study showed an optimal site for landfilling in Freetown. The study showed that using the combination of GIS and MCDA was an ideal methodology to limit the alternatives sites and ease selection of the optimum one.

Agaji and Wajiga (2012) presented a study on an object oriented system for the location of landfills for Nigerian municipals. The study based on the requirements of finding new landfills in Nigeria with proper waste management decision. The existing landfills were selected without using/developing model such as GIS or any mathematical programming. Therefore, this study aimed to create a model to select proper landfills sites for Nigeria. The selected modeling approach was mathematical programming, it begins with translating the design into a form that can be coded into a computer system for execution. In this work Visual Basic; version 6.0 was selected as a programming language as it had excellent graphical interface and good interface facilities to the database. The back end of the software is a data base made of five tables created in Microsoft

Access. Access is chosen because of its excellent link facilities with visual basic. Five tables were created in Access and randomly populated to reflect the nature of the data for testing the software. The output from the model gave 5 sites as the best sites suitable for landfills out of 20 sites selected randomly at the beginning of the study.

Strength of this study was in the design phase. It designed the process of selection the sites, the main criteria, and the phases/stages of selection method. Then, the design was translated and implemented in a program to select and show the physical location of the selected sites. In other hand, the weakness of the study was in the beginning of the selection as the selection done randomly.

Yesilnacar et al. (2012) developed a study in Turkey on MSW landfill site selection for the city of Sanliurfa. It aimed to apply MCDA integrated with GIS to select possible sites of a MSW landfill with the same cognitive parameters used for selection of the present landfill. The selection process used the fundamental of MCDA and the simple additive weighting (SAW) approach throughout the analyses. Thirteen criterion of selection were specified: settlement; land use; aquifer; geology / lithology; surface water-perennial stream; surface water-intermittent stream; elevation; slope; airports; infrastructures-power lines; roads-highways; roads-small roads; and industrial sites.

The suitable areas for landfill siting were clustered in three zones. These three zones have different characteristics and locations, but classified as suitable sites because they were satisfying the proposed weighted criteria. The open ended finding of three possible alternatives rather than single site appears as a weakness in the study, thus, the outcome results need

further extensive studies to select the optimal site among the three zones' sites.

Chen (2013) presented a study on data construction process and qualiflex-based method for multiple-criteria group decision making with interval-valued intuitionistic fuzzy sets. A statistical inference approach was used in the study with finite population to construct interval-valued intuitionistic fuzzy numbers. In addition, the study incorporated the relative importance of decision makers and fuse individual opinions to form collective ratings using a modified method with weighted interval estimations. The quality of presenting the methodology is most likely focusing on the arithmetic calculations and detailed illustrations of how to apply the calculations needed in the study without showing clear picture of a selection model for the landfill site. At the end of the paper and after implementing the long non-linear programming, the results show the best order of the candidate landfill and the best choice.

In Serbia, Bronja and Bronja, (2014) prepared a research aimed to preserve the environment and meeting several criteria such as communal and economic criteria, etc. for finding the optimal site. The research was based on multi-criteria analysis and selection of the appropriate landfill site based on defined criteria. A professional team of several members suggested possible locations that meet all property legal, and technical requirements for the future landfill site. Also, those decision-makers defined the necessary criteria to be used for the evaluation of landfill site eligibility. The criteria included ownership of land, planning and design documentation, distance from residential areas, distance from surface waters, average path taken, the average of infrastructure, available space locations, terms of exploitation and overlay material, relief characteristics of the site, distance from agricultural land. Evaluation of the relative

importance of the criteria and their weights was done based on the defined scale for criteria assessment. Maximal value as a product of weight of each criterion and value of criteria obtained by measuring or recording in practice was established based on the defined procedure. The obtained values were used for ranking of landfills. The measuring procedure of the weight was applied on 5 proposed sites. Then, the analytical hierarchical process was used to find out the optimal site based on multi-criteria site selection. The results showed the optimal site, and the decision maker selected the site referring to the AHP results. The decision procedure was simple and applicable in most situations of landfill site selection. It had justified several aspects by dealing with several professionals while determining the site criteria.

Shah and Wani (2014) presented a study in India based on multi-criteria analysis and GIS to select the suitable site for waste disposal. The title of their study was “geospatial based approach for enhancing environment sustainability of Srinagar city - a study on solid waste disposal”, and the major objective is to select the suitable site for waste disposal. The study used integrated methodology through Geographic Information System (GIS) by defining the barriers of the constraints for the selection of sites. The methodology incorporated many environmental and socio-economic parameters that were essential to identify the sites, which had minimum adverse impact on environment. Criteria for selecting the suitable landfill were forest area, water body, wet land, plantation area, recreational area, built up, road network, airport, water table landfill, and slope. The study successfully identified two potential sites in north and south of the city. Geospatial technology, as an information tool, helped in the generation of information on different aspects like land use, road, slope, etc., which were used as criteria for the study. Integration of different data sets in

GIS resulted in multi-layer display of the data, which would have otherwise been difficult to do manually.

Ghoseiri and Lessan (2014) prepared a study entitled “Waste disposal site selection using an analytic hierarchal pairwise comparison and ELECTRE approaches under fuzzy environment”. The study used the pairwise comparison and ELECTRE approaches for selection among 5 alternative sites based on 5 major criteria. Criteria were identified from interviews and studies. The most important objectives involved in this project identified as environmental issues, economic issues, social concerns, political issues, and agricultural issue, which were divided further to several criteria. After implementing the methodology, the 5 sites were ranked and the best site was tested by sensitivity analysis to take the final decision. At the end, the results showed the optimum site.

In parallel to the literature from various countries around the world and belong to several periods within the last ten years, selection of suitable landfill site in Bahrain will definitely be based on multi criteria analysis to enhance the decision making as most of the literature have applied.

In the other hand, the best methodology is difficult to be specified, however it has to be between Analytical Hierarchical Process and Fuzzy Set Analysis. Both are applicable to select landfill site in Kingdom of Bahrain. Therefore, the two methodologies will be used; AHP and the most recent fuzzy set theory. By applying two methodologies, decision making will get an enhancement to select the optimal landfill site.

Chapter 3: Methodology

- 3.1 Introduction
- 3.2 Study the Previous Reports and Literature
- 3.3 Interviews
- 3.4 Data Collection
- 3.5 Procedures of Study

Chapter 3: Methodology

3.1 Introduction

This chapter gives an overview of the methodology of the study, starting with reviewing the previous studies, making interviews, data collection, problem formulation, modeling and decision of results. Figure 3.1 summaries the methodology and procedure of the study.

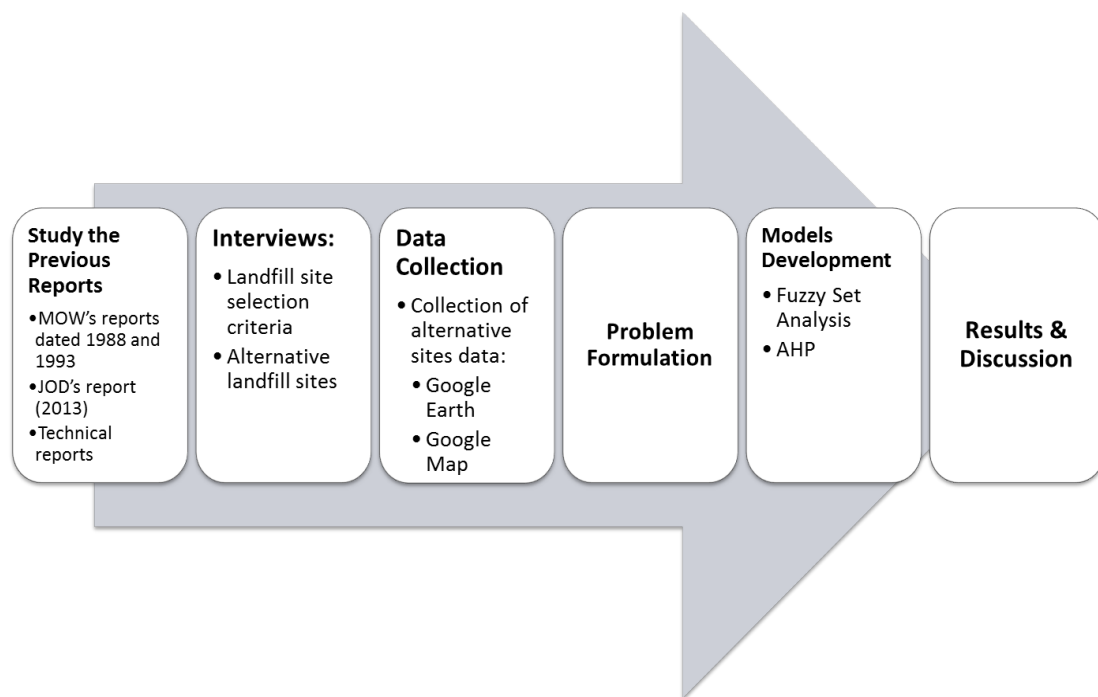


Figure (3.1)

Methodology and Procedure of the Study

3.2 Study the Previous Reports and Literature

At the beginning of the research, the main data sources available were previous studied done by MOW and other engineering consultants who provide studies for the benefit of MOW. These studies are mainly about the existing landfill at Askar. The consultant that provided a

comprehensive study for the existing landfill at Askar is Jennings's O'Donovan and Partners (JOD), (Project no. 8298, 2013); they are specialized in environmental and other engineering consultancy services. Their report was submitted to Ministry of Municipality Affairs and Urban Planning on 2013. This ministry becomes under MOWUP nowadays.

The other sources of information available about the existing landfill are two reports prepared by MOW; these reports are dated back to 1988 and 1993. However, these reports have been considered in the most recent report prepared by JOD. The first report is "Review of Waste Disposal Operations at Askar landfill Site" which prepared by Central Municipal Council Environment Health Directorate, 1988 (MOWUP). The second one is the factual report entitled "Site Investigation Report for Askar landfill" of the year 1993 (MOWUP). These two reports and that prepared by JOD are important because they provide an overview of the operations and geotechnical status of Askar landfill and surrounding areas.

3.3 Interviews

For the purpose of selecting the suitable zone to be used for the future landfill and the criteria needed to be considered, the study starts by discussions with official who are working for Bahrain government and concerned with the problem of waste landfill and land distribution, namely, Central Planning Office (CPO) and General Directorate of Urban Planning (GDUP) of MOWUP, and Supreme Council for Environment (SCE). The aim of the discussions is to identify and define the landfill site selection criteria and the potential alternative locations for such sites.

The second step is to specify the required landfill area for the coming 15 years and to finalize the alternative locations. Landfill area is based on

the estimated waste generation and the capacity for the lifetime of 15 years. After determining the area, the locations' alternatives are specified on the selected zone as advised by CPO.

The criteria are also discussed with the same authorities and the proposed criteria are considered for selecting the best alternative.

3.4 Data Collection

To achieve the main goal of the research various tools are involved for data collection, applying the model, and to take the final decision. The main tools used are Google Maps and Google Earth to determine the routes to the landfill sites, distances, and areas of landfill. Further to that, collected data were input to Excel Sheet for applying the two methods. Google Earth is the most used tool with an overlay of Bahrain map showing the different land uses as per 2030 plan. Both Google maps and Google earth were excellent sources for the most recent and real data inline to the distances' measures and roads' routes. The collected data were reliable and valid for Bahrain as it matches the 2030 plan. Illustrated figures and sample of data collection can be found in Appendix (A).

3.5 Procedures of Study

By defining the landfill alternatives and criteria, the decision making is taken as suggested in Chapter 2 by multi criteria decision analysis (MCDA).

The selected analytical methods for this study are analytical hierarchical process (AHP) and fuzzy set theorem as suggested in previous chapter. These two methodologies have been highly recommended for such problems that require a proper decision making. The reasons of selecting

two methodologies are to enhance the study and support the final decision to be taken. A comparison between the two results will ensure the final decision of selecting the best landfill site.

The theories of the two methods and their application to the research problem will be discussed in Chapters 5 and 6, to give clear explanation of the model developed by each method and its outcome results.

To accomplish the research objective, i.e. select the best landfill alternative, the two methodologies are applied based on the data collected for these criteria in relation to each alternative. Then, the results are discussed and compared, and finally recommendations are made.

Chapter 4: Problem Formulation

4.1 Landfill Design

4.2 Landfill Alternatives

4.3 Selected Criteria

4.4 Data Collection

4.4.1 Average path taken (Road network)

4.4.2 Distances for other criteria

Chapter 4: Problem Formulation

4.1 Landfill Design

The study aims to select suitable landfill in the kingdom of Bahrain for the coming fifteen years. Therefore the main concept is to determine the adequate landfill area to accommodate the generated wastes during these fifteen years. From this point, the landfill life time is 15 years.

Torr (2011) stated that the daily Municipal waste generation in Bahrain is approximately equal to 2,200 tonnes. JOD (2013) the consultant Engineers determined the daily generation of municipal waste as 2,500 tonnes for the following ten years in their study of Askar landfill risk assessment. JOD estimation is the most recent one and has taken future forecast of waste generation, as well it is higher than the other estimate. Thus, municipal waste generation for the coming fifteen years is taken as 2,500 tonnes per day, and the yearly amount is given by:

$$\begin{aligned}\text{Yearly Municipal Waste Generation} &= (2,500 \text{ tonnes/day}) \times (365 \text{ days}) \\ &= 912,500 \text{ tonnes/year}\end{aligned}$$

And the total municipal waste generation for the estimated landfill's life time is:

$$\begin{aligned}\text{Waste generation for (15years)} &= (912,500 \text{ tonnes/year}) \times (15 \text{ years}) \\ &= 13,687,500 \text{ tonnes}\end{aligned}$$

The expected waste generations during the coming fifteen years give an indication to the required capacity for the future landfill. The following step is to determine the required space/volume of the landfill.

In order to find the volume of generated waste, waste density need to be defined. Based on the Environmental Protection Agency Landfill Design Manual of year 2000, waste density is considered to be 1 tonne/m³. Adding to that, the existing landfill at Askar has a density around 1 tonne/m³ as per the review of waste disposal operation at Askar report on the year 1988. Therefore, the waste density is taken as 1 tonne per cubic meter.

Hence, the required space can be determined by dividing the total waste generation for the coming fifteen years over the density as follow:

$$\begin{aligned}\text{Required landfill space (volume)} &= (13,687,500 \text{ tonnes}) / (1 \text{ tonne/m}^3) \\ &= 13,687,500 \text{ m}^3\end{aligned}$$

As the required space has been estimated, the main measures to be estimated for the landfill are depth and land area. In line to the landfill depth and back to the studies related to the existing landfill at Askar, the acceptable depth is used to be eight meters. This has been considered with reference to the geotechnical investigation and analysis for the surrounding area of the existing landfill. As the proposed zone is near to the existing landfill and has the same topographical and geotechnical specification based on the review of waste disposal operations at Askar provided by the Environmental Health Directorate (1988), the estimated depth for the future landfill is taken as 8 meters.

Thus, the required land area can be found as following:

$$\begin{aligned}\text{Required Landfill Area} &= (\text{Landfill Space/Volume for 15years}) / \\ &\quad (\text{Landfill Depth}) \\ &= (13,687,500 \text{ m}^3) / (8 \text{ m})\end{aligned}$$

$$= 1710937.5 \text{ m}^2 (1.71 \text{ km}^2)$$

4.2 Landfill Alternatives

Further to the discussion with the responsible authorities in Kingdom of Bahrain in relation to the land use and classification, General Directorate of Urban Planning (GDUP) and Central Planning Office (CPO) which both are under Ministry of Works and Municipalities Affairs, they stated that the Environmental Strategy for Kingdom of Bahrain is going to be changed. Another strategy instead of landfilling is planned to be used in the future. As yet, there is no clear plan for the new strategy. Further though, several sites have been selected and operated recently for industrial wastes (e.g. Al Dur industrial waste landfill).

As results of meetings and discussions with both authorities; GDUP and CPO, it has been suggested to select an area within the blue zone around the existing landfill at Askar as illustrated in the latest land use map which has been issued by Gazette on 19th May, 2016 (Refer to Appendix B for the Kingdom of Bahrain National Detail Land Use map 2030). The blue zone surrounding the existing landfill at Askar is defined as Community Services land. This type of lands has a total of 8.04% of Bahrain area as per the National Plan of Kingdom of Bahrain for 2030. Figure 4.1 shows the selected zone where the area alternatives for landfill need to be allocated, while Figure 4.2 shows the five alternatives for landfill site within the selected zone.

Based on these suggestions and discussions, five alternatives' sites have been defined with an area of 1.71 km² or more. All these sites are located in the blue zone area and near to the existing landfill. Table 4.1 describes the landfill location, area, and coordinates for each of the five alternatives.

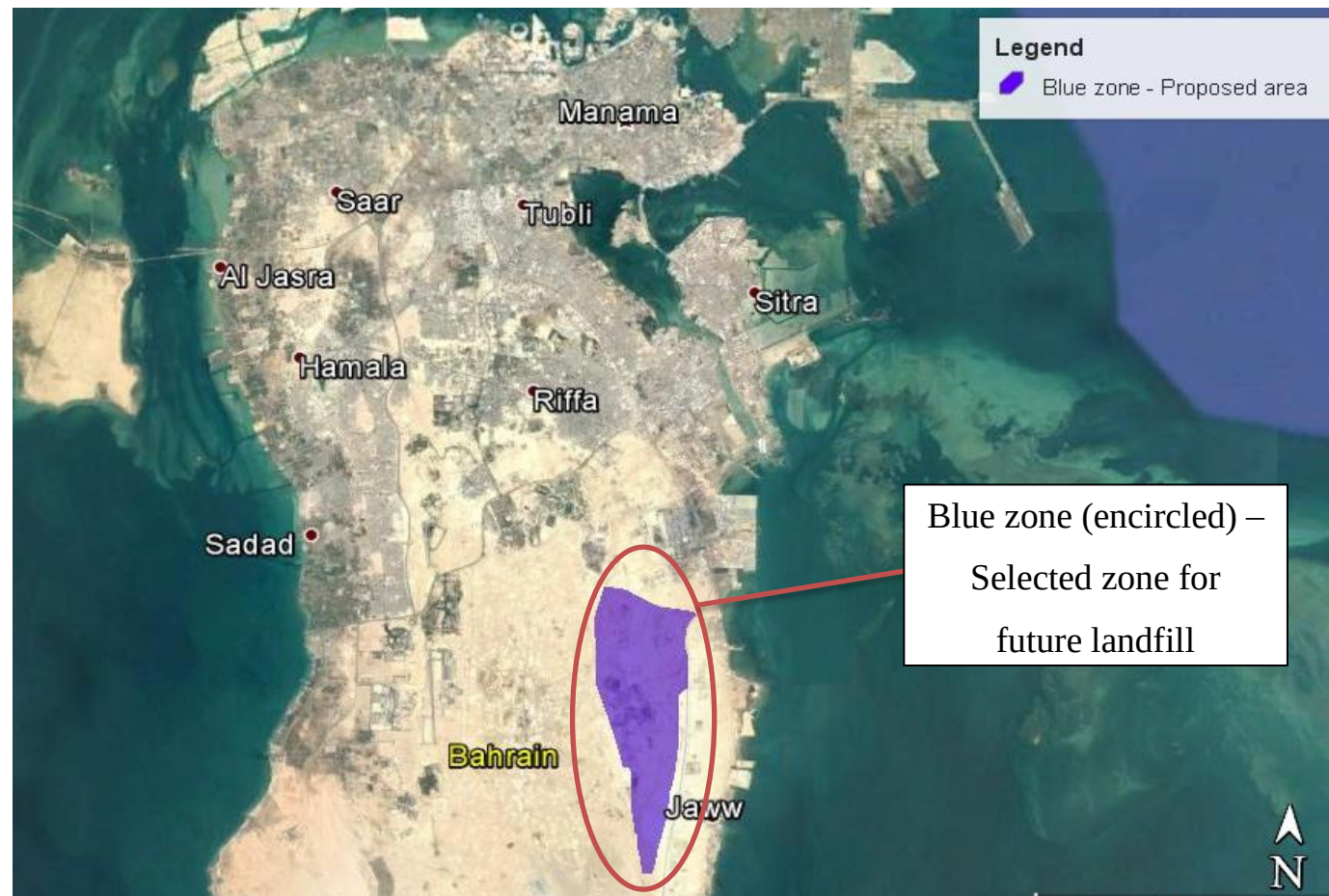


Figure (4.1)

Selected Zone for Future Landfill

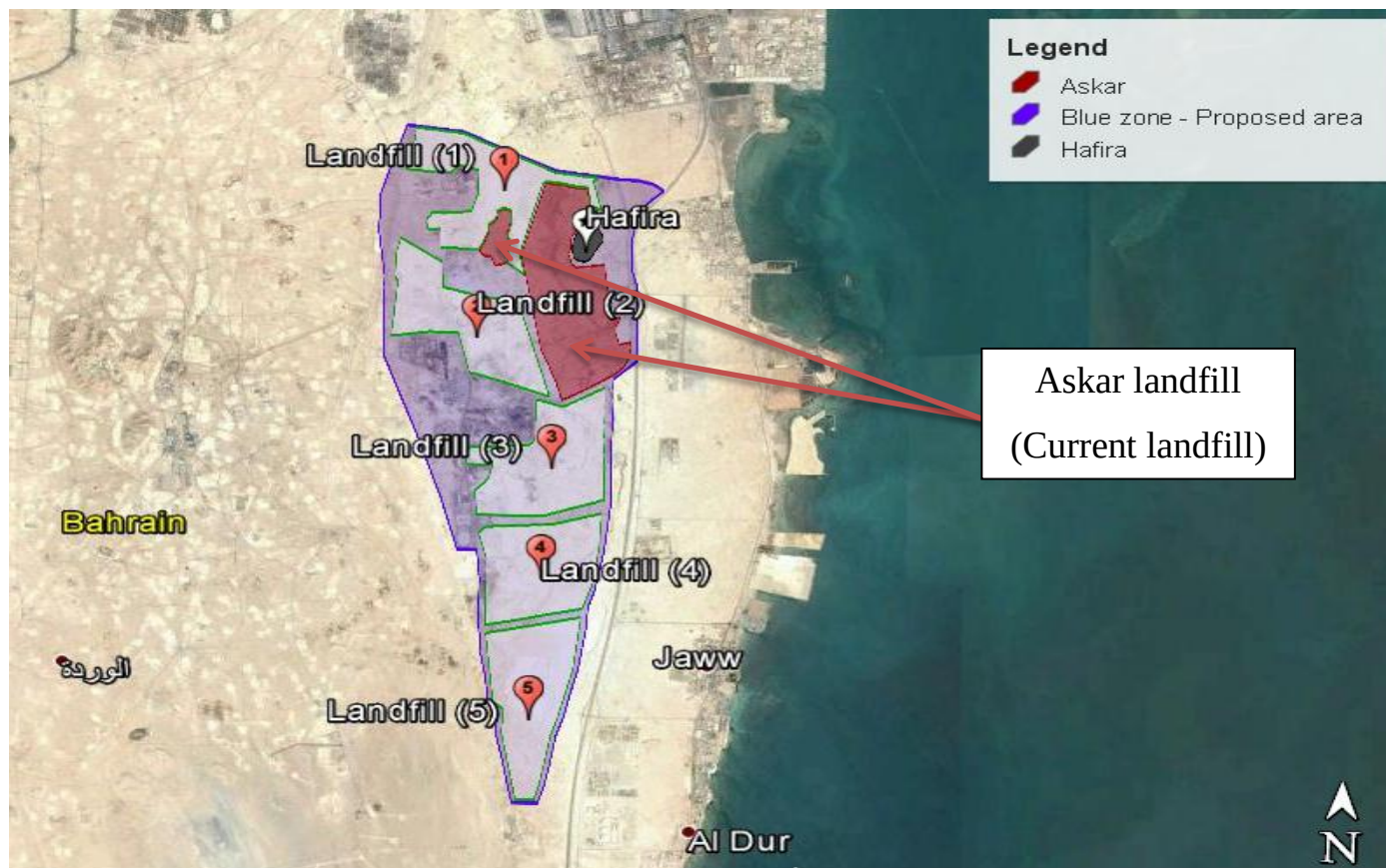


Figure (4.2)

Landfill Sites' Alternatives

It's clearly observed that the five sites alternatives have nearly equal areas. It is ranging from 1.71 km² to 1.95 km² with a possibility to extend any of these lands as necessary and if required after selecting any of them. That can be observed clearly from Figure 4.2. The existing municipal waste landfill at Askar is at top right shadowed on dark where the small quarry at the left side is the most recent occupied area. The area at the right to the Askar landfill is the industrial waste landfill and known as Hafira. The alternatives for landfill site have been decided to be as located in Figure 4.2 based on the most suitable, clearly empty and unplanned area. Further to these main conditions, the second major impact to select those alternatives was based on the required space that not to be less than 1.71 km².

Table (4.1)

Information of the Landfill Sites' Alternatives

Sites no.	Location Description	Area (km²)	Northing °	Easting °
1	North of the existing landfill at Askar	1.71	26.061576°	50.591542°
2	West of the existing landfill at Askar	1.82	26.042043°	50.588799°
3	South of the existing landfill at Askar and middle of the community services land (Blue zone area)	1.95	26.025226°	50.597991°
4	Centre to south of the community services land	1.71	26.010915°	50.597120°

	(Blue zone area)			
5	Farthest South of the community services land (Blue zone area)	1.72	25.992841°	50.596139°

4.3 Selected Criteria

After defining the landfill sites alternatives, the second stage is to decide on the study criteria for selecting the best alternative. The first step for limiting the criteria of the study is collecting the most used criteria in the literature. As a result of that, the collected criteria are given in Table 4.2.

Table (4.2)

Most Used Criteria in Selecting Landfill

NO.	Criteria	considered / not considered (X)
1	Distance from surface water, water body, wet land, water table, aquifer	X
2	Average path taken, road network	Considered
3	Relief characteristics of the site, geological	X
4	Distance from agricultural land	Considered
5	Ecological impact	X
6	Ownership of land	X

7	Sensitive sites	Considered
8	Slope	X
9	Available space locations	X
10	Construction cost	X
11	Terrain suitability	X
12	Distance from residential areas	Considered
13	Built up	Considered
14	settlements	X
15	Political issues	X
16	Planning and design documentation	X
17	The average of infrastructure	X
18	Nearby airports	Considered
19	Terms of exploitation – overlay material	X
20	Industrial sites	Considered
21	Impact on local industry	X

Some of the criteria mentioned in Table 4.2 can be applied to this study for Kingdom of Bahrain and some are not applicable. From this point of view, further analysis is carried out to investigate the criteria which can be taken into consideration to select the landfill for Kingdom of Bahrain.

Some of the criteria are not considered due to the fact that they will not have a significant impact on the selection of the landfill site as it has the same effect for all alternative sites. These are:

Criterion no. 1: Distance from surface waters, water body, wet land, water table, aquifer: This criterion is not considered as all the alternatives are located on one region (Blue zone) near Askar. This area has been investigated previously to check the water table and aquifer, and based on these investigations the maximum depth for the landfill has been specified.

Criteria nos. 2, 8, 9, 10, 11, 14 and 17: Relief characteristics of the site (Geological), slope, available space locations, construction cost, terrain suitability, settlements, and the average of infrastructure: These criteria are not considered as all the alternatives have almost the same characteristics.

Criterion no. 6: Ownership of land: Because all proposed sites owned by Bahrain Government, this criterion is not considered.

Other Criteria that are not considered for different reasons, such as:

Criterion no. 5: Ecological impact: It is not considered due to the fact that the ecological area equals to 0.53% of Bahrain land. It is small area and far away from the proposed lands.

Criterion no. 15: Political issues. Usually, political issues considered as criterion for big countries with varieties of religions and cultures. In that view of point, Bahrain is quite small country with unified religion and culture. Therefore, this criterion is not considered.

Criterion no. 16: Planning and design documentation: As the objective of the study is focusing in landfill selection, planning and design are considered preliminary during identification of the locations' alternatives and specification of the criterion. Further design and planning should be considered on later stages, after selecting new landfill location.

Criterion no. 19: Terms of exploitation – overlay material: There is no guideline to overlay material in Bahrain landfill. As per the lack of information, this criterion will not be considered.

Criterion no. 21: Impact on local industry. This criterion is eliminated because its impact is similar to that of criterion no. 20 (Industrial sites) and counting this as separate criterion might has duplicative effect for the same subject.

On other hand, the criteria considered for the study are being analyzed to select the suitable ones for enhancing the decision of selecting the best landfill site. The initial criteria considered in Table 4.2 are:

Criterion no. 2: Average path taken / Road network: This criterion is very important as it justifies the suitability of selected landfill's location relative to the five Bahraini governorates and transportation routes. It is highly recommended to be considered based on the high impact of road network, average path taken, and availability of routes options as well as the delivery time which related to the traffic.

Criterion no. 4: Distance from agricultural land: Agriculture lands occupy 5% of Bahrain land as per Bahrain land use map for year 2030. These lands vary in distance relative to the proposed landfills. Back to the literature, a buffer zone up to one kilometer

away from agriculture lands is usually considered in landfill selections.

Criterion no. 7: Sensitive sites: There are several areas, projects or development buildings sectors considered as sensitive sites around the landfill alternatives' zone, such as proposed Bahrain-Qatar causeway, existing gas well, industrial sites, etc. These sites must be considered in evaluation of the landfill alternatives, however, each of these sites requires to be considered separately. From this point, sensitive sites included:

- Proposed Bahrain-Qatar causeway
- Industrial sites
- Bahrain International Circuit

Existing gas wells are classified as one of the industrial sites, therefore it will not be considered separately.

Criterion no. 12: Distance from residential areas: Residential areas are equal to 35% of Bahrain land. This criterion is one of the major criteria that being considered in most if not all decision making for a landfill selection.

Criterion no. 13: Built up: There is no clear definition for built up, some literatures refer it to the new development, and others refer it to the infrastructure. Based on these definitions, the built up in the Bahrain land use map for year 2030 is the Preserved Area. It is near to the landfill alternatives' zone, and it is defined as the areas provided for developments with special regulation. Therefore, this criterion is renamed as "Preserved Area".

Criterion no. 18: Nearby airports: Bahrain International Airport (BIA) at Muharraq is the main and only civil airport. The others are military airports; Shaikh Isa Air Base, Sakhir Air Base, and Riffa Air Base. These military airports are near to the proposed landfill zone, while BIA is too far. Therefore, this criterion is considered as Military Airports.

Criterion no. 20: Industrial sites: As mentioned above in criterion no. 7, industrial sites can be categorized as sensitive sites. Thus, it is being taken into account for the decision making.

In order to make the study more reliable for the Kingdom of Bahrain, discussions were held with some experts to identify other criteria specific for Bahrain which may have impact to the landfill site selection. As a result, two more criteria have been suggested:

Specific criterion no. 1: Existing Bapco Oil Field and Oil Pipeline: This specific criterion is highly related to the proposed lands, where Bapco Oil Field is close to the selected landfill alternatives, and Oil pipeline is routing next to these lands. Both are related with various impacts. Thus, they will be divided into two criteria:

- Existing Bapco Oil Field
- Distance to the Oil Pipeline

Specific criterion no. 2: Military Airbase and Campus. This criterion again is specific for Bahrain, and is related to the proposed lands as Military Airbase and Campus are close to the selected landfill alternatives. However, in criterion no. 18 (Airports) military airports have been considered, thus, it is suggested to add the Military Campus to that criterion.

To summarize the above analysis and discussions of selecting the adequate criteria for this study, Table 4.3 shows the selected criteria that will be considered for decision making on the best landfill site.

Table (4.3)

Selected Criteria

No.	Criteria
1	Average path taken (Road network)
2	Distance from residential areas
3	Distance from agricultural land
4	Industrial areas
5	Existing Bapco Oil Field
6	Distance to the Oil Pipeline
7	Preserved areas
8	Bahrain International Circuit
9	Proposed Bahrain -Qatar Causeway
10	Military Airports
11	Military Camps

4.4 Data Collection

The previous sections of this chapter have identified the main two fundamentals to construct the decision making process for this study.

These fundamentals are the alternative sites, and the criteria for studying the problem. On that basis, data need to be collected to find out the suitable solution and making decision.

The main data required are distances from the proposed landfill sites (alternatives) to the defined areas, which considered as the main criteria. Google maps were used to collect data for criterion no. 1: Average path taken (road network), whereas, Google earth was used for finding distances of the rest criteria.

4.4.1 Average path taken (Road network)

To find the average path taken to the proposed landfill, five Bahraini governorates were put under study. Routes from each of these governorates to the landfill alternatives were identified using Google maps. Figure 4.3 shows the routes connecting Manama to the alternative sites (2) as taken from Google maps.

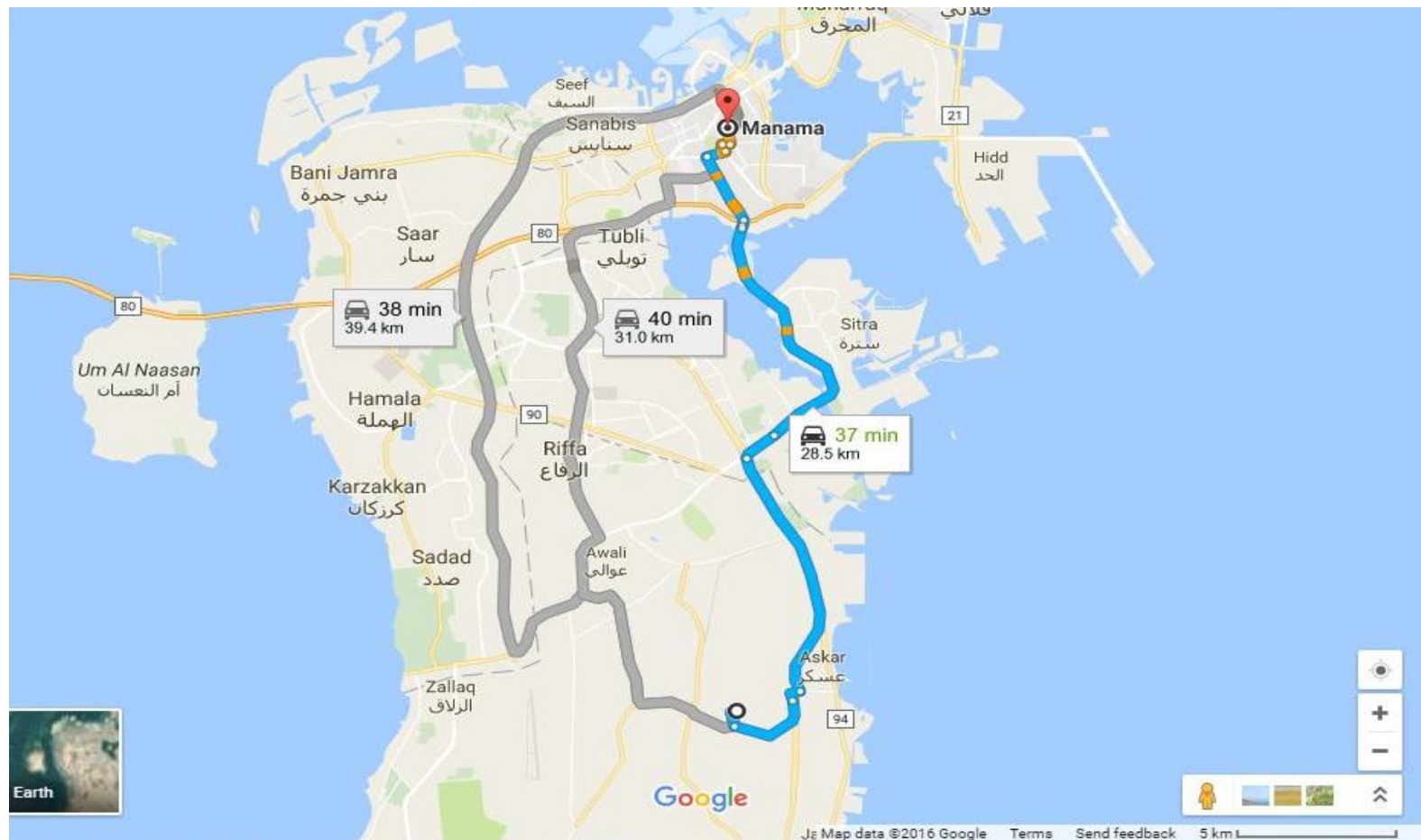


Figure (4.3)

Sample of Routes Connecting Manama to the Alternative Site 2 (Taken from Google Maps)

Data collected for the different routes are shown in Table 4.4. It illustrates distances on the road networks from Bahraini governorates to the landfill sites alternatives.

Table (4.4)
Distances of the Road Networks in (km)

Governorate	Route no.	Distance (km) to landfill				
		1	2	3	4	5
Muharraq	1	37.6	37.5	37.3	38.8	41.9
	2	48.6	40	39.7	41.2	48.1
	3	40	48.6	50.6	52.1	53.5
Manama	1	28.5	28.5	28.2	29.7	43.6
	2	39.4	39.4	41.4	42.9	32.8
	3	31	31	31.6	33.1	39.1
Northern	1	21.8	21.8	26.9	25.3	26
	2	24.8	24.8	23.8	28.3	29
	3	25.5	25.5	25.2	26.7	
Central	1	20.4	17.4	17.1	18.6	21.7
	2	20.8	17.6	21.6	23	27.9
	3		19.5			21.8
Southern	1	17	17	16.6	18.1	7
	2	15.4	15.4	17.5	18.9	
	3					

From Table 4.4, road networks for each governorate to any landfill alternative have maximum of three routes and minimum of one route. It

has been suggested to take the average path to generalize the data for this criterion in order to have single data point connecting a governorate and a landfill alternative.

Table (4.5)

Road Network Average Distance for Bahraini Governorates (d_{ij})

$i \backslash j$	Muharraq Gov. (km)	Manama Gov. (km)	Northern Gov. (km)	Central Gov. (km)	Southern Gov. (km)
Landfill (1)	42.1	33.0	24.0	20.6	16.2
Landfill (2)	42.0	33.0	24.0	18.2	16.2
Landfill (3)	42.5	33.7	25.3	19.4	17.1
Landfill (4)	44.0	35.2	26.8	20.8	18.5
Landfill (5)	47.8	38.5	27.5	23.8	7.0
Population	188,597	296,427	273,105	314,719	100,388
Avg. Weight (Population)	0.161	0.253	0.233	0.268	0.086

Table 4.5 estimates the average path taken from each governorate to the five proposed landfills. And to generalize further the distances for criteria no. 1, population for each governorate based on Census 2011 has been used to normalize that criterion. Average path taken to a specific landfill i is (d_i), and it is given by:

$$d_i = \sum_j w_j \times d_{ij} ; \quad i = 1, 2, \dots, 5 \quad (4.1)$$

w_j is the population average weight of governorate j ; d_{ij} is the average distance from governorate j to landfill i ; j is one of the five governorates; and i is one of the five landfills.

Following is sample of calculation:

Total Population for Kingdom of Bahrain (2011) = 1,173,236

Population average weight for Muharraq Governorate = $(188,597 / 1,173,236) = 0.161$

Average path taken to Landfill (1) (d_1) = $(0.161 \times 42.1) + (0.253 \times 33) + (0.233 \times 24) + (0.268 \times 20.6) + (0.086 \times 16.2) = 27.60$ km

The final results for the average path taken for each landfill alternative are shown in Table 4.6.

Table (4.6)

Average Path Taken for All Governorate for Each Alternative (d_i)

i	Average path taken (Road network) in km (d_j)
Landfill (1)	27.60
Landfill (2)	26.94
Landfill (3)	27.90
Landfill (4)	29.37
Landfill (5)	30.80

4.4.2 Distances for other criteria

Distances for the rest criteria have been determined using Google Earth. A sample of the data collected using Google earth is illustrated in Figure 4.4, for distance from landfill (3) to Bahrain International Circuit.

All distances being determined by Google earth in addition to those determined by Google maps for the different criteria are combined in one table (Table 4.7).

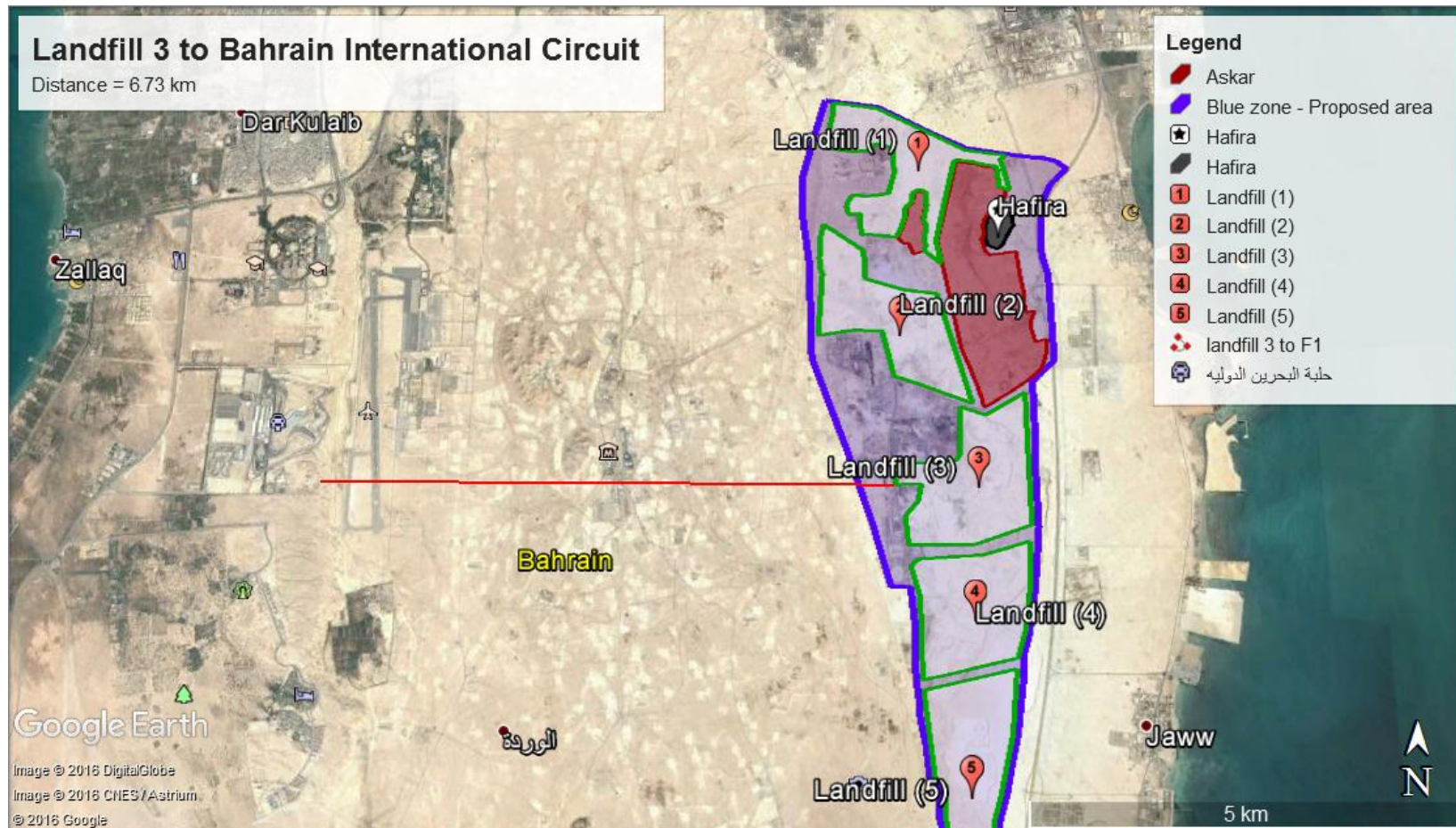


Figure (4.4)

The Distance from Landfill (3) to Bahrain International Circuit (Google Earth Map)

Table (4.7)

Distances Between Landfills and Criteria (km)

Alternative Site Criterion	Average path taken for all governorate	Distance from:									
		Residential areas	Agricultural land	Industrial areas	Existing Bapco Oil Field	Oil Pipeline	Preserved areas	Bahrain International Circuit	Proposed Bahrain - Qatar Causeway	Military Airports	Military Campus
Landfill (1)	27.60	0.51	7.6	0.16	9.29	0.03	5.01	6.5	5.69	4.57	2.59
Landfill (2)	26.94	1.46	7.68	1.8	7.95	0.12	3.36	6.1	7	4.2	2.41
Landfill (3)	27.90	0.89	9.14	3.12	6.93	0.95	1.47	6.73	6.65	5.11	3.52
Landfill (4)	29.37	0.7	8.19	3.42	6.28	1.08	0.24	7	7.85	5.33	3.83
Landfill (5)	30.80	0.43	7.99	4.13	4.73	2.68	0.14	7.48	9.08	3.05	4.45

Chapter 5 - Fuzzy Set Approach

5.1 Fuzzy Set Theory

5.1.1 Step 1: Constructing fuzzy judgment matrix

5.1.2 Step 2: Deriving priorities from fuzzy comparisons

5.1.3 Step 3: Calculating α -cut

5.1.4 Step 4: Estimating degree of optimism

5.2 Modeling Using Fuzzy Set

5.3 Fuzzy Set Results

Chapter 5: Fuzzy Set Approach

5.1 Fuzzy Set Theory

Fuzzy Set Theory (FST) or what called in other literatures as Fuzzy Multi-criteria Hierarchy Process (FMHP) considers the fuzziness of the factors affecting site selection problem. It is mainly based on defining the alternatives and criteria for such selection problem.

In line with literatures and specifically the article presented by Ghoseiri and Lessan (2014) on their study of landfill selection in Iran. The fuzzy set analysis was used, and it was extensively helpful and well judged on the alternatives under their study.

Fuzzy set theory was developed by Zadeh and Klaua (1965), (wikipedia). Their approach was the classical theory of the fuzzy set theory that was refined by others later on to be used in different areas of studies and researches such as linguistics, clustering, and decision making. There are various uses of fuzzy set theory which have classified into two main kinds. The classical fuzzy set theory does a gradual assessment of the items under study. This is a kind of valuing these items with binary unit of interval $[0, 1]$. Fuzzy set then had been generalized as the membership function with two values only 0 or 1. The classical fuzzy set can be used in special cases where there is lack of information whether it's incomplete or imprecise.

The other fuzzy set, the most recent one, is not relying on the binary assessment. It usually prefers widely gradual assessment (Zadeh, 1965), it can be used with scale of measurement ranging from 1 to 9 or less scale ranging from 1 to 5. Referring to this measure, fuzzy set will introduce lower and upper limit for each value. In this case each value or

membership function will consist of three sets; lower limit, medium, and upper limit. Otherwise, it is similar to the classical approach.

The new fuzzy set has extensively been used for decision making, and it has provided excellent results on complex decision making studies. From above, it is clearly that fuzzy set will give a comprehensive and precise decision. Therefore, it is also recommended to be applied in this study.

At the beginning, it is required to formulate the alternatives versus criteria matrix. The first matrix is rating the criteria for each alternative site. After that, the rating matrix is converted to the judgment matrix based on Saaty's scale. Saaty's scale is usually used for rating of various types of comparison. It ranges from 1 to 9, where 1 belongs to equally important and 9 is extremely important. Table 5.1 shows the ranges of Saaty's scale.

Table (5.1)

Saaty's Scale

Scale of importance	Saaty's scale
Equally important	1
Little important	3
Obviously important	5
Intensively important	7
Extremely important	9
~ among them	2, 4, 6, and 8

The main process of FMHP consists of four steps. These steps are explained in the following sub-sections.

5.1.1 Step 1: Constructing fuzzy judgment matrix

The FMHP process begins with construction of the fuzzy judgment matrix which denotes the relative importance of each alternative compared with the criteria with respect to the main goal. It is often constructed by measures presented by Saaty as shown in Table 5.1. These measures then are converted to the fuzzy triangular numbers as defined in Table 5.2 and Figure 5.1.

Table (5.2)

The Fuzzy Triangular Numbers

Saaty's measure	Lower (L)	Medium (M)	Upper (U)
Exact number 1	1	1	1
Approximate 1	1	1	2
$X = \{2 \text{ to } 8\}$	$X-1$	X	$X+1$
Approximate 9	8	9	9
$1/X$	$1/(X+1)$	$1/X$	$1/(X-1)$
$1/(9)$	0.11	0.11	0.13

For Saaty's measure at the diagonal of the matrix, is exactly number 1, the fuzzy triangular number becomes (1, 1, 1). In the other matrix cells (i.e. not in the diagonal), if Saaty's measure is 1, Approximate 1, and then the fuzzy triangular number becomes (1, 1, 2). Saaty's measures from 2 to 8 and their inverse, the fuzzy triangular number follow the equations in Table 5.2 for $X = \{2 \text{ to } 8\}$ and $1/X$. For the highest Saaty's measure (i.e. Approximate number 9), the fuzzy triangular number limit will not exceed the highest measure, therefore it becomes as (8, 9, 9). The same will follow for its inverse as the upper limit equals to (1/9, 1/9, 1/8).

As shown in Figure 5.1, the triangular number presented by (L, M, U), where its membership function is defined as follows;

$$\begin{aligned}\mu(x) &= (x - L) / (M - L), & L \leq x \leq M & \quad \text{or} \\ &= (U - x) / (U - M), & M \leq x \leq U & \quad \text{or} \\ &= 0 & \text{otherwise} & \quad (5.1)\end{aligned}$$

With $-\infty < L \leq M \leq U < \infty$

The strongest grade membership is parameter M for medium, while U for upper and L for lower bounds.

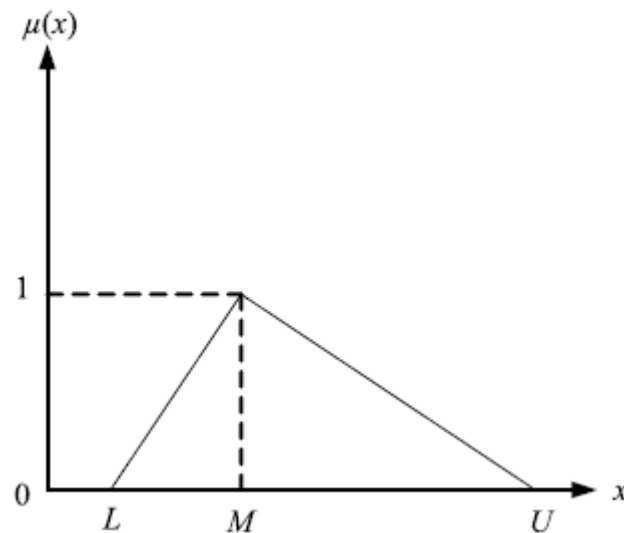


Figure (5.1)

Membership Function of a Triangular Fuzzy Number

Thus, the measures in the fuzzy matrix are represented by fuzzy numbers as follows (Ghoseiri and Lessan, 2014):

$$X_{ij} = (L_{ij}, M_{ij}, U_{ij}) \quad (5.2)$$

$$X_{ji} = (1/U_{ij}, 1/M_{ij}, 1/L_{ij}), \text{ for } i, j = 1, 2, \dots, n \text{ and } (i \neq j) \quad (5.3)$$

Where n is the number of criteria.

5.1.2 Step 2: Deriving priorities from fuzzy comparisons

To calculate a priority vector for the triangular fuzzy comparison matrix, a normalization formula is used as follows (Ghoseiri and Lessan, 2014):

$$\tilde{X}_{ij} = (\text{Lower bound}, \text{Medium bound}, \text{Upper bound})$$

$$\tilde{X}_{ij} = \left(\frac{\sum_{j=1}^n \sum_{i=1}^m L_{ij}}{\sum_{j=1}^n (\sum_{i=1}^m L_{ij} + \sum_{j=1}^n U_{ij})}, \frac{\sum_{j=1}^n \sum_{i=1}^m M_{ij}}{\sum_{j=1}^n (\sum_{i=1}^m M_{ij} + \sum_{j=1}^n M_{ij})}, \frac{\sum_{j=1}^n \sum_{i=1}^m U_{ij}}{\sum_{j=1}^n (\sum_{i=1}^m U_{ij} + \sum_{j=1}^n L_{ij})} \right)$$

$$\text{Where m is the number of alternatives} \quad (5.4)$$

By using the above equation, the fuzzy weights and priorities judgment matrix for criteria and alternatives $\tilde{X}$ is obtained.

5.1.3 Step 3: Calculating α -cut

α -cut is an important concept of fuzzy set. It is based on the confidence level of decision maker, where:

$$\alpha \in [0, 1]$$

By defining α -cut the initial fuzzy triangular number (L, M, U) is converted to fuzzy number with two bounds (X^L , X^U). The fuzzy number will become:

$$X^L = L + (M - L)\alpha \quad (5.5)$$

$$X^U = U - (U - M)\alpha \quad (5.6)$$

Note that a larger α value indicates a more confident decision maker.

5.1.4 Step 4: Estimating degree of optimism

Last step is to estimate degree of optimism λ , where:

$$\lambda \in [0, 1]$$

That will lead to get the real decision making matrix for the criteria and alternative, by combining steps 3 and 4, the final weight can be expressed as:

$$X = \lambda X^U + (1 - \lambda) X^L \quad (5.7)$$

In practical applications, $\lambda=0$, $\lambda=0.5$ and $\lambda=1$ are used to indicate decision maker has a pessimistic, moderate or optimistic view, respectively.

5.2 Modeling Using Fuzzy Set

FMHP modeling requires at beginning to define the alternatives and criteria for the selection problem, this step has already been done in Chapter 4. However, to formulate the problem it's required to create the comparison matrix for the sites' alternatives and criteria. Table 5.3 shows the criteria ratios for each landfill, which are obtained by dividing the distances collected in Table 4.7 using the following equation;

$$X_{ij}^R = DC_i / DC_j \quad (5.8)$$

An example for such calculation of X_{12}^R for landfill (1) using the values of C_1 and C_2 from Table 4.7 is:

$$X_{12, \text{landfill 1}}^R = 27.06 / 0.51 = 54.11$$

Table (5.3)

Criteria Ratios Matrix ($X^{R_{ij}}$)

Sites	Criteria	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁
Landfill (1)	C ₁	1	54.11	3.63	172.49	2.97	919.93	5.51	4.25	4.85	6.04	10.66
	C ₂	0.02	1	0.07	3.19	0.05	17.00	0.10	0.08	0.09	0.11	0.20
	C ₃	0.28	14.90	1	47.50	0.82	253.33	1.52	1.17	1.34	1.66	2.93
	C ₄	0.01	0.31	0.02	1	0.02	5.33	0.03	0.02	0.03	0.04	0.06
	C ₅	0.34	18.22	1.22	58.06	1	309.67	1.85	1.43	1.63	2.03	3.59
	C ₆	0.00	0.06	0.00	0.19	0.00	1	0.01	0.00	0.01	0.01	0.01
	C ₇	0.18	9.82	0.66	31.31	0.54	167.00	1	0.77	0.88	1.10	1.93
	C ₈	0.24	12.75	0.86	40.63	0.70	216.67	1.30	1	1.14	1.42	2.51
	C ₉	0.21	11.16	0.75	35.56	0.61	189.67	1.14	0.88	1	1.25	2.20
	C ₁₀	0.17	8.96	0.60	28.56	0.49	152.33	0.91	0.70	0.80	1	1.76
	C ₁₁	0.09	5.08	0.34	16.19	0.28	86.33	0.52	0.40	0.46	0.57	1
Landfill (2)	C ₁	1	18.45	3.51	14.97	3.39	224.50	8.02	4.42	3.85	6.41	11.18
	C ₂	0.05	1	0.19	0.81	0.18	12.17	0.43	0.24	0.21	0.35	0.61

Table (5.3) Continue

	C₃	0.29	5.26	1	4.27	0.97	64.00	2.29	1.26	1.10	1.83	3.19
	C₄	0.07	1.23	0.23	1	0.23	15.00	0.54	0.30	0.26	0.43	0.75
	C₅	0.30	5.45	1.04	4.42	1	66.25	2.37	1.30	1.14	1.89	3.30
	C₆	0.00	0.08	0.02	0.07	0.02	1	0.04	0.02	0.02	0.03	0.05
	C₇	0.12	2.30	0.44	1.87	0.42	28.00	1	0.55	0.48	0.80	1.39
	C₈	0.23	4.18	0.79	3.39	0.77	50.83	1.82	1	0.87	1.45	2.53
	C₉	0.26	4.79	0.91	3.89	0.88	58.33	2.08	1.15	1	1.67	2.90
	C₁₀	0.16	2.88	0.55	2.33	0.53	35.00	1.25	0.69	0.60	1	1.74
	C₁₁	0.09	1.65	0.31	1.34	0.30	20.08	0.72	0.40	0.34	0.57	1
Landfill (3)	C₁	1	31.35	3.05	8.94	4.03	29.37	18.98	4.15	4.20	5.46	7.93
	C₂	0.03	1	0.10	0.29	0.13	0.94	0.61	0.13	0.13	0.17	0.25
	C₃	0.33	10.27	1	2.93	1.32	9.62	6.22	1.36	1.37	1.79	2.60
	C₄	0.11	3.51	0.34	1	0.45	3.28	2.12	0.46	0.47	0.61	0.89
	C₅	0.25	7.79	0.76	2.22	1	7.29	4.71	1.03	1.04	1.36	1.97
	C₆	0.03	1.07	0.10	0.30	0.14	1	0.65	0.14	0.14	0.19	0.27
	C₇	0.05	1.65	0.16	0.47	0.21	1.55	1	0.22	0.22	0.29	0.42

Table (5.3) Continue

	C₈	0.24	7.56	0.74	2.16	0.97	7.08	4.58	1	1.01	1.32	1.91
	C₉	0.24	7.47	0.73	2.13	0.96	7.00	4.52	0.99	1	1.30	1.89
	C₁₀	0.18	5.74	0.56	1.64	0.74	5.38	3.48	0.76	0.77	1	1.45
	C₁₁	0.13	3.96	0.39	1.13	0.51	3.71	2.39	0.52	0.53	0.69	1
Landfill (4)	C₁	1	41.96	3.59	8.59	4.68	27.20	122.39	4.20	3.74	5.51	7.67
	C₂	0.02	1	0.09	0.20	0.11	0.65	2.92	0.10	0.09	0.13	0.18
	C₃	0.28	11.70	1	2.39	1.30	7.58	34.13	1.17	1.04	1.54	2.14
	C₄	0.12	4.89	0.42	1	0.54	3.17	14.25	0.49	0.44	0.64	0.89
	C₅	0.21	8.97	0.77	1.84	1	5.81	26.17	0.90	0.80	1.18	1.64
	C₆	0.04	1.54	0.13	0.32	0.17	1	4.50	0.15	0.14	0.20	0.28
	C₇	0.01	0.34	0.03	0.07	0.04	0.22	1	0.03	0.03	0.05	0.06
	C₈	0.24	10.00	0.85	2.05	1.11	6.48	29.17	1	0.89	1.31	1.83
	C₉	0.27	11.21	0.96	2.30	1.25	7.27	32.71	1.12	1	1.47	2.05
	C₁₀	0.18	7.61	0.65	1.56	0.85	4.94	22.21	0.76	0.68	1	1.39
	C₁₁	0.13	5.47	0.47	1.12	0.61	3.55	15.96	0.55	0.49	0.72	1
Landfill	C₁	1	71.63	3.85	7.46	6.51	11.49	220.01	4.12	3.39	10.10	6.92

Table (5.3) Continue

(5)	C₂	0.01	1	0.05	0.10	0.09	0.16	3.07	0.06	0.05	0.14	0.10
	C₃	0.26	18.58	1	1.93	1.69	2.98	57.07	1.07	0.88	2.62	1.80
	C₄	0.13	9.60	0.52	1	0.87	1.54	29.50	0.55	0.45	1.35	0.93
	C₅	0.15	11.00	0.59	1.15	1	1.76	33.79	0.63	0.52	1.55	1.06
	C₆	0.09	6.23	0.34	0.65	0.57	1	19.14	0.36	0.30	0.88	0.60
	C₇	0.00	0.33	0.02	0.03	0.03	0.05	1	0.02	0.02	0.05	0.03
	C₈	0.24	17.40	0.94	1.81	1.58	2.79	53.43	1	0.82	2.45	1.68
	C₉	0.29	21.12	1.14	2.20	1.92	3.39	64.86	1.21	1	2.98	2.04
	C₁₀	0.10	7.09	0.38	0.74	0.64	1.14	21.79	0.41	0.34	1	0.69
	C₁₁	0.14	10.35	0.56	1.08	0.94	1.66	31.79	0.59	0.49	1.46	1

After finding the criteria ratios for each landfill, a judgment matrix is created based on Saaty's scale. Table 5.4 shows Saaty's scale measures and their inverse measures. These measures are used to evaluate the ratios in Table 5.3 by taking the round value of the ratio and wherever the values above 9 is taken as 9, and any values less than 0.11 is taken as 0.11, taking into consideration that any cell and its inverse (i.e. X_{12}^R and X_{21}^R) should have the original scale on one of them and its inverse on the other.

Table (5.4)

Saaty's Scale and Inverses Measures

Scale of importance	Saaty's scale	Inverse of Saaty's scale
Equally important	1	1.00
	2	0.50
Little important	3	0.33
	4	0.25
Obviously important	5	0.20
	6	0.17
Intensively important	7	0.14
	8	0.13
Extremely importance	9	0.11

The criteria ratios' (X_{ij}^R) matrix of (Table 5.3) is converted into criteria judgment (X_{ij}^j) matrix as represented in Table 5.5 based on Saaty's judgment scale of Table 5.4.

Table (5.5)

Criteria Judgment Matrix Based on Saaty's Scale (X_{ij}^j)

Sites	Criteria	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁
Landfill (1)	C ₁	1	9	4	9	3	9	6	4	5	6	9
	C ₂	0.11	1	0.11	3	0.11	9	0.11	0.11	0.11	0.11	0.2
	C ₃	0.25	9	1	9	1	9	2	1	1	2	3
	C ₄	0.11	0.33	0.11	1	0.11	5	0.11	0.11	0.11	0.11	0.11
	C ₅	0.33	9	1	9	1	9	2	1	2	2	4
	C ₆	0.11	0.11	0.11	0.2	0.11	1	0.11	0.11	0.11	0.11	0.11
	C ₇	0.17	9	0.5	9	0.5	9	1	1	1	1	2
	C ₈	0.25	9	1	9	1	9	1	1	1	1	3
	C ₉	0.2	9	1	9	0.5	9	1	1	1	1	2
	C ₁₀	0.17	9	0.5	9	0.5	9	1	1	1	1	2
	C ₁₁	0.11	5	0.33	9	0.25	9	0.5	0.33	0.5	0.5	1
Landfill (2)	C ₁	1	9	4	9	3	9	8	4	4	6	9
	C ₂	0.11	1	0.2	1	0.2	9	0.5	0.25	0.2	0.33	0.5

Table (5.5) Continue

	C₃	0.25	5	1	4	1	9	2	1	1	2	3
	C₄	0.11	1	0.25	1	0.25	9	0.5	0.33	0.25	0.5	1
	C₅	0.33	5	1	4	1	9	2	1	1	2	3
	C₆	0.11	0.11	0.11	0.11	0.11	1	0.11	0.11	0.11	0.11	0.11
	C₇	0.13	2	0.5	2	0.5	9	1	0.5	0.5	1	1
	C₈	0.25	4	1	3	1	9	2	1	1	1	3
	C₉	0.25	5	1	4	1	9	2	1	1	2	3
	C₁₀	0.17	3	0.5	2	0.5	9	1	1	0.5	1	2
	C₁₁	0.11	2	0.33	1	0.33	9	1	0.33	0.33	0.5	1
Landfill (3)	C₁	1	9	3	9	4	9	9	4	4	5	8
	C₂	0.11	1	0.11	0.25	0.13	1	0.5	0.13	0.14	0.17	0.25
	C₃	0.33	9	1	3	1	9	6	1	1	2	3
	C₄	0.11	4	0.33	1	0.5	3	2	0.5	0.5	0.5	1
	C₅	0.25	8	1	2	1	7	5	1	1	1	2
	C₆	0.11	1	0.11	0.33	0.14	1	0.5	0.14	0.14	0.2	0.25
	C₇	0.11	2	0.17	0.5	0.2	2	1	0.2	0.2	0.33	0.5

Table (5.5) Continue

	C₈	0.25	8	1	2	1	7	5	1	1	1	2
	C₉	0.25	7	1	2	1	7	5	1	1	1	2
	C₁₀	0.2	6	0.5	2	1	5	3	1	1	1	1
	C₁₁	0.13	4	0.33	1	0.5	4	2	0.5	0.5	1	1
Landfill (4)	C₁	1	9	4	9	5	9	9	4	4	6	8
	C₂	0.11	1	0.11	0.2	0.11	0.5	3	0.11	0.11	0.13	0.2
	C₃	0.25	9	1	2	1	8	9	1	1	2	2
	C₄	0.11	5	0.5	1	0.5	3	9	0.5	0.5	0.5	1
	C₅	0.2	9	1	2	1	6	9	1	1	1	2
	C₆	0.11	2	0.13	0.33	0.17	1	5	0.17	0.14	0.2	0.25
	C₇	0.11	0.33	0.11	0.11	0.11	0.2	1	0.11	0.11	0.11	0.11
	C₈	0.25	9	1	2	1	6	9	1	1	1	2
	C₉	0.25	9	1	2	1	7	9	1	1	1	2
	C₁₀	0.17	8	0.5	2	1	5	9	1	1	1	1
	C₁₁	0.13	5	0.5	1	0.5	4	9	0.5	0.5	1	1
Landfill	C₁	1	9	4	7	7	9	9	4	3	9	7

Table (5.5) Continue

(5)	C₂	0.11	1	0.11	0.11	0.11	0.17	3	0.11	0.11	0.14	0.11
	C₃	0.25	9	1	2	2	3	9	1	1	3	2
	C₄	0.14	9	0.5	1	1	2	9	0.5	0.5	1	1
	C₅	0.14	9	0.5	1	1	2	9	0.5	0.5	2	1
	C₆	0.11	6	0.33	0.5	0.5	1	9	0.33	0.33	1	0.5
	C₇	0.11	0.33	0.11	0.11	0.11	0.11	1	0.11	0.11	0.11	0.11
	C₈	0.25	9	1	2	2	3	9	1	1	2	2
	C₉	0.33	9	1	2	2	3	9	1	1	3	2
	C₁₀	0.11	7	0.33	1	0.5	1	9	0.5	0.33	1	1
	C₁₁	0.14	9	0.5	1	1	2	9	0.5	0.5	1	1

After creating the criteria judgment matrix based on Saaty's scale, the FMHP starts by constructing the fuzzy judgment matrix using triangular fuzzy numbers (L, M, U) defined by Equation (5.2) in Section 5.1.1 and Table 5.2. Thus, for example the fuzzy numbers for criteria 1 and 3 of landfill (1) are given by:

$$\begin{aligned} X_{13, \text{Landfill 1}}^f &= (4-1, 4, 4+1) \\ &= (3, 4, 5) \end{aligned}$$

Where number 4 represents the medium.

The fuzzy judgment matrix for the alternative sites with respect to each criterion is shown in Table 5.6.

Table (5.6)

Fuzzy Judgment Matrix for Alternative Sites With Respect to Each Criterion (X_{ij}^f, κ)

Sites	Criteria	C ₁			C ₂			C ₃			C ₄			C ₅			C ₆			C ₇			C ₈			C ₉			C ₁₀			C ₁₁		
		L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Landfill (1)	C ₁	1	1	1	8	9	9	3	4	5	8	9	9	2	3	4	8	9	9	5	6	7	3	4	5	4	5	6	5	6	7	8	9	9
	C ₂	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	2	3	4	0.11	0.11	0.13	8	9	9	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.17	0.2	0.25
	C ₃	0.2	0.25	0.33	8	9	9	1	1	1	8	9	9	1	1	2	8	9	9	1	2	3	1	1	2	1	1	2	1	2	3	2	3	4
	C ₄	0.11	0.11	0.13	0.25	0.33	0.5	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	4	5	6	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13
	C ₅	0.25	0.33	0.5	8	9	9	1	1	2	8	9	9	1	1	1	8	9	9	1	2	3	1	1	2	1	2	3	1	2	3	3	4	5
	C ₆	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.17	0.2	0.25	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13
	C ₇	0.14	0.17	0.2	8	9	9	0.33	0.5	1	8	9	9	0.33	0.5	1	8	9	9	1	1	1	1	1	2	1	1	2	1	1	2	1	2	3
	C ₈	0.2	0.25	0.33	8	9	9	1	1	2	8	9	9	1	1	2	8	9	9	1	1	2	1	1	1	1	1	2	1	1	2	2	3	4
	C ₉	0.17	0.2	0.25	8	9	9	1	1	2	8	9	9	0.33	0.5	1	8	9	9	1	1	2	1	1	2	1	1	1	1	1	2	1	2	3
	C ₁₀	0.14	0.17	0.2	8	9	9	0.33	0.5	1	8	9	9	0.33	0.5	1	8	9	9	1	1	2	1	1	2	1	1	2	1	1	1	1	2	3
	C ₁₁	0.11	0.11	0.13	4	5	6	0.25	0.33	0.5	8	9	9	0.2	0.25	0.33	8	9	9	0.33	0.5	1	0.25	0.33	0.5	0.33	0.5	1	0.33	0.5	1	1	1	1
Landfill (2)	C ₁	1	1	1	8	9	9	3	4	5	8	9	9	2	3	4	8	9	9	7	8	9	3	4	5	3	4	5	5	6	7	8	9	9
	C ₂	0.11	0.11	0.13	1	1	1	0.17	0.2	0.25	1	1	2	0.17	0.2	0.25	8	9	9	0.33	0.5	1	0.2	0.25	0.33	0.17	0.2	0.25	0.25	0.33	0.5	0.33	0.5	1
	C ₃	0.2	0.25	0.33	4	5	6	1	1	1	3	4	5	1	1	2	8	9	9	1	2	3	1	1	2	1	1	2	1	2	3	2	3	4
	C ₄	0.11	0.11	0.13	1	1	2	0.2	0.25	0.33	1	1	1	0.2	0.25	0.33	8	9	9	0.33	0.5	1	0.25	0.33	0.5	0.2	0.25	0.33	0.33	0.5	1	1	1	2
	C ₅	0.25	0.33	0.5	4	5	6	1	1	2	3	4	5	1	1	1	8	9	9	1	2	3	1	1	2	1	1	2	1	2	3	2	3	4
	C ₆	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13
	C ₇	0.11	0.13	0.14	1	2	3	0.33	0.5	1	1	2	3	0.33	0.5	1	8	9	9	1	1	1	0.33	0.5	1	0.33	0.5	1	1	1	2	1	1	2
	C ₈	0.2	0.25	0.33	3	4	5	1	1	2	2	3	4	1	1	2	8	9	9	1	2	3	1	1	1	1	1	2	1	1	2	2	3	4
	C ₉	0.2	0.25	0.33	4	5	6	1	1	2	3	4	5	1	1	2	8	9	9	1	2	3	1	1	2	1	1	1	1	2	3	2	3	4
	C ₁₀	0.14	0.17	0.2	2	3	4	0.33	0.5	1	1	2	3	0.33	0.5	1	8	9	9	1	1	2	1	1	2	0.33	0.5	1	1	1	1	1	2	3
	C ₁₁	0.11	0.11	0.13	1	2	3	0.25	0.33	0.5	1	1	2	0.25	0.33	0.5	8	9	9	1	1	2	0.25	0.33	0.5	0.25	0.33	0.5	0.33	0.5	1	1	1	1
Landfill (3)	C ₁	1	1	1	8	9	9	2	3	4	8	9	9	3	4	5	8	9	9	8	9	9	3	4	5	3	4	5	4	5	6	7	8	9
	C ₂	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	0.2	0.25	0.33	0.11	0.13	0.14	1	1	2	0.33	0.5	1	0.11	0.13	0.14	0.13	0.14	0.17	0.14	0.17	0.2	0.2	0.25	0.33
	C ₃	0.25	0.33	0.5	8	9	9	1	1	1	2	3	4	1	1	2	8	9	9	5	6	7	1	1	2	1	1	2	1	2	3	2	3	4
	C ₄	0.11	0.11	0.13	3	4	5	0.25	0.33	0.5	1	1	1	0.33	0.5	1	2	3	4	1	2	3	0.33	0.5	1	0.33	0.5	1	0.33	0.5	1	1	1	2
	C ₅	0.2	0.25	0.33	7	8	9	1	1	2	1	2	3	1	1	1	6	7	8	4	5	6	1	1	2	1	1	2	1	1	2	1	2	3
	C ₆	0.11	0.11	0.13	1	1	2	0.11	0.11	0.13	0.25	0.33	0.5	0.13	0.14	0.17	1	1	1	0.33	0.5	1	0.13	0.14	0.17	0.13	0.14	0.17	0.17	0.2	0.25	0.2	0.25	0.33

Table (5.6) Continue

	C ₇	0.11	0.11	0.13	1	2	3	0.14	0.17	0.2	0.33	0.5	1	0.17	0.2	0.25	1	2	3	1	1	1	0.17	0.2	0.25	0.17	0.2	0.25	0.25	0.33	0.5	0.33	0.5	1
	C ₈	0.2	0.25	0.33	7	8	9	1	1	2	1	2	3	1	1	2	6	7	8	4	5	6	1	1	1	1	1	2	1	1	2	1	2	3
	C ₉	0.2	0.25	0.33	6	7	8	1	1	2	1	2	3	1	1	2	6	7	8	4	5	6	1	1	2	1	1	1	1	1	2	1	2	3
	C ₁₀	0.17	0.2	0.25	5	6	7	0.33	0.5	1	1	2	3	1	1	2	4	5	6	2	3	4	1	1	2	1	1	2	1	1	1	1	1	2
	C ₁₁	0.11	0.13	0.14	3	4	5	0.25	0.33	0.5	1	1	2	0.33	0.5	1	3	4	5	1	2	3	0.33	0.5	1	0.33	0.5	1	1	1	2	1	1	1
Landfill (4)	C ₁	1	1	1	8	9	9	3	4	5	8	9	9	4	5	6	8	9	9	8	9	9	3	4	5	3	4	5	5	6	7	7	8	9
	C ₂	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	0.17	0.2	0.25	0.11	0.11	0.13	0.33	0.5	1	2	3	4	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.13	0.14	0.17	0.2	0.25
	C ₃	0.2	0.25	0.33	8	9	9	1	1	1	1	2	3	1	1	2	7	8	9	8	9	9	1	1	2	1	1	2	1	2	3	1	2	3
	C ₄	0.11	0.11	0.13	4	5	6	0.33	0.5	1	1	1	1	0.33	0.5	1	2	3	4	8	9	9	0.33	0.5	1	0.33	0.5	1	0.33	0.5	1	1	1	2
	C ₅	0.17	0.2	0.25	8	9	9	1	1	2	1	2	3	1	1	1	5	6	7	8	9	9	1	1	2	1	1	2	1	1	2	1	2	3
	C ₆	0.11	0.11	0.13	1	2	3	0.11	0.13	0.14	0.25	0.33	0.5	0.14	0.17	0.2	1	1	1	4	5	6	0.14	0.17	0.2	0.13	0.14	0.17	0.17	0.2	0.25	0.2	0.25	0.33
	C ₇	0.11	0.11	0.13	0.25	0.33	0.5	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.17	0.2	0.25	1	1	1	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13
	C ₈	0.2	0.25	0.33	8	9	9	1	1	2	1	2	3	1	1	2	5	6	7	8	9	9	1	1	1	1	1	2	1	1	2	1	2	3
	C ₉	0.2	0.25	0.33	8	9	9	1	1	2	1	2	3	1	1	2	6	7	8	8	9	9	1	1	2	1	1	1	1	1	2	1	2	3
	C ₁₀	0.14	0.17	0.2	7	8	9	0.33	0.5	1	1	2	3	1	1	2	4	5	6	8	9	9	1	1	2	1	1	2	1	1	1	1	1	2
	C ₁₁	0.11	0.13	0.14	4	5	6	0.33	0.5	1	1	1	2	0.33	0.5	1	3	4	5	8	9	9	0.33	0.5	1	0.33	0.5	1	1	1	2	1	1	1
Landfill (5)	C ₁	1	1	1	8	9	9	3	4	5	6	7	8	6	7	8	8	9	9	8	9	9	3	4	5	2	3	4	8	9	9	6	7	8
	C ₂	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.14	0.17	0.2	2	3	4	0.11	0.11	0.13	0.11	0.11	0.13	0.13	0.14	0.17	0.11	0.11	0.13
	C ₃	0.2	0.25	0.33	8	9	9	1	1	1	1	2	3	1	2	3	2	3	4	8	9	9	1	1	2	1	1	2	2	3	4	1	2	3
	C ₄	0.13	0.14	0.17	8	9	9	0.33	0.5	1	1	1	1	1	1	2	1	2	3	8	9	9	0.33	0.5	1	0.33	0.5	1	1	1	2	1	1	2
	C ₅	0.13	0.14	0.17	8	9	9	0.33	0.5	1	1	1	2	1	1	1	1	2	3	8	9	9	0.33	0.5	1	0.33	0.5	1	1	2	3	1	1	2
	C ₆	0.11	0.11	0.13	5	6	7	0.25	0.33	0.5	0.33	0.5	1	0.33	0.5	1	1	1	1	8	9	9	0.25	0.33	0.5	0.25	0.33	0.5	1	1	2	0.33	0.5	1
	C ₇	0.11	0.11	0.13	0.25	0.33	0.5	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	1	1	1	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13	0.11	0.11	0.13
	C ₈	0.2	0.25	0.33	8	9	9	1	1	2	1	2	3	1	2	3	2	3	4	8	9	9	1	1	1	1	1	2	1	2	3	1	2	3
	C ₉	0.25	0.33	0.5	8	9	9	1	1	2	1	2	3	1	2	3	2	3	4	8	9	9	1	1	2	1	1	1	2	3	4	1	2	3
	C ₁₀	0.11	0.11	0.13	6	7	8	0.25	0.33	0.5	1	1	2	0.33	0.5	1	1	1	2	8	9	9	0.33	0.5	1	0.25	0.33	0.5	1	1	1	1	1	2
	C ₁₁	0.13	0.14	0.17	8	9	9	0.33	0.5	1	1	1	2	1	1	2	1	2	3	8	9	9	0.33	0.5	1	0.33	0.5	1	1	1	2	1	1	1

The following step is to derive priorities using the normalization formula represented by Equation (5.4). It is used twice, first for finding the weight for each criterion (W_i), and then for finding the priorities for each alternative with respect to each criterion (P_{ki}), where (i) is the criterion and (k) is the alternative.

Following are samples for calculating W_i and P_{ki} using Equation (5.4):

$$\tilde{X}_{ij} = \left(\frac{\sum_{j=1}^n \sum_{i=1}^m L_{ij}}{\sum_{j=1}^n (\sum_{i=1}^m L_{ij})}, \frac{\sum_{j=1}^n \sum_{i=1}^m M_{ij}}{\sum_{j=1}^n (\sum_{i=1}^m M_{ij})}, \frac{\sum_{j=1}^n \sum_{i=1}^m U_{ij}}{\sum_{j=1}^n (\sum_{i=1}^m U_{ij})} \right)$$

$$\begin{aligned} W_1 &= ([(1+1+1+1+1) + (8+8+8+8+8) + ... + \\ &\quad (8+8+7+7+6)] / [\\ &\quad (1+0.13+0.33+0.13+0.5+0.13+0.2+0.33+0.25+0.2+0.13+1+0. \\ &\quad 13+0.33+0.13+0.5+0.13+0.14+0.33+0.33+0.2+0.13+1+0.13+ \\ &\quad 0.5+0.13+0.33+0.13+0.13+0.33+0.33+0.25+0.14+1+0.13+0.3 \\ &\quad 3+0.13+0.25+0.13+0.13+0.33+0.33+0.2+0.14+1+0.13+0.33+ \\ &\quad 0.17+0.17+0.13+0.13+0.33+0.5+0.13+0.17) + \\ &\quad (9+1+9+0.5+.....+9+9+8+9) + ... + \\ &\quad (9+0.25+4+0.13+.....+3+3+2+1)] , [1+1+1+1+1+ \\ &\quad +8+7] / [1+0.11+0.25+ +2+1+1] , [1+1+.....+9+8] / \\ &\quad [1+0.11+.....+1+1]) \\ &= (0.164, 0.231, 0.301) \end{aligned}$$

$$\begin{aligned} P_{11} &= ([1+8+3+8+2+8+5+3+4+5+8] / [\\ &\quad (1+0.13+0.33+0.13+0.5+0.13+0.2+0.33+0.25+0.2+0.13) + \\ &\quad (9+1+9+0.5+9+0.13+9+9+9+9+6) + \\ &\quad (5+0.13+1+0.13+2+0.13+1+2+2+1+0.5) + ... + \\ &\quad (9+0.25+4+0.13+5+0.13+3+4+3+3+1)] , [1+9+.....+9] / \\ &\quad [1+0.11+.....+2+1] , [1+9+.....+9] / [1+0.11+.....+1+1]) \\ &= (0.145, 0.195, 0.248) \end{aligned}$$

Table 5.7 shows the results of the derived priorities.

Table (5.7)
Fuzzy Weights and Priorities Judgment Matrix for Criteria and Alternatives

Criteria	C ₁			C ₂			C ₃			C ₄			C ₅			C ₆			C ₇			C ₈			C ₉			C ₁₀			C ₁₁		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Weight	0.164	0.231	0.301	0.021	0.029	0.041	0.082	0.12	0.173	0.039	0.057	0.086	0.076	0.11	0.162	0.018	0.026	0.038	0.031	0.045	0.066	0.076	0.109	0.161	0.076	0.111	0.163	0.063	0.089	0.133	0.052	0.074	0.109
Landfill (1)	0.145	0.195	0.248	0.032	0.042	0.053	0.085	0.115	0.155	0.016	0.022	0.03	0.088	0.121	0.163	0.006	0.007	0.008	0.079	0.103	0.137	0.085	0.109	0.148	0.081	0.104	0.141	0.079	0.103	0.137	0.06	0.08	0.103
Landfill (2)	0.172	0.25	0.331	0.036	0.05	0.072	0.071	0.111	0.172	0.039	0.054	0.081	0.071	0.111	0.173	0.006	0.008	0.011	0.044	0.069	0.111	0.065	0.099	0.158	0.071	0.111	0.172	0.05	0.078	0.125	0.041	0.06	0.093
Landfill (3)	0.171	0.257	0.343	0.011	0.015	0.027	0.094	0.144	0.21	0.03	0.053	0.095	0.075	0.116	0.185	0.011	0.015	0.028	0.015	0.028	0.051	0.075	0.116	0.185	0.072	0.112	0.18	0.054	0.086	0.146	0.035	0.059	0.105
Landfill (4)	0.164	0.229	0.296	0.012	0.019	0.029	0.085	0.122	0.173	0.05	0.073	0.108	0.079	0.112	0.161	0.02	0.032	0.048	0.006	0.008	0.011	0.08	0.112	0.161	0.082	0.115	0.165	0.072	0.1	0.149	0.055	0.078	0.116
Landfill (5)	0.169	0.234	0.306	0.012	0.017	0.026	0.075	0.113	0.164	0.063	0.087	0.127	0.063	0.09	0.131	0.048	0.067	0.096	0.006	0.008	0.011	0.072	0.11	0.16	0.075	0.113	0.165	0.055	0.074	0.111	0.063	0.087	0.127

The last two steps in FMHP are estimating α -cut and λ , which are confidence level of decision maker and degree of optimism, respectively. The study relies on two methodologies to take the final decision not only FMHP. Hence, the level of confidence on FMHP results is evaluated at 50%. On the other hand, the degree of optimism is varying, and it depends on the accuracy of data collected and expectations of changes in the coming years. Moderate degree of optimism is suggested for the study. Thus, each of α -cut and λ are taken equal to 0.5.

Having estimated α -cut and λ , Equations (5.5), (5.6) and (5.7) are used to create the final comparison matrix, which is presented in Table 5.8. Below are sample of calculations to produce that matrix. The calculations of the weight of criterion (1) are given below.

Using Equation (5.5):

$$X^L (W_1) = 0.164 + [(0.231 - 0.164) \times 0.5] = 0.195$$

Using Equation (5.6):

$$X^U (W_1) = 0.301 - [(0.301 - 0.231) \times 0.5] = 0.265$$

Using Equation (5.7):

$$X (W_1) = (0.5 \times 0.265) + [(1 - 0.5) \times 0.195] = 0.232$$

Using the same equations to calculate landfill (1) – criterion (1) score, to obtain:

$$X^L (P_{11}) = 0.145 + [(0.195 - 0.145) \times 0.5] = 0.170$$

$$X^U (P_{11}) = 0.248 - [(0.248 - 0.195) \times 0.5] = 0.222$$

$$X (P_{11}) = (0.5 \times 0.222) + [(1 - 0.5) \times 0.170] = 0.196$$

Table (5.8)

Final Comparison Matrix (X_{ij})

Criteria	C₁	C₂	C₃	C₄	C₅	C₆	C₇	C₈	C₉	C₁₀	C₁₁
Weight	0.232	0.030	0.124	0.060	0.114	0.027	0.046	0.114	0.115	0.093	0.077
Landfill (1)	0.196	0.042	0.118	0.022	0.123	0.007	0.105	0.113	0.108	0.105	0.081
Landfill (2)	0.251	0.052	0.116	0.057	0.116	0.008	0.073	0.105	0.116	0.083	0.064
Landfill (3)	0.257	0.017	0.148	0.058	0.123	0.018	0.031	0.123	0.119	0.093	0.064
Landfill (4)	0.229	0.020	0.126	0.076	0.116	0.033	0.008	0.116	0.120	0.105	0.082
Landfill (5)	0.236	0.018	0.116	0.091	0.094	0.069	0.008	0.113	0.117	0.078	0.091

The last stage is to evaluate the alternative sites using the average weighted concept, and then to rank the final results.

The alternative average weight is given by:

Average weight (Landfill i) = $\sum$ for all criteria (Criterion weight x Alternative weight associated with the criterion)

$$AW_k = \sum_{i=1}^n W_i \times P_{ki} \quad (5.9)$$

Where AW_k is the average weight of alternative k.

An example of the calculation for landfill (1) is illustrated below:

$$AW_1 = (0.232 \times 0.196) + (0.03 \times .042) + (0.124 \times .118) + (0.06 \times 0.022) + (0.114 \times 0.123) + (0.027 \times 0.007) + (0.046 \times 0.105) + (0.114 \times 0.113) + (0.115 \times 0.108) + (0.093 \times 0.105) + (0.077 \times 0.081) = 0.1231$$

The alternative sites evaluation is summarized in Table 5.9.

Table (5.9)

Sites alternative evaluation

Alternative (k)	Average Weight	Ranking
Landfill (1)	0.1231	5
Landfill (2)	0.1324	2
Landfill (3)	0.1391	1
Landfill (4)	0.1315	3
Landfill (5)	0.1286	4

5.3 Fuzzy Set Results

The fuzzy sets basically depends on formulating the data collected with respect to the criteria defined and alternative sites selected at the beginning. The problem formulation is then transferred to fuzzy comparison matrix, followed with the FMHP, and is finalized with the average weighted analysis.

The final results of applying FMHP are shown in Table 5.9. The highest weight achieved by landfill 3 with 0.1391, followed by landfills 2, 4, 5, and 1 with weights equal to 0.1324, 0.1315, 0.1286, and 0.1231, respectively.

The ranking weights for the five alternatives are too close to each other where the highest weight is 0.1391 and the lowest is 0.1231. The range of variation between minimum and maximum among the five alternatives equals to 0.016. This small variation indicates that the five alternative sites have almost the same preference, and therefore all of them are suitable to be utilized as a landfill site. This is expected because all the alternative sites are located in the same zone and are located next to each other.

The results and ranking of the alternatives may give different impact due to changes in the estimations of confidence level (α -cut) and degree of optimism (λ). The results in Table 5.9 are based on the moderate level for both α -cut and λ .

Chapter 6: Analytical Hierarchical Process

Approach

- 6.1 Analytical Hierarchical Process Methodology
- 6.2 Modeling Using Analytical Hierarchical Process
 - 6.2.1 Stage 1: Developing weights for the criteria
 - 6.2.2 Stage 2: Developing ratings for landfill alternative sites
 - 6.2.3 Stage 3: Weighted average rating
- 6.3 Analytical Hierarchical Process Results

Chapter 6: Analytical Hierarchical Process Approach

6.1 Analytical Hierarchical Process Methodology

Analytical Hierarchical Process (AHP) is an algorithm to solve kind of problems that can be decomposed into hierarchical structure. The structure usually consists of an objective of what need to be resolved, problem alternatives, and criteria to justify the selection between these alternatives.

From the literature that belong to landfill, the most decision makers were relied on multi criteria analysis. The most used and integrated methodologies to make the judgment of selection the optimal landfill sites among the alternatives were Analytical Hierarchical Process, Fuzzy Set Analysis, Global Information System, and few others.

The analytical hierarchical process (AHP) is a widely used approach in decision making studies. It is structured to analyze the medium to complex decisions. AHP was developed by Thomas Saaty since 1990, it was used at that time and updated on the following years. AHP is a structured technique that weighting the factors/criteria of the goal or the main objective of a study, and then weighting the alternatives with relative to these factors. The outcome of AHP ranks the alternatives, and the option in the first rank is considered as the best alternative. Unlike the other approaches which assist in finding out the optimal solution and ignoring the rest.

It is a comprehensive methodology which provides clear understanding of the full case study. Adding to that it is simple and well known

methodology. The above strengths of using AHP make that approach very recommended to be used for analyzing the landfill sites in Kingdom of Bahrain.

The AHP procedure consists of three basic stages. The first stage is to develop the weights for the criteria. At this stage, a single pair wise comparison matrix is established for the weights of criteria by calculating comparison ratios based on the distances of each criterion. After that, the ratios' matrix is converted to the judgment matrix based on Saaty's scale which presented in Table 5.1.

In the following part of the first stage, the values in each row are multiplied and the n th root of each criterion is calculated (where n is the number of criteria). Then, the aforementioned n th root is normalized to get the appropriate weights or priority vector (PV) for each criterion.

The last part of this stage is calculating and checking the Consistency Ratio (CR). CR gives an idea to the decision maker of whether the analysis is consistent or not. The CR is calculated by applying five steps process:

1. Find the summation of each column in the matrix (Sum (C_i))
2. each sum is then multiplied by the respective weight for C_i (Priority Vector (PV))
3. Find Lambda-max ($\lambda_{\max}$) by adding all values calculated in the previous step

$$\lambda_{\max} = \sum_{\forall \text{ criteria/alternatives}} (\text{Sum PV } (C_i)) \quad (6.1)$$

4. Calculate Consistency index (CI)

$$CI = (\lambda_{\max} - n) / (n-1) \quad (6.2)$$

Where n is the number of criteria

5. CR is then calculated by dividing CI by a Random Index (RI).

$$CR = CI / RI \quad (6.3)$$

RI is a direct function related to the number of criteria which has been identified by several authors. Various authors have computed and obtained different RIs depending on the simulation method and the number of generated matrices involved in the process. Saaty also has defined RI by simulating the experiment with 500 runs. Table 6.1 shows RI values defined by Saaty (1990) and presented by Alonso and Lamata (2006).

Table (6.1)

Random index (RI) (Saaty, 1990)

n	RI
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51

By defining RI, CR can be calculated. CR gives an idea of how consistent the decision maker has been when making the pair-wise comparisons. A higher number means the decision maker has been less consistent,

whereas a lower number means the decision maker has been more consistent. Moreover, If the CR is less than or equal to 0.10, that's means the pair-wise comparisons are relatively consistent. However, if CR is more than 0.10, then are should seriously consider reevaluating the pair wise comparisons and the sources of inconsistency must be identified and resolved (Alonso and Lamata, 2006).

The second stage of AHP procedure is developing the ratings for each decision alternative for each criterion. At this step a pair wise comparison matrix for each criterion is created with each matrix containing the performance of decision alternatives on that criterion. The same procedure used to find the ratings in the first stage is applied here for each decision alternative under each criterion.

In the third stage the weighted average rating is calculated for each decision alternative, and the best alternative with the highest score is selected.

6.2 Modeling Using Analytical Hierarchical Process

At this section the AHP methodology is applied to find a solution to the study problem. The required data is already compiled in Chapter 4 and further formulation to the problem is discussed in Chapter 5.

AHP process for selecting the best landfill with the basic stages defined in the previous section is applied in the following sub-sections.

6.2.1 Stage 1: Developing the weights for the criteria

a) First round of analysis

As criteria have the same preference in the study where the aim is to find the best site alternative relative to the distances for each criterion,

developing the weights for the criteria are based on taking the average for each pair of criteria in the criteria judgment matrix for all the five landfills alternatives presented in Table 5.5. Therefore, the weights of the criteria matrix (X_{ij}) are obtained by the following Equation:

$$X_{ij} = \text{Average of values of criteria } i \text{ and } j \text{ in the criteria judgment matrix for all landfill alternatives} \quad (6.4)$$

To illustrate the application of this Equation, the weight of criteria 1 and 2 (X_{12}) is calculated as follows:

$$X_{12} = (9 + 9 + 9 + 9 + 9) / 5 = 9$$

Other weights are calculated in a similar way, and the results are tabulated in Table 6.2. Then, the n th roots of the criteria are calculated, and as the study relies on 11 criteria that leads to take the 11th root for the summation of weights of each criterion relative to other criteria. This is done by the following Equation:

$$nth \text{ root } (C_i) = \left(\sqrt[n]{\prod_j^n X_{ij}} \right) = (\prod_j^n X_{ij})^{(1/n)} \quad (6.5)$$

Where C_i is criterion (i). Applying the Equation for the criterion (1):

$$11^{th} \text{ root } (C_1) = (1 \times 9 \times 3.8 \times 8.6 \times 4.4 \times 9 \times 8.2 \times 4 \times 4 \times 6.4 \times 8.2)^{(1/11)} = 5.23$$

The priority vector $PV(C_i)$ is established by:

$$PV(C_i) = nth \text{ root } (C_i) / \sum_{i=1}^n nth \text{ root } (C_i) \quad (6.6)$$

Thus, $PV(C_1)$ is obtained as follows:

$$PV(C_1) = 5.23 / 17.42 = 0.30$$

The criteria 11th roots as well as the priority vector are included in Table 6.2.

Then, by summation of each column in the weight of criteria matrix, Table 6.2 (Sum(C_i)) is established, and it is multiplied by the PV of the same criterion to obtain, (SumPV(C_i)):

$$\text{SumPV}(C_i) = \text{Sum}(C_i) * \text{PV}(C_i) \quad (6.7)$$

For example, the calculation for criteria 1 is:

$$\text{SumPV}(C_1) = 2.77 \times 0.30 = 0.83$$

Next step is to find $\lambda_{\max}$, CI, and CR by applying Equations 6.1, 6.2, and 6.3, respectively.

For $\lambda_{\max}$:

$$\begin{aligned} \lambda_{\max} &= \sum_{i=1}^{11} (\text{Sum PV}(C_i)) \\ &= 0.83 + 1.22 + 1.11 + 1.55 + 1.19 + 1.27 + 1.87 + 1.09 + \\ &\quad 1.12 + 1.27 + 1.31 = 13.86 \end{aligned}$$

For Consistency Index,

$$\begin{aligned} \text{CI} &= (\lambda_{\max} - n) / (n-1) \\ &= (13.86 - 11) / (11 - 1) = 0.286 \end{aligned}$$

Then, the Consistency Ratio is calculated, which depends on the Random Index for a matrix size of 11 (RI = 1.51, from Table 6.1). Thus,

$$\begin{aligned} \text{CR} &= \text{CI} / \text{RI} \\ &= 0.286 / 1.51 = 0.189 \end{aligned}$$

Based on the above results and as shown in Table 6.2, CR is greater than 0.10 which is not acceptable and the matrix is considered as inconsistent. Therefore, the analysis needs to be redone.

Table (6.2)

AHP 1 - Weights of Criteria (X_{ij})

Criteria	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁		11th root	PV
C ₁	1	9.00	3.80	8.60	4.40	9.00	8.20	4.00	4.00	6.40	8.20		5.23	0.30
C ₂	0.11	1	0.13	0.91	0.13	3.93	1.42	0.14	0.13	0.18	0.25		0.34	0.02
C ₃	0.27	8.20	1	4.00	1.20	7.60	5.60	1.00	1.00	2.20	2.60		2.04	0.12
C ₄	0.12	3.87	0.34	1	0.47	4.40	4.12	0.39	0.37	0.52	0.82		0.80	0.05
C ₅	0.25	8.00	0.90	3.60	1	6.60	5.40	0.90	1.10	1.60	2.40		1.85	0.11
C ₆	0.11	1.84	0.16	0.29	0.21	1	2.94	0.17	0.17	0.32	0.24		0.36	0.02
C ₇	0.13	2.73	0.28	2.34	0.28	4.06	1	0.38	0.38	0.51	0.74		0.68	0.04
C ₈	0.25	7.80	1.00	3.60	1.20	6.80	5.20	1	1.00	1.20	2.40		1.85	0.11
C ₉	0.26	7.80	1.00	3.80	1.10	7.00	5.20	1.00	1	1.60	2.20		1.89	0.11
C ₁₀	0.16	6.60	0.47	3.20	0.70	5.80	4.60	0.90	0.77	1	1.40		1.36	0.08
C ₁₁	0.12	5.00	0.40	2.60	0.52	5.60	4.30	0.43	0.47	0.80	1		1.02	0.06
Sum	2.77	61.84	9.47	33.95	11.21	61.80	47.99	10.32	10.39	16.33	22.26		17.42	1.00

Table (6.2) Continue

Sum*PV	0.83	1.22	1.11	1.55	1.19	1.27	1.87	1.09	1.12	1.27	1.31			
$\lambda_{\max}$	13.86													
CI	0.286													
CR	0.189													

b) Second round of analysis

The second suggestion for developing the weights for the criteria is to estimate the range of variations on the distances to the sites' alternatives for each criterion. These ranges for the second round of analysis are obtained by applying Equation (6.8) to the distances of Table 4.7:

$$\Delta \text{ distance } (C_i) = \text{maximum distance} - \text{minimum distance} \quad (6.8)$$

Thus, for criterion 1, the range is given by:

$$\Delta \text{ distance } (C_1) = 30.80 - 26.94 = 3.86$$

The results of the distance ranges are shown in Table 6.3.

Based on the calculated variations of distances for each criterion, the pair wise comparison matrix of criteria weights can be created by calculating the ratios between criteria using:

$$X_{ij} = \Delta \text{ distance } (C_i) / \Delta \text{ distance } (C_j) \quad (6.9)$$

For example, the ratio between criteria (1) and (2) is given by:

$$X_{12} = 3.86 / 1.03 = 3.75$$

The weights of criteria are included in Table 6.3.

After that, the ratios are converted into Saaty's measures and the same steps done in the first analysis are repeated, and the results are shown in Table 6.4.

Based on the results shown in Table 6.4, CR is less than 0.10 (i.e. CR = 0.01) which is highly consistent as it is small and near to zero. Therefore, the analysis is acceptable and the calculation to be considered.

Table (6.3)**AHP 2 – Distance Range and Weights of Criteria (Ratios)**

Δ Dist.	3.86	1.03	1.54	3.97	4.56	2.65	4.87	1.38	3.39	2.28	2.04
Criteria	C₁	C₂	C₃	C₄	C₅	C₆	C₇	C₈	C₉	C₁₀	C₁₁
C₁	1.00	3.75	2.51	0.97	0.85	1.46	0.79	2.80	1.14	1.69	1.89
C₂	0.27	1.00	0.67	0.26	0.23	0.39	0.21	0.75	0.30	0.45	0.50
C₃	0.40	1.50	1.00	0.39	0.34	0.58	0.32	1.12	0.45	0.68	0.75
C₄	1.03	3.85	2.58	1.00	0.87	1.50	0.82	2.88	1.17	1.74	1.95
C₅	1.18	4.43	2.96	1.15	1.00	1.72	0.94	3.30	1.35	2.00	2.24
C₆	0.69	2.57	1.72	0.67	0.58	1.00	0.54	1.92	0.78	1.16	1.30
C₇	1.26	4.73	3.16	1.23	1.07	1.84	1.00	3.53	1.44	2.14	2.39
C₈	0.36	1.34	0.90	0.35	0.30	0.52	0.28	1.00	0.41	0.61	0.68
C₉	0.88	3.29	2.20	0.85	0.74	1.28	0.70	2.46	1.00	1.49	1.66
C₁₀	0.59	2.21	1.48	0.57	0.50	0.86	0.47	1.65	0.67	1.00	1.12
C₁₁	0.53	1.98	1.32	0.51	0.45	0.77	0.42	1.48	0.60	0.89	1.00

Table (6.4)**AHP 2 - Weights of Criteria based on Saaty's Judgment**

Criteria	C₁	C₂	C₃	C₄	C₅	C₆	C₇	C₈	C₉	C₁₀	C₁₁		11th root	PV
C₁	1.00	4.00	3.00	1.00	1.00	1.00	1.00	3.00	1.00	2.00	2.00		1.57	0.13
C₂	0.25	1.00	1.00	0.25	0.25	0.33	0.20	1.00	0.33	0.50	0.50		0.43	0.03
C₃	0.33	1.00	1.00	0.33	0.33	0.50	0.33	1.00	0.50	1.00	1.00		0.59	0.05
C₄	1.00	4.00	3.00	1.00	1.00	1.00	1.00	3.00	1.00	2.00	2.00		1.57	0.13
C₅	1.00	4.00	3.00	1.00	1.00	2.00	1.00	3.00	1.00	2.00	2.00		1.67	0.14
C₆	1.00	3.00	2.00	1.00	0.50	1.00	0.50	2.00	1.00	1.00	1.00		1.11	0.09
C₇	1.00	5.00	3.00	1.00	1.00	2.00	1.00	4.00	1.00	2.00	2.00		1.75	0.14
C₈	0.33	1.00	1.00	0.33	0.33	0.50	0.25	1.00	0.50	0.50	1.00		0.54	0.04
C₉	1.00	3.00	2.00	1.00	1.00	1.00	1.00	2.00	1.00	1.00	2.00		1.33	0.11
C₁₀	0.50	2.00	1.00	0.50	0.50	1.00	0.50	2.00	1.00	1.00	1.00		0.88	0.07
C₁₁	0.50	2.00	1.00	0.50	0.50	1.00	0.50	1.00	0.50	1.00	1.00		0.78	0.06
Sum	7.91	30.00	21.00	7.91	7.41	11.33	7.28	23.00	8.83	14.00	15.50		12.22	1.00

Table (6.4) Continue

Sum*PV	1.02	1.05	1.01	1.02	1.01	1.02	1.04	1.01	0.96	1.01	0.99	
$\lambda_{\max}$	11.15											
CI	0.015											
CR	0.010											

6.2.2 Stage 2: Developing ratings for landfill alternative sites

At this step a pair wise comparison matrix is developed for each criterion. It is almost the same procedure applied in step one with minor changes.

Here, development of the ratings for each alternative with respect to the different criteria relies on the data collected and presented in Table 4.7. Basically the ratings of the alternatives are based on the distances from the criteria to the proposed landfill sites.

Thus, the rating of decision alternative (i) relative to alternative (j) (X_{ij}) for each criterion is given by:

$$X_{ij} = \text{Distance to landfill (i)} / \text{Distance to landfill (j)} \quad (6.9)$$

For example, the rating of landfill (1) relative to landfill (2) based on criterion (1) is:

$$X_{12} (C_1) = 27.60 / 26.94 = 1.02$$

All the relative ratings (ratios) for the different alternatives based on each criterion are included in Table 6.5.

Table (6.5)

AHP – Relative Ratings (Ratios) for Each Decision Alternatives

C1: Average path taken (Road network)					
Sites	L1	L2	L3	L4	L5
L1	1.00	1.02	0.99	0.94	0.90
L2	0.98	1.00	0.97	0.92	0.87
L3	1.01	1.04	1.00	0.95	0.91
L4	1.06	1.09	1.05	1.00	0.95
L5	1.12	1.14	1.10	1.05	1.00

Table (6.5) Continue

C2: Distance from residential areas					
Sites	L1	L2	L3	L4	L5
L1	1.00	0.35	0.57	0.73	1.19
L2	2.86	1.00	1.64	2.09	3.40
L3	1.75	0.61	1.00	1.27	2.07
L4	1.37	0.48	0.79	1.00	1.63
L5	0.84	0.29	0.48	0.61	1.00
C3: Distance from agricultural land					
Sites	L1	L2	L3	L4	L5
L1	1.00	0.99	0.83	0.93	0.95
L2	1.01	1.00	0.84	0.94	0.96
L3	1.20	1.19	1.00	1.12	1.14
L4	1.08	1.07	0.90	1.00	1.03
L5	1.05	1.04	0.87	0.98	1.00
C4: Industrial areas					
Sites	L1	L2	L3	L4	L5
L1	1.00	0.09	0.05	0.05	0.04
L2	11.25	1.00	0.58	0.53	0.44
L3	19.50	1.73	1.00	0.91	0.76
L4	21.38	1.90	1.10	1.00	0.83
L5	25.81	2.29	1.32	1.21	1.00
C5: Existing Bapco Oil Field					
Sites	L1	L2	L3	L4	L5
L1	1.00	1.17	1.34	1.48	1.96
L2	0.86	1.00	1.15	1.27	1.68

Table (6.5) Continue

L3	0.75	0.87	1.00	1.10	1.47
L4	0.68	0.79	0.91	1.00	1.33
L5	0.51	0.59	0.68	0.75	1.00
C6: Distance to the Oil Pipeline					
Sites	L1	L2	L3	L4	L5
L1	1.00	0.25	0.03	0.03	0.01
L2	4.00	1.00	0.13	0.11	0.04
L3	31.67	7.92	1.00	0.88	0.35
L4	36.00	9.00	1.14	1.00	0.40
L5	89.33	22.33	2.82	2.48	1.00
C7: Preserved areas					
Sites	L1	L2	L3	L4	L5
L1	1.00	1.49	3.41	20.88	35.79
L2	0.67	1.00	2.29	14.00	24.00
L3	0.29	0.44	1.00	6.13	10.50
L4	0.05	0.07	0.16	1.00	1.71
L5	0.03	0.04	0.10	0.58	1.00
C8: Bahrain International Circuit					
Sites	L1	L2	L3	L4	L5
L1	1.00	1.07	0.97	0.93	0.87
L2	0.94	1.00	0.91	0.87	0.82
L3	1.04	1.10	1.00	0.96	0.90
L4	1.08	1.15	1.04	1.00	0.94
L5	1.15	1.23	1.11	1.07	1.00
C9: Proposed Bahrain -Qatar Causeway					

Table (6.5) Continue

Sites	L1	L2	L3	L4	L5
L1	1.00	0.81	0.86	0.72	0.63
L2	1.23	1.00	1.05	0.89	0.77
L3	1.17	0.95	1.00	0.85	0.73
L4	1.38	1.12	1.18	1.00	0.86
L5	1.60	1.30	1.37	1.16	1.00
C10: Military Airports					
Sites	L1	L2	L3	L4	L5
L1	1.00	1.09	0.89	0.86	1.50
L2	0.92	1.00	0.82	0.79	1.38
L3	1.12	1.22	1.00	0.96	1.68
L4	1.17	1.27	1.04	1.00	1.75
L5	0.67	0.73	0.60	0.57	1.00
C11: Military Camps					
Sites	L1	L2	L3	L4	L5
L1	1.00	1.07	0.74	0.68	0.58
L2	0.93	1.00	0.68	0.63	0.54
L3	1.36	1.46	1.00	0.92	0.79
L4	1.48	1.59	1.09	1.00	0.86
L5	1.72	1.85	1.26	1.16	1.00

Then, the relative weights (ratios matrix) are converted to Saaty's judgment matrix using Saaty's scale of Table 5.4.

In the following step the nth roots of the alternatives are calculated. As the study considers 5 sites' alternatives, the 5th root for the summation of ratings of each alternative relative to the other alternatives are calculated by Equation (6.5), and then PV obtained using Equation (6.6), applying this for landfill (1) and criterion (2):

$$5\text{th root (Landfill (1), } C_2) = (1 \times 0.33 \times 0.5 \times 1 \times 1)^{(1/5)} = 0.70$$

$$PV (C_2) = 0.70 / 5.50 = 0.13$$

Then, the summation of each column in the judgment matrix of the alternative relative rating is multiplied by the PV for the same alternative. Thus, for landfill (1) and criterion (2):

$$\text{Sum PV (Landfill (1), } C_2) = 8.00 \times 0.70 = 1.01$$

Next step is to find $\lambda_{\max}$, CI, and CR by applying Equations 6.1, 6.2, and 6.3, respectively.

Lambda-max for criterion (2):

$$\begin{aligned} \lambda_{\max} (C_2) &= \sum_{i=1}^5 (\text{Sum PV (landfill}(i))) \\ &= 1.01 + 0.99 + 1.04 + 1 + 0.99 = 5.04 \end{aligned}$$

For Consistency Index of criterion (2):

$$\begin{aligned} CI (C_2) &= (\lambda_{\max}(C_2) - n) / (n-1) \\ &= (5.04 - 5) / (5 - 1) = 0.01 \end{aligned}$$

Table (6.6) Continue

Then, the Consistency Ratio is calculated, which depends on the number of Random Index for a matrix size of 5 (RI = 1.12, from Table 6.1). Thus, CR for criterion (2) is:

$$\begin{aligned} CR(C_2) &= CI(C_2) / RI(C_2) \\ &= 0.01 / 1.12 = 0.01 \end{aligned}$$

Saaty's judgment matrices for alternatives ratings based on each criterion are presented in Table 6.6.

Table (6.6)**AHP - Judgment Matrix for Each Decision Alternative**

C1: Average path taken (Road network)							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L2	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L3	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L4	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L5	1.00	1.00	1.00	1.00	1.00	1.00	0.20
Sum	5.00	5.00	5.00	5.00	5.00	5.00	1.00
Sum*PV	1.00	1.00	1.00	1.00	1.00		
λmax	5.00						
CI	0.00						
CR	0.00						
C2: Distance from residential areas							
Sites	L1	L2	L3	L4	L5	5th root	PV

Table (6.6) Continue

L1	1.00	0.33	0.50	1.00	1.00	0.70	0.13
L2	3.00	1.00	2.00	2.00	3.00	2.05	0.37
L3	2.00	0.50	1.00	1.00	2.00	1.15	0.21
L4	1.00	0.50	1.00	1.00	2.00	1.00	0.18
L5	1.00	0.33	0.50	0.50	1.00	0.61	0.11
Sum	8.00	2.66	5.00	5.50	9.00	5.50	1.00
Sum*PV	1.01	0.99	1.04	1.00	0.99		
λmax	5.04						
CI	0.01						
CR	0.01						
C3: Distance from agricultural land							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L2	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L3	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L4	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L5	1.00	1.00	1.00	1.00	1.00	1.00	0.20
Sum	5.00	5.00	5.00	5.00	5.00	5.00	1.00
Sum*PV	1.00	1.00	1.00	1.00	1.00		
λmax	5.00						
CI	0.00						
CR	0.00						
C4: Industrial areas							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	0.11	0.11	0.11	0.11	0.17	0.03

Table (6.6) Continue

L2	9.00	1.00	0.50	0.50	0.50	1.02	0.16
L3	9.00	2.00	1.00	1.00	1.00	1.78	0.27
L4	9.00	2.00	1.00	1.00	1.00	1.78	0.27
L5	9.00	2.00	1.00	1.00	1.00	1.78	0.27
Sum	37.00	7.11	3.61	3.61	3.61	6.54	1.00
Sum*PV	0.97	1.11	0.98	0.98	0.98		
λmax	5.03						
CI	0.01						
CR	0.01						
C5: Existing Bapco Oil Field							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	2.00	1.15	0.23
L2	1.00	1.00	1.00	1.00	2.00	1.15	0.23
L3	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L4	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L5	0.50	0.50	1.00	1.00	1.00	0.76	0.15
Sum	4.50	4.50	5.00	5.00	7.00	5.06	1.00
Sum*PV	1.02	1.02	0.99	0.99	1.05		
λmax	5.07						
CI	0.02						
CR	0.02						
C6: Distance to the Oil Pipeline							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	0.25	0.11	0.11	0.11	0.20	0.03
L2	4.00	1.00	0.13	0.11	0.11	0.36	0.05

Table (6.6) Continue

L3	9.00	8.00	1.00	1.00	0.33	1.88	0.24
L4	9.00	9.00	1.00	1.00	0.50	2.10	0.26
L5	9.00	9.00	3.00	2.00	1.00	3.45	0.43
Sum	32.00	27.25	5.24	4.22	2.05	7.99	1.00
Sum*PV	0.81	1.24	1.24	1.11	0.88		
λmax	5.27						
CI	0.07						
CR	0.06						
C7: Preserved areas							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	3.00	9.00	9.00	3.00	0.38
L2	1.00	1.00	2.00	9.00	9.00	2.77	0.35
L3	0.33	0.50	1.00	6.00	9.00	1.55	0.20
L4	0.11	0.11	0.17	1.00	2.00	0.33	0.04
L5	0.11	0.11	0.11	0.50	1.00	0.23	0.03
Sum	2.55	2.72	6.28	25.50	30.00	7.88	1.00
Sum*PV	0.97	0.95	1.23	1.08	0.88		
λmax	5.12						
CI	0.03						
CR	0.03						
C8: Bahrain International Circuit							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L2	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L3	1.00	1.00	1.00	1.00	1.00	1.00	0.20

Table (6.6) Continue

L4	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L5	1.00	1.00	1.00	1.00	1.00	1.00	0.20
Sum	5.00	5.00	5.00	5.00	5.00	5.00	1.00
Sum*PV	1.00	1.00	1.00	1.00	1.00		
λmax	5.00						
CI	0.00						
CR	0.00						
C9: Proposed Bahrain -Qatar Causeway							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	0.50	0.87	0.17
L2	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L3	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L4	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L5	2.00	1.00	1.00	1.00	1.00	1.15	0.23
Sum	6.00	5.00	5.00	5.00	4.50	5.02	1.00
Sum*PV	1.04	1.00	1.00	1.00	1.03		
λmax	5.06						
CI	0.01						
CR	0.01						
C10: Military Airports							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L2	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L3	1.00	1.00	1.00	1.00	2.00	1.15	0.23
L4	1.00	1.00	1.00	1.00	2.00	1.15	0.23

Table (6.6) Continue

L5	1.00	1.00	0.50	0.50	1.00	0.76	0.15
Sum	5.00	5.00	4.50	4.50	7.00	5.06	1.00
Sum*PV	0.99	0.99	1.02	1.02	1.05		
λmax	5.07						
CI	0.02						
CR	0.02						
C11: Military Camps							
Sites	L1	L2	L3	L4	L5	5th root	PV
L1	1.00	1.00	1.00	1.00	0.50	0.87	0.17
L2	1.00	1.00	1.00	0.50	0.50	0.76	0.15
L3	1.00	1.00	1.00	1.00	1.00	1.00	0.20
L4	1.00	2.00	1.00	1.00	1.00	1.15	0.23
L5	2.00	2.00	1.00	1.00	1.00	1.32	0.26
Sum	6.00	7.00	5.00	4.50	4.00	5.10	1.00
Sum*PV	1.02	1.04	0.98	1.01	1.04		
λmax	5.10						
CI	0.02						
CR	0.02						

The results shown in Table 6.6 for all criteria are acceptable. CRs are ranging from 0 to 0.06 as a maximum. Thus, all CRs for all criteria are less than 0.10 and therefore the calculations are considered consistent.

6.2.3 Stage 3: Weighted average rating

The last stage is to calculate the weighted average rating for each decision alternative after combining the PV of all matrices created in stages one

and two. The average ratings are calculated using Equation (5.9), the following example shows the calculation of the average weight for Landfill (1):

$$AW_k = \sum_{i=1}^n W_i \times P_{ki} \quad (5.9)$$

$$AW_1 = (0.13 \times 0.20) + (0.03 \times 0.13) + (0.05 \times 0.20) + (0.13 \times 0.03) + (0.14 \times 0.23) + (0.09 \times 0.03) + (0.14 \times 0.038) + (0.04 \times 0.20) + (0.11 \times 0.17) + (0.07 \times 0.20) + (0.06 \times 0.17) = 0.184$$

Where, W_i and P_{ki} are the weights (i.e. PV) of the criteria and landfill alternatives that calculated in Tables 6.4 and 6.6, respectively. These weights are summarized in Table 6.7.

The calculated average weights for the landfills are used to rank the alternative sites, and select the best one with the highest score.

The final results of average weights for each alternative and its ranking are presented in Table 6.7.

Table (6.7)

Weighted Average Rating for Each Decision Alternative

Criteria		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	Average Weight	Ranking
Weight		0.13	0.03	0.05	0.13	0.14	0.09	0.14	0.04	0.11	0.07	0.06		
Alternative	L1	0.20	0.13	0.20	0.03	0.23	0.03	0.38	0.20	0.17	0.20	0.17	0.184	5
	L2	0.20	0.37	0.20	0.16	0.23	0.05	0.35	0.20	0.20	0.20	0.15	0.208	2
	L3	0.20	0.21	0.20	0.27	0.20	0.24	0.20	0.20	0.20	0.23	0.20	0.214	1
	L4	0.20	0.18	0.20	0.27	0.20	0.26	0.04	0.20	0.20	0.23	0.23	0.195	4
	L5	0.20	0.11	0.20	0.27	0.15	0.43	0.03	0.20	0.23	0.15	0.26	0.199	3

6.3 Analytical Hierarchical Process Results

The first stage "Developing the weights for the criteria" is carried out twice to achieve consistency of comparison matrix for the weights of criteria. From the first analysis, a CR of 0.189 is obtained, which is not acceptable (Saaty, 1989). Thus, another analysis is required to achieve consistency. In the second round of analysis a lower CR of 0.01 is obtained. Therefore, the comparison matrix is assumed to be very consistent.

The CRs for alternatives' ratings are found to be very consistent for all criteria as shown in Table 6.6. The CRs for all alternatives are ranging from 0 to 0.06 as a maximum. Therefore, no corrective action is necessary since all values are less than 0.10. That gives a good indication of consistency on the alternative matrices and later on decision making.

The final results of applying AHP approach are shown in Table 6.7. The highest score is for site alternative no. 3, followed by sites' alternatives 2, 5, 4 and 1, respectively. The ranking weights for the five alternatives are close to each other, where the highest weight is 0.214 and the lowest is 0.184. The variation weight between minimum and maximum among the five alternatives is 0.030.

Chapter 7: Discussion of Results

- 7.1 Discussion of Fuzzy Set Results
- 7.2 Sensitivity Analysis of Fuzzy Set Results
- 7.3 Discussions of Analytical Hierarchical Process
- 7.4 Comparisons of Results
- 7.5 Recommended Site

Chapter 7: Discussion of Results

7.1 Discussion of Fuzzy Set Results

Referring to Chapter 5 and the methodology applied to find the best landfill site, the fuzzy set theorem is used to formulate a comprehensive relation between the criteria and alternative sites. The ratings in the comparison matrices are intended to measure the level importance between each two criteria with respect to each alternative. There is strong interrelation between the whole factors affecting the site selection.

The fuzzy set represents the comparison values as triangular number showing the upper, medium and lower bounds of ratings' weights. This gives the fuzzy approach higher credibility, furthermore the estimation of confidence level and degree of optimism are good opportunities to justify the decision making as being more reliable.

In line with that, changing the level of confidence and degree of optimism may have impact on the final results. It may lead to a significant change on the average weights among the alternatives and minor or none on the final ranking. Thus, a sensitivity analysis may support the decision making of selecting landfill no. 3 as the best alternative site.

7.2 Sensitivity Analysis of Fuzzy Set Results

Following the suggestion to conduct sensitivity analysis, in this section the effects of changing the level of confidence (α -cut) and degree of optimism (λ), are investigated.

In Chapter 5, the original analysis assumes that both α -cut and λ are equal to 0.5. The values of α -cut and λ are varied between 0.5 and 1 which are

the most considerable values by the decision makers. Table 7.1 shows the options of changing α -cut and λ .

Table (7.1)

Sensitivity Analysis Options

Option	α-cut	λ	Table of results
Original	0.5	0.5	Table 5.9
1	0.5	1	Table 7.2
2	1	0.5	Table 7.3
3	1	1	Table 7.4

The results of applying the options presented in Table 7.1 are shown in Tables 7.2, 7.3, and 7.4, whereas the original results are shown in Table 5.9.

Table (7.2)

Sensitivity Analysis Option 1 (α -cut = 0.5, λ = 1)

	Average Weight	Ranking
Landfill (1)	0.1643	5
Landfill (2)	0.1845	2
Landfill (3)	0.1957	1
Landfill (4)	0.1795	3
Landfill (5)	0.1761	4

Table (7.3)

Sensitivity Analysis Option 2 (α -cut = 1, λ = 0.5)

	Average Weight	Ranking
Landfill (1)	0.11791	5
Landfill (2)	0.12542	2
Landfill (3)	0.13137	1
Landfill (4)	0.12541	3
Landfill (5)	0.12264	4

Table (7.4)

Sensitivity Analysis Option 3 (α -cut = 1, λ = 1)

	Average Weight	Ranking
Landfill (1)	0.11791	5
Landfill (2)	0.12542	2
Landfill (3)	0.13137	1
Landfill (4)	0.12541	3
Landfill (5)	0.12264	4

The results of sensitivity analysis different options show that there are little differences on the average weights ranging; approximately between 0.20 and 0.16 for option 1, and 0.13 to 0.11 for option 2 and 3. However, alternative sites ranking remains the same as the original option where Landfill 3 has the highest score and Landfill 1 the lowest.

7.3 Discussions of Analytical Hierarchical Process

AHP approach as discussed in chapter 6 has depended on rating the alternatives and weighting criteria. It is mainly evaluating the results of comparison matrices created for alternative rates and criteria weights based on the Consistency ratio.

As though, Criteria weights analysis has repeated due to the fact that the first analysis which relies on the overall criteria rating with respects to all alternatives has a high consistency ratio equals to 0.189; and the acceptable limit is up to 0.10.

Therefore, a second analysis was required to justify criteria weights. It has suggested to weighting criteria based on the distances variations for each criterion. Then, criteria weights measured based on variations values. The final output of criteria comparison matrix reached a CR of 0.010 which is high consistent.

On the other hand, the CR for the alternative ratings on all matrices has been acceptable with a maximum value of 0.06.

Overall the results are consistent. The alternative rankings are starting with the highest weight reached by Landfill 3, following by 2, 5, 4 and 1.

7.4 Comparisons of Results

A comparison of results between FMHP and AHP is summarized in Table 7.5. It is clearly shown that the alternative landfill weights not exceeding 0.214 and not less than 0.118; the range of weights is 0.013 and 0.030 for FMHP and AHP, respectively.

Rankings of the landfills using FMHP and AHP are the same for the first, second, and last alternatives. But the third and fourth ranks are exchanged between landfills (4) and (5) alternatively for the two approaches.

The similarity of the rankings are expected as both approaches are based on the same criteria; FMHP relies on the ratings among the criteria, whereas AHP relies on the differences between the distances for each criteria. The weight generated by FMHP are based on the distances between alternatives and criteria, while AHP first round results are not acceptable when are based on these distances as the CR is higher than 0.10. Therefore, AHP needed another round of analysis where distance range for each criterion have been used for finding the criteria relative weights.

Table 7.5 presents the average weights and ranking results for both approaches.

Table (7.5)

Comparisons of Results

	FMHP		AHP	
	Average Weight	Ranking	Average Weight	Ranking
Landfill (1)	0.11791	5	0.184	5
Landfill (2)	0.12542	2	0.208	2
Landfill (3)	0.13137	1	0.214	1
Landfill (4)	0.12541	3	0.195	4
Landfill (5)	0.12264	4	0.199	3

As shown in Table 7.5 landfill no. 3 has the highest weight by both approaches, and so it is the best alternative site. The second rank is for Landfill no. 2. The third and fourth ranks are for Landfills no. 4 and 5 based on FMHP and for Landfills no. 5 and 4 based on AHP. The last preference site is landfill no. 1.

It is preferred to select a landfill near the existing one from economical, operational, and environmental dimensions. Selection of the new landfill location away from the existing one will require extra cost for site preparation, extra operational cost, and extra environmental hazards. As though, landfill (2) and (3) are the most preferable alternatives with higher preference to landfill (3) as it is the first ranked by both approaches and is away from the most sensitive locations (i.e. Bahrain International Circuit and Proposed Bahrain-Qatar Causeway).

7.5 Recommended Site

The results show that Landfill no. 3 has the highest weight. As though, it is considered as the best site.

However, the landfill weights are too close to each other which give an indication of the opportunity for any of the other landfills to be preferred, specially the next highest weight: landfill no. 2.

Back to Figure 4.2; landfill no. 3 is in the middle of the blue zone (Proposed area) and just below the existing landfill. Landfill no. 2 is adjacent to the existing landfill and has a nonhomogeneous shape due to some buildings for Bramco staff just next to this landfill proposed area. Adding to that, the proposed area for landfill no.3 is bigger than landfill no. 2, their areas are 1.95 km² and 1.82 km², respectively, as shown in Table 4.1. Therefore, the recommended site is Landfill no.3.

Chapter 8: Conclusion and Recommendations

8.1 Conclusion

8.2 Recommendations

8.3 Further Research

Chapter 8: Conclusion and Recommendations

8.1 Conclusion

The main objective of the study is to find out municipal waste landfill site for Kingdom of Bahrain as a replacement for the existing landfill at Askar which is almost fully occupied.

Selected criteria have covered all objectives of the research, namely, economic, social and environmental aspects (constraints) that lead to selection of the best alternative landfill. These are reflected by: economic constraints such as Bahrain International Circuit and proposed Bahrain Qatar causeway; social constraints such as residential areas; environmental constraints such as selecting new alternative adjacent to the existing landfill. As well, transportation routes to be used to deliver municipal wastes are taken into consideration.

Five alternative sites next to the existing landfill were proposed and analyzed using two methodologies; fuzzy multi-criteria hierarchy process and analytical hierarchical process. The outcome of the analysis ranked landfill no. 3 (N 26.025226°; E 50.597991°; 1.95 km²) as the best choice; followed by landfill no. 2 (N 26.042043°; E 50.588799°; 1.82 km²) by both methodologies.

The location of the best two alternative sites are just adjacent to the existing landfill, where landfill (3) is below and landfill (2) is to the west of it. Hence, the decision of selecting a landfill has three options; either selecting a new landfill or extending the existing one to either of these two alternatives as both of them are allocated on the community services zone and close to Askar landfill. Adding to that, these best two

alternatives are adjacent to each other, thus, the final location of the landfill site can be partially located on both alternatives.

As though, the results of the study give the decision maker relative preference of the landfill sites: landfill no. 3 as the best; and landfill no. 2 the second best choice. Based on that and the above options, decision maker can justify and provide the solution of the new landfill location.

At the end of the research and as stated in Chapter 7; section 7.4, the preferred alternative is landfill (3) as it the first ranked in the both approaches and away from the most sensitive locations in Bahrain.

8.2 Recommendations

Further to the results and discussions with reference to the conclusion, it is recommended to utilize the proposed landfill no. 3 as it scores the first rank. As the location of landfill no. 3 is below the existing landfill at Askar, the option of expanding the existing landfill is an excellent decision. It will be better to have one location for landfilling municipal waste rather than separated into two areas. The extension option has several benefits such as integrated operation of landfilling and avoids spreading the environmental impacts of waste landfill to other location. The exact location of the new municipal waste landfill is highly recommended to be below the existing landfill (i.e. Landfill no. 3), because it is better to expand the existing landfill to the south rather than expanding to the west (i.e. using landfill no. 2) as there are several sensitive areas and new development projects based on 2030 plan for Kingdom of Bahrain located in the west side of Askar landfill.

Transportation of the waste requires proper management, it is important to ensure use of the shortest and quickest route to deliver the wastes to the landfill.

8.3 Further Research

The current study can be enhanced by carrying the following:

- Developing a software using AHP and Fuzzy theory for optimal selection of landfill.
- Inclusion of descriptive parameters for social and environmental issues, and applying Fuzzy TOPSIS for their analysis.

Further studies and researches are required to obtain better waste management in Kingdom of Bahrain. Such studies include:

- Adoption of new technologies to replace the current process of waste disposal by landfilling.
- Obtaining a sustainable solution for the waste disposal by allocating an area for recycling near the current or future landfill.
- Preparing a study on the environmental risk assessment to evaluate the effects of the temperature, pressures, gas emission for the existing and proposed landfill
- Preparing a study on the transportation routes used to deliver municipal waste

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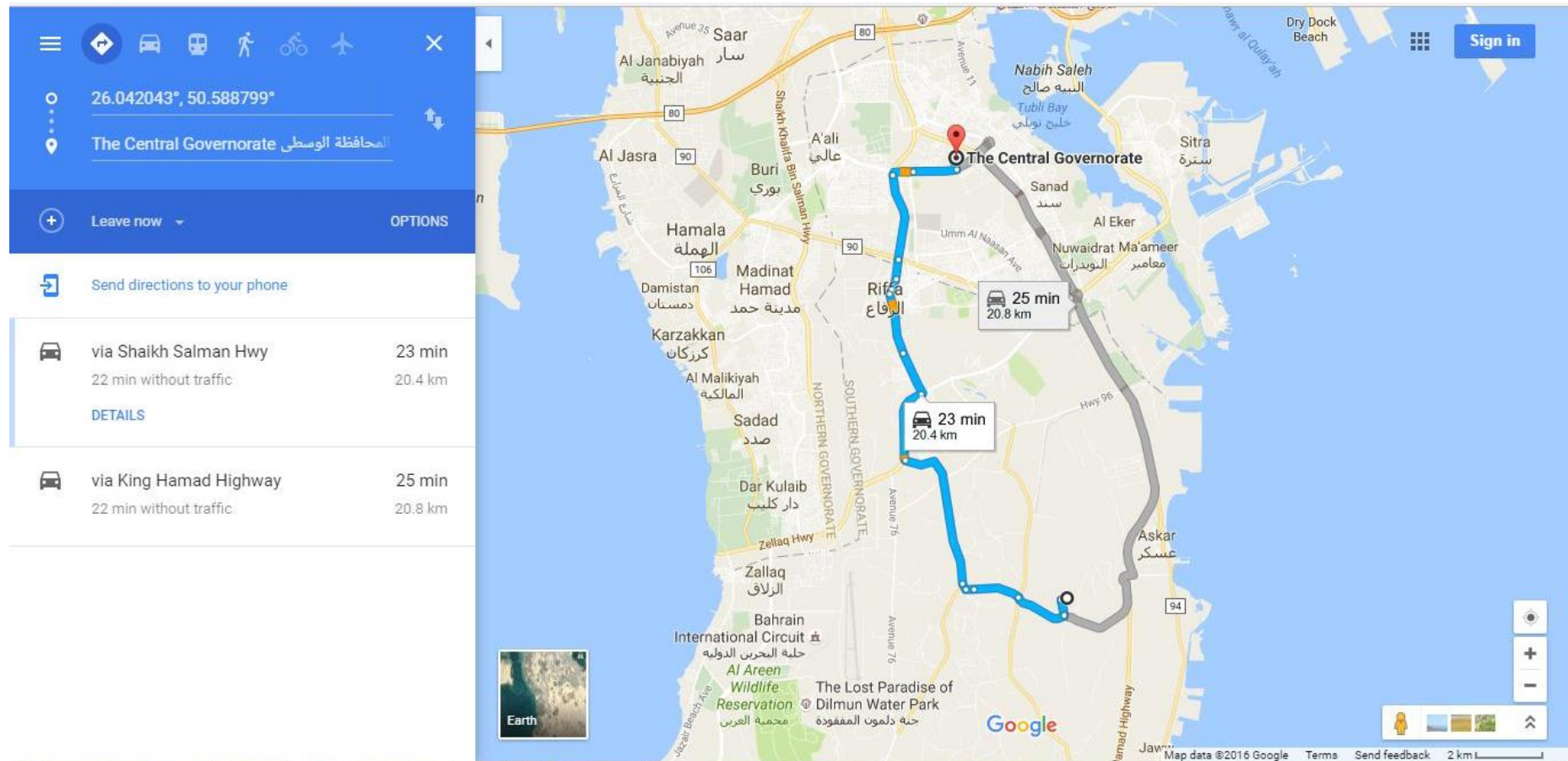
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Appendices

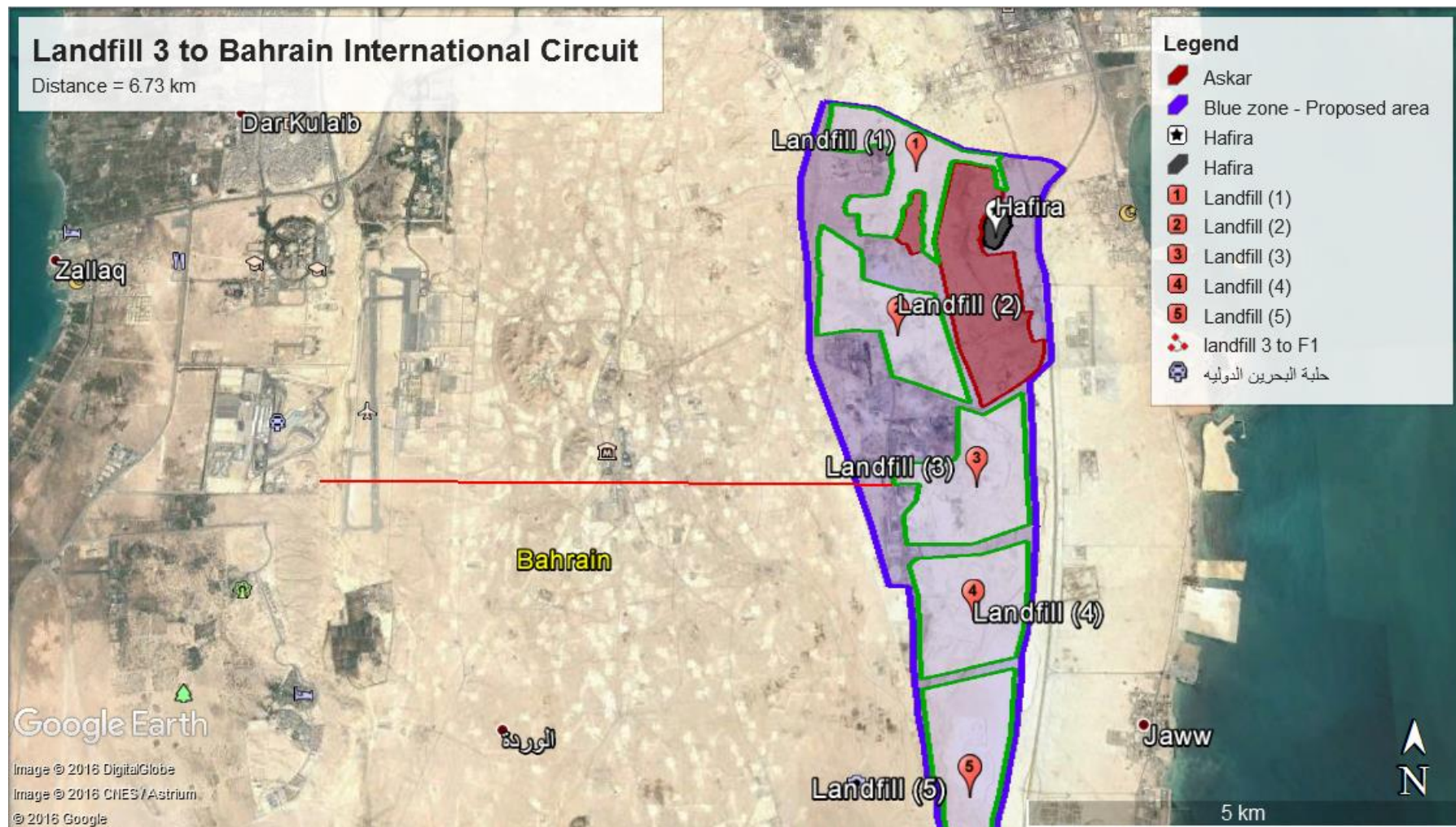
Appendix A: Sample of Data Collection

Appendix B: Kingdom of Bahrain National Detail Land Use Map 2030

Appendix A: Sample of Data Collection



Average Path Taken form Central Governorate to Landfill (1) Using Google Map



Distance from Landfill (3) to Bahrain International Circuit (Google Earth Map)

Appendix B: Kingdom of Bahrain National Detail Land Use Map 2030

ملخص

النفایات البلدية في مملكة البحرين هي واحدة من القضايا ذات الأولوية التي تحتاج إلى حل جذري. التقنية المستخدمة حالياً للتخلص من هذه النفایات هي الطمر، ويعتبر مكب عسكر هو المكب الرئيسي والوحيد لطرر جميع النفایات البلدية في مملكة البحرين. وفقاً لدراسات سابقة، فقد وصلت قدرة استيعاب المكب الحالي نهايتها بحلول عام 2016، ومع ذلك فإنه لا يزال يعمل ويتلقى النفایات البلدية بشكل يومي. يهدف هذا البحث لإيجاد بديل للمكب الحالي ليستخدم في العاجل والمستقبل القريب، بينما تبحث وزارة الأشغال وشؤون البلديات بالتعاون مع المجلس الأعلى للبيئة في إيجاد حل مناسب وتقنية تكون مستدامة للتخلص من النفایات البلدية بدلاً عن الطمر. وفي هذا البحث اقترح الباحث خمسة بدائل لمكب النفایات تقع في المنطقة الزرقاء بجانب عسكر في خريطة استخدام الأراضي لرؤية البحرين لعام 2030، بالإضافة إلى إحدى عشر معياراً لاتخاذ القرار. وتمت الدراسة باستخدام منهجين للتحقق من أفضل مكب. هذين المنهجين هما تحليل المجموعة الضبابي وتحليل التسلسل الهرمي. يستند كلا النهجين إلى القرار المتعدد المعايير، في حين تحليل التسلسل الهرمي يعتمد ببساطة على ربط البدائل مع مدى المسافات لكل معيار، بينما يعتمد التحليل الضبابي على مسافات هذه المعايير نفسها وعلاقتها الضمنية بين المعايير لكل بديل من البدائل الخمسة. لقد وُجِدَ تشابه في نتائج المنهجين من ناحية ترتيب البدائل الخمسة لكليهما مع اختلاف طفيف في ترتيب البديلين 3 و 4. أما الناتج النهائي كان واحداً لكلا المنهجين، والتي عينت البديل الثالث على أنه المكب الأفضل، حيث يقع في وسط المنطقة الزرقاء تحت المكب الحالي في عسكر.

جامعة البحرين

قسم الهندسة الميكانيكية

كلية الهندسة



نموذج اختيار مكب للنفايات البلدية في مملكة البحرين

بحث لاستكمال متطلبات الحصول على درجة (الماجستير) في برنامج الإدارة الهندسية

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