LANDFILLS NEEDS ASSESSMENT IN GAZA
STRIP AND SITES SELECTION USING GIS

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A thesis submitted in partial fulfillment of the requirements
of the degree of Master of Science in Infrastructure
Management-Civil Engineering

١٤٣٢-٢٠١١
Dedication

I proudly dedicate this thesis to my beloved wife Engr. Tahreer Fayyad for her unconditional and total support in any endeavor of my life and to my son Mohammed who adds more values to our life.

With all loves…
ACKNOWLEDGEMENTS

All praise is to ALLAH Subhanahu wa ta’ala for bestowing me with health, opportunity, patience and knowledge to complete this work.

I would like to express my sincere gratitude and heartfelt thanks to Dr. Jehad Hamad; the supervisor of my thesis, for his strong support and guidance throughout the duration of this research.

Deep thanks and gratitude are also due to my father Mr. Fahmi abdalqader and my mother Mrs. Halima Alhila for their infinite support and encouragement. I would like to express my thanks to my wife Eng. Tahreer Fayyad for her patience, support, encouragement and forbearance during the time in which this work was done. I also offer great thanks to my brothers and my sisters for their love and encouragements.


Moreover, I would like to thank Mr. Mohammed Toman and Mr. Mansour Abu Kwaik for their help in conducting the GIS model.

I would also like to thank the Islamic Development Bank for their support.

In addition, appreciation goes to everybody made special contributions in formulating the criteria for assessment and filling the multi-criteria questionnaire.

High appreciation is due to my colleagues in Ministry of Planning and in the Civil Engineering Department at the Islamic University of Gaza for their assistance during this research.
ABSTRACT

Currently, Gaza Strip is facing solid waste management (SWM) issues as landfills are rapidly filling up, increasing amount of waste are generated, shortage of disposal land, resulting of serious environmental and human health impacts.

This research aims to conduct a baseline for landfilling planning by focusing on three issues related to SWM in Gaza Strip, the first is the lack of updated information about the solid waste characteristics especially the composition of it. The second issue is the absence of a unified vision for landfilling system and landfill numbers in Gaza Strip because there is no real integration between all stakeholders in SWM. The third issue is the disappearance of defining the suitable locations of landfills in Gaza Strip.

To achieve the objectives of the research, many approaches and tools are used namely; a field work was conducted in the main landfills to determine the composition of municipal solid waste (MSW) according to American Society for Testing and Materials (ASTM) standards; structured interviews, questionnaire, and DEFINITE (Decisions on a Finite Set of Alternative) model are adapted to find out the optimal needed number of landfills; geographical information system (GIS) technology is exploited to select the best locations of landfills.

It is found that the potential of recycling in MSW of Gaza Strip is high since its composition constitutes of 47.5% Organic wastes, 14.5% Paper, 12% Plastic, 11.5% Other inorganics, 8% Metals, and 6.5% Glass.

According to the multi criteria decision analysis (MCDA) and based on the stakeholders feedbacks, it is found that central landfill, area equals 1000 dunum, would be efficient and enough to manage the produced waste in Gaza Strip. However, some requirements are required for that such that the location of this landfill should be appropriate for all districts, transfer stations should be constructed to facilitate the transfer of waste, and adequate trucks with spare parts should be secured to transfer the waste.

The results obtained from implementing a loose scenario of siting criteria and using GIS show that the available areas for landfill sitting are less than 30 km² divided to seven candidate areas. Because of its location in middle distance between all solid waste generation centers, the fourth site is considered the most suitable site for a landfill location.

It is recommended that additional studies should be done on the characteristics of MSW like seasonal variations, laboratory experiments, and volume of MSW components. Also other studies should be done to conduct recycling plans for potential recyclables. These plans could contain the required recycling techniques for each material, feasibility studies, cost benefit analysis, and the responsibilities of all stakeholders. Furthermore, detailed investigations should be required for choosing the best location specifically by conducting MCDA based on experts’ opinions and field studies.
الملخص

يواجه قطاع غزّة حاليًا العديد من القضايا المتعلقة بإدارة النفايات الصلبة حيث أن مكونات النفايات قد اندثرت، وكميات النفايات قد ازدادت، بالإضافة إلى شح الأراضي التي يمكن استغلالها لمكبات النفايات، مما أدى إلى وجود مشاكل صحية وبيئية.

تهدف هذه الدراسة إلى إيجاد مرتكز أساسي للتخطيط لعملية التحكم الصحي وذلك بالتركيز على ثلاث مشاكل رئيسة وهي: تعدد، وشيوع، وھيرة، اتخاذ الإجراءات اللازمة لمواجهة الوضع، وعدم وجود رؤية موحدة للتعامل مع مكبات النفايات من حيث العدد، وأخيراً عدم تعريف المناطق التي يمكن وضع مكبات النفايات فيها.

ذا تم اتباع العديد من المنهجيات والطرق واستخدام العديد من الآليات لتحقيق هذه الأهداف وهي كالتالي: عمل مباني لتحديد مكونات النفايات وذلك بدراسة مكونات البداية، بالإضافة إلى عمل مراقب، وتحديد أفضل عدد من مكونات النفايات لاستخدامها لقطاع غزة، كما تم تطبيق نظام GIS للمعلومات الجغرافية لإيجاد الأماكن المناسبة لوضع المكبات فيها.

النتائج أوضح أن العديد من مكونات النفايات الصلبة في قطاع غزة صالح لإعادة التدوير حيث تتكون من: 47.5% نفايات مواد غذائية، 41.5% مواد غير مواد معدنية، 11.5% مركبات، و12.0% ورق وكرتون، و14.5% مواد عضوية.

كما تبين من النتائج أن الخبراء يوصون إضافة أعداد كبيرة من المكبات لتعليم النفايات الصلبة في قطاع غزة وقد تم احصاء مساحة لتكون حوالي 1000 دونم، مع ذلك اشترط الخبراء أن تكون إضافة هذا المكبات العديد من المتطلبات مثل اختيارها في موقع مناسب لجميع المناطق، وإدارة مهارات تخزين لتسهيل عملية نقله، مع توفر مركبات مناسبة للنقل وقطع غيار لها.

وبالنسبة للنتائج المتعلقة باختيار الأماكن المناسبة لإقامة مكبات النفايات، فقد وجد أن هناك سبع أماكن فقط صالحًا لوضع مثل هذه المكبات ولا تتجاوز مساحة هذه المناطق 30 كم²، حيث أن المكان الرابع يعتبر منطقين وسطية وقد تم التوصيف لاختيار لوضع مكبات النفايات المرموق فيه.

أوصت الدراسة بأن المزيد من الدراسات الخاصة بخصائص النفايات الصلبة يجب الاهتمام بها وذلك مثل أثر التغيرات الفصلية على مكونات النفايات، والتجارب المخبرية لابد تحصص هذه المكونات، بالإضافة إلى تحديد أحماء هذه المكونات. كما يوصي بأن هناك ضرورة لإعداد الدراسات والخطط الخاصة بإعادة التدوير من حيث التفاصيل اللازمة ودراسات الجدوى وغيرها. علاوة على ذلك يجب اتخاذ المزيد من الدراسات المعققة لتحديد أفضل مكان للمكث.
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<td>AHP</td>
<td>Analytical Hierarchy Process</td>
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<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<td>DEFINITE</td>
<td>Decisions on a Finite Set of Alternative</td>
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<td>DM</td>
<td>Decision Maker</td>
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<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>EQA</td>
<td>Environmental Quality Authority</td>
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<td>GIS</td>
<td>Geographical Information System</td>
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<td>INGOs</td>
<td>International Non-Governmental Organizations</td>
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<td>IUG</td>
<td>Islamic University of Gaza</td>
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<td>LNGOs</td>
<td>Local Non-Governmental Organizations</td>
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<td>MCDA</td>
<td>Multi Criteria Decision Analysis</td>
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<td>METAP</td>
<td>Mediterranean Environmental Technical Assistance Programme</td>
</tr>
<tr>
<td>MoLG</td>
<td>Ministry of Local Government</td>
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<tr>
<td>Mop</td>
<td>Ministry of Planning</td>
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<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
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<td>MSWM</td>
<td>Municipal Solid Waste Management</td>
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<td>PEF</td>
<td>Palestinian Environmental Friends</td>
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<td>PWA</td>
<td>Palestinian Water Authority</td>
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<td>SWM</td>
<td>Solid Waste Management</td>
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<td>Acronym</td>
<td>Description</td>
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<td>SWMC</td>
<td>Solid Waste Management Council</td>
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<tr>
<td>UCAS</td>
<td>University College of Applied Science</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations of Development Program</td>
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<td>UNRWA</td>
<td>United Nations Relief and Works Agency</td>
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Chapter (1)

Introduction
1.1. Introduction

Currently, Gaza Strip is facing complicated solid waste management issues as landfills are rapidly filling up, increasing amount of waste are generated, shortage of disposal land, resulting in serious environmental and human health impacts. These circumstances happened due to the growing amount of waste generated in relation with the rapid population, and also due to the rising in the standard of living of the people.

Ministry of planning (MoP, 2010) estimated that the total daily solid waste produced in the Gaza Strip is about 1,300 tons/day. In order for government agencies to develop and implement effective strategies to meet the targets for municipal solid waste (MSW), reliable information on the composition of all parts of the MSW stream are required (Bumleya et al., 2007).

Moreover, to support integrated solid waste management which is now requested, it is necessary to ascertain environmental, economic and social impacts associated with various waste management options before decision makers can trade them off to achieve a better waste management strategy (Bazzani, 1998).

Landfilling is the oldest and most widely practiced method for disposing of solid waste. Properly constructed and operated landfill sites offer a safe disposal way for MSW, typically at the lowest cost compared to other disposal options. Should the financial resources be limited (as this is the case in many developing countries), it may not be necessary from health and/or environmental viewpoints to invest in other disposal methods given that suitable sites are available for landfills (Al-Yousfi, 2004).

Accordingly, landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life. Thus numerous criteria must be taken into consideration in the landfill sitting and weights must be assigned to each of them (Ball, 2005; Luthbom and Lagerkvist, 2003).

Actually, different tools and techniques are being developed for solid waste disposal site selection in developed countries. The Geographical Information System (GIS) can provide an opportunity to integrate field parameters with population and other relevant data or other associated features, which will help in the selection of suitable disposal sites (Rahman et al., 2008).
In the future there should be more and more waste avoidance so that landfilling of waste can be steadily reduced. On the long term landfills are not the appropriate method for waste management (Stegmann, 2005).

1.2. Statement of the Problem

Gaza Strip struggles from many environmental problems due to political, economical, institutional, technical, and social reasons. Therefore, solid waste sector as one of the vulnerable environmental issue has the same constraints.

The state of SWM in Gaza Strip is a serious concern. Currently, Waste management is one of the major challenges confronting the local authorities in Gaza Strip. Another aspect is the continuous expanding of the residential areas in the study area, which goes along with increasing waste collection areas. Together with these changes, solid waste has also undergone rapid changes in recent years (more plastics, papers, etc.). Unfortunately, waste management system never could keep pace with these changes, which lead to enormous waste problems in this region. The severity of the solid waste situation in the Gaza Strip can be attributed to many factors. These include: the continuing fiscal crisis, due to Israel’s blockage and the boycott on international aid; the lack of infrastructure and land for solid waste disposal, including sanitary landfills and recycling facilities; the physical damage caused to infrastructure and equipment by armed conflict; the absence of updated data in the solid waste sector; the lack of public awareness on how to properly dispose of solid waste and the need for doing so; the weak and underfunded environmental institutions on the national level; and the continual interruption of public civil services, by the Israeli Occupation.

This study focused on three problems related to SWM in Gaza Strip, those problems were concluded from the stakeholders statements. The first of all is the lack of updated information about the solid waste characteristic especially the composition of it. Secondly, there is no real integration between all stakeholders in SWM which leads to an absence of a unified vision for landfilling system in Gaza Strip. The final problem, which correlates strongly with the previous one, can be introduced by the disappearance of defining the suitable locations of landfills in Gaza Strip.

Indeed solving the previous addressed problems is considered as a baseline for landfilling planning in Gaza Strip which will manage not only the technical aspect but also the
Chapter 1

economical and environmental aspects.

1.3. Aim and Objectives

The primary aim of the research is to establish an optimum scenario and a baseline for landfilling planning taking into consideration other disposing management of the solid waste for the Gaza Strip till 2030.

The study is designed to support initiatives, bring useful information to all involved stakeholders (policymakers, communities, industries and academic/training bodies), and contribute to the setting-up of a vision for integrated management of waste in Gaza Strip. More specifically, the research work is intended to achieve the following objectives:

a. To review the composition of solid waste, and to carry out a representative and updated waste composition survey in purpose of identifying MSW composition in Gaza Strip.

b. To study the applicability of recycling and material recovery alternatives in the Gaza Strip and its impact on prolonging design period of landfills.

c. To determine the best number of landfills to be used as an end disposal facility of the solid waste in the Gaza Strip.

d. To identify suitable landfill sites for waste disposal in Gaza Strip by GIS.

1.4. Methodology

It is intended to achieve the objectives of the study by the following integrated steps:

a. Literature review

Relevant documents, papers and reports were reviewed in the fields of:

- Integrated solid waste management,
- Composition of waste,
- Landfill site selection and design considerations,
- Multi criteria decision analysis (MCDA), and
- Materials recovery.

b. Data collection

Data about solid waste quantities, sources, compositions and rate of generation, landfill descriptions and recycling practices in the Gaza strip were collected and revised from various
sources.

c. Field work

A survey was conducted at the landfills to study the real composition of MSW in Gaza Strip, thus a study of reduction options and recycling alternative depending on the waste composition was reported.

d. Meetings and Structured interviews

To choose the criteria needed for evaluation and comparison the optimal number of landfills in Gaza Strip, a set of meetings with experts was done using structured interviews in this field.

e. Questionnaire

For the purpose of assigning a weight for each criteria and sub-criteria, besides evaluating the options based on those criteria, a questionnaire was distributed to experts and stakeholders so that their feedback was modeled.

f. DEFINITE modeling

It is a model used to evaluate the scenarios and to support choosing the best scenario based on various techniques.

g. GIS modeling

After determining the optimal number of landfills, GIS tool was used to find out the suitable locations for landfills in Gaza Strip.

1.5. Thesis Outline

Thesis includes six chapters and four appendices. A brief description of the chapters’ contents is presented below:

Chapter one highlights the need for research in the field of SWM. Also, the aim and objectives of the research are described. At the end, the structure of the thesis is presented.

Chapter two reviews the main related topics such that definitions, SWM, landfilling as well as landfill site selection, and multi criteria decision analysis (MCDA). Meanwhile this chapter shows the previous studies done in the field of SWM.
Chapter one

Chapter three describes the study area and its demographical and meteorological characteristic, besides the properties of SWM in the study area.

Chapter four introduces and outlines the approaches and methodologies implemented to achieve the specific objectives of the study and the overall goal of the research.

Chapter five presents the results of the field work survey, the questionnaire as well as definite modeling, and the GIS modeling. Additionally, in this chapter deep analysis and interpretations of these results are introduced.

Achievements and main conclusions of the research with recommendations for future researches are formulated in chapter six.
Chapter (2)

Literature Review
2.1. Definitions

MSW is defined as solid waste includes all domestic refuse and non-hazardous wastes such as commercial and institutional wastes, street sweepings and construction debris (Shekdar, 2009).

MSW is defined by the U.S. EPA to include wastes from residential, multifamily, commercial, and institutional (e.g., schools, government offices) sources. This definition excludes many materials that are frequently disposed with MSW in landfills including combustion ash, water and wastewater treatment residuals, construction and demolition (C&D) waste, and nonhazardous industrial process wastes (Staley and Barlaz, 2009).

Ogwueleka (2009) defined MSW to include refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste, and street sweepings.

SWM may therefore be defined as that discipline associated with the control of generation, storage, collection, transfer and transport, processing and recovery, and final disposal of solid wastes in a manner that is in accordance with the best principles of public health, economics, engineering, urban and regional planning, conservation, aesthetics, and other environmental considerations which are also responsive to public attitudes (Jaya, 2004).

Municipal Solid Waste Management (MSWM) refers to the collection, transfer, treatment, recycling, resource recovery, and disposal of solid waste generated in urban areas. MSWM is a major responsibility of local government and a complex service involving appropriate organizational, technical, and managerial capacity and cooperation between numerous stakeholders in both the private and public sectors (Bernstein, 2004).

2.2. Integrated Solid Waste Management

Initially, SWM techniques aimed simply to eliminate waste from the vicinity of habitable areas as a means of maintaining public health.

Shekdar (2009) showed that the approaches for SWM should be compatible with the nature of a given society, and, in this regard, Asian countries are no exception. In keeping with global
trends, the systems are being oriented to concentrate on sustainability issues; mainly through the incorporation of 3R (reduce, reuse and recycle) technologies.

To support integrated solid waste management which is now requested it is necessary to ascertain environmental, economic and social impacts associated with various waste management options before decision makers can trade them off to achieve a better waste management strategy (Bazzani, 1998).

Also, an integrated approach to waste management will have to take into account community and regional-specific issues and needs and formulate an integrated and appropriate set of solutions unique to each context. As with any issue in developing nations, solutions which work for some countries or areas will be inappropriate for others. Specific environmental conditions will dictate the appropriateness of various technologies, and the level of industrialization and technical knowledge present in various countries and cities will constrain solutions. Studies on MSW issues however repeatedly discuss certain approaches as being at least adaptable to many developing nation scenarios. These approaches emphasize waste reduction (creation of less waste and increased material recovery) and appropriate disposal options as part of an integrated evaluation of needs and conditions (Zerbock, 2003).

Warith (2005) stated that source reduction and waste minimization, resource recovery and recycling, waste processing and treatment, combustion and landfilling have all significantly affected the sufficiency of waste management systems. Of all available management options for solid waste management, landfill disposal is the most commonly employed waste management worldwide.

In most cities of developing countries, waste management is inadequate: a significant portion of the population does not have access to waste collection services and only a fraction of the generated waste is actually collected. Systems for transfer, recycling and/or disposal of solid waste are unsatisfactory from the environmental, economic and financial points. Problems of shortage of cover, lack of leachate collection and treatment, inadequate compaction, poor site design, and many pickers working at the site are common. Thus, these dump sites are essentially uncontrolled, creating considerable health, safety, and environmental problems (Schubeler et al, 1996).
2.3. Solid Waste Composition

In many regions and countries, national and international targets have been set for MSW recycling, recovery and diversion from landfill. To develop and implement effective strategies to meet these targets requires reliable information on the composition of all parts of the MSW stream (Burnleya et al., 2007).

The cornerstone of successful planning for a waste management program is the availability of reliable information about the quantity and the type of material being generated and the understanding about how much of that material can expect to prevent or capture. Waste characterization studies are also used to assist in planning, policy development, and infrastructure sizing decisions for various facets of an integrated solid waste management program (Gidarakos et al., 2005; Staley and Barlaz, 2009).

Gidarakos et al. (2005) argued that effective waste management through MSW composition studies is important for numerous reasons, including the need to estimate material recovery potential, to identify sources of component generation, to facilitate design of processing equipment, to estimate physical, chemical, and thermal properties of the waste and to maintain compliance with national law and European directives. The composition of generated waste is extremely variable as a consequence of seasonal, lifestyle, demographic, geographic, and legislation impacts. This variability makes defining and measuring the composition of waste more difficult and at the same time more essential.

The two most widely used methods for waste characterization are the materials flow method and site-specific sampling via sorting and weighing refuse by category. The materials flow method uses industry data on the production and import and export of goods to estimate waste generation. It is best applied at the national level. In addition, the materials flow approach cannot account for seasonal, geographic, and socioeconomic differences at regional or local levels (Staley and Barlaz, 2009).

A standard method for determining waste composition by sorting method has been published by ASTM D5231-92 (2003). The ASTM method notes that: 1) the number of samples should be defined based on statistical criteria; 2) load selection for sampling should be randomized and performed over a 5–7-days period and; 3) the initial sample should weigh approximately
four times the subsample that will be sorted. The method also provides an abbreviated list of waste component categories and category definitions (Gidarakos et al., 2005; Staley and Barlaz, 2009).

2.4. Landfilling

Landfilling as “fate of waste” has been playing an important role in waste management, and is still the most common technique for waste management in most countries. The placement of solid waste in landfills is the probably the oldest and definitely the most prevalent form of ultimate garbage disposal. From the outset, it must be recognized that many “landfills” are nothing more than open, sometimes controlled, dumps. The difference between landfills and dumps is the level of engineering, planning, and administration involved. Open dumps are characterized by the lack of engineering measures, no leachate management, no consideration of landfill gas management, and few, if any, operational measures such as registration of users, control of the number of “tipping fronts” or compaction of waste. ‘Sanitary’ landfills, on the other hand, are sites where waste is allowed to decompose into biologically and chemically inert materials in a setting isolated from the environment (Haiyun, 2008; Zerbock, 2003).

Thurgood (1997) stated that as a minimum, four basic conditions should be met by any site design and operation before it can be regarded as a sanitary landfill:

- Full or partial hydrogeological isolation
  If a site cannot be located on land which naturally contains leachate securely, additional lining materials should be brought to the site to reduce leakage from the base of the site (leachate) and help reduce contamination of groundwater and surrounding soil.

- Formal engineering preparations
  Designs should be developed from local geological and hydrogeological investigations. A waste tipping plan and a final restoration plan should also be developed.

- Permanent control
  Trained staff should be based at the landfill to supervise site preparation and construction, the depositing of waste and the regular operation and maintenance.
Chapter 2

Planned waste emplacement and covering

Waste should be spread in layers and compacted. A small working area which is covered daily helps make the waste less accessible to pests and vermin.

Landfilling is the oldest and most widely practiced method for disposing of solid waste. Properly constructed and operated landfill sites offer a safe disposal way for municipal (and industrial) solid wastes, typically at the lowest cost compared to other disposal options. Should the financial resources be limited (as this is the case in many developing countries), it may not be necessary from health and/or environmental viewpoints to invest in other disposal methods given that suitable sites are available for landfills. In other words, sanitary landfills can be “stand alone” facilities under constrained conditions. Landfills however, form the basis of every integrated solid waste management plan. There are a number of complementary (or alternative) treatment options for waste, e.g., incineration, composting…etc., but none of these treatment options can function alone. All require landfill as a final stage: all other waste management options, such as recycling and incineration, rely on landfills for disposing of unsuitable refuse or inert residues, respectively. Therefore availability of some landfill space is essential for every region, and will continue to be so in the future in spite of technological advancements (Al-Yousfi, 2004).

Cheremisinoff (2003) stated that the advantages of landfilling as a waste disposal option include:

• It costs less than other disposal options
• A wide variety of wastes are suitable for landfill
• It frequently offers the only final disposal route for residues arising from end-of-pipe treatment technologies and other waste management options, such as incineration
• Landfill gas can be collected and utilized for heat and as a low-polluting fuel for energy generation.
• Restored land can provide valuable space for wildlife habitat or leisure use.
In the other hand, the disadvantages of landfills include:

- Older sites, constructed before the impacts of leachate and landfill gas were realized, are now sources of pollution with uncontrolled leakages.
- There is continued risk of contamination from operational landfill sites.
- Some parts of the world are experiencing shortages of suitable landfill sites close to the source of waste generation.
- Landfilling achieves a lower conversion of wastes into energy than other solid waste management strategies.
- The convenience of landfilling tends to discourage the development of innovative waste management strategies.
- Landfilling may produce contaminated land that is unsuitable for some future uses.
- Landfilling causes noise pollution, odors, unsightliness, and often heavy vehicle movement adding to air pollution problems.

Al-Yousfi (2004) showed that there are four universal types of landfills: Uncontrolled Dumps, Total Containment, Modified Containment and Controlled Release. The first type (common in many under-developed countries) is not at all a waste management method. The other types are indeed different forms of the engineered “Sanitary Landfill”. The second landfill type attempts per se to prevent all inflow and outflow of liquids into/from the landfill system, slowing down the rate of waste degradation and impeding stabilization (sealed entombment approach). However, since total containment cannot be practically guaranteed, this type is not usually recommended. However, some of its applications can be utilized for hazardous waste disposal with repetitive layers of containments. Modified containment landfill allows some surface water to penetrate and the surplus leachate to flow through to be later collected and removed. This third type is technically preferred and can be accompanied with leachate-recirculation in order to control the microbially mediated decomposition processes, accelerating wastes stabilization; such a special type is further developed to a new family known as the “Landfill Bioreactor”. Finally, controlled release landfills can be used for inert wastes such as construction debris and incineration ash. As for the ultimate disposal of hazardous wastes, a unique type of Landfilling known as the “Secure Landfill” should be
employed to provide extensive protection of human health and the environment against the perceived risks.

The enhancement of the biological processes in the landfill reduces the emission potential of a landfill much faster, high gas production is more concentrated to a shorter time period and leachate concentrations are significantly reduced at an earlier time. There is a lot of mystery about bioreactor landfills, but what it means in most cases, is that leachate is recirculated in a more or less controlled way (Stegmann, 2005).

Today, the “bioreactor landfill” is one idea that has gained significant attention. A bioreactor landfill is a sanitary landfill that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 10 years of bioreactor process implementation (Warith et al., 2005).

2.5. Landfill Site Selection

Proper landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life. It determines many of the subsequent steps in the landfill process, which, if properly implemented, should ensure against nuisances and adverse long-term effects. For example, a well-selected landfill site will generally facilitate an uncomplicated design and provide ample cover material, which would facilitate an environmentally and publicly acceptable operation at a reasonable cost (Ball, 2005).

Numerous criteria must be taken into consideration in the landfill sitting and weights must be assigned to each of them. These criteria include natural physical characteristics as well as socioeconomic, ecological, environmental, socio-political, and land use factors (Ball, 2005; Luthbom and Lagerkvist, 2003; Rahman et al., 2008).

2.5.1. Site Selection Criteria for Landfills

Several countries (like Australia, Malaysia, Niger, North Dakota, Philippines, Uganda, and United States among others) have put in place guidelines for selecting suitable sites for sanitary landfills for waste management. These guidelines and policies act as the primary mechanism used to protect the environment and avoid nuisance to the host community. Below are the factors that several researchers (EPA, 2007; Gaim, 2004; North Dakota Department of
Health, 2009; Twumasi et al., 2006; Despotakis and Economopoulos, 2007; Chang et al., 2008; Lin and Kao, 1999; Bagchi, 1994) have used to determine the appropriateness of a site to be used as a sanitary landfill.

1. Site Capacity: A site should provide at least 10 years of use in order to; minimize costs for site establishment and closure, smooth running of operations, and provision of adequate time for acquiring the next site.

2. Adjacent Land Uses or Land cover: Location of a landfill facility should not endanger any environmentally sensitive areas or have a negative impact on existing or future land uses. Risks to public health and impacts on the areas surrounding the landfill can be limited by providing buffer zones between the landfill and sensitive areas. Several researchers have recommended appropriate buffer distances between a landfill facility and other land uses. For example; at least 100 meters from public roads, and at least 200 meters from industrial developments.

3. Airports: Because it attracts birds, the distance from an airport should be a minimum of 3.0 km, unless there is a clear demonstration of bird control measures.

4. Surface Water: The distance between the areas dedicated for waste disposal and the nearest surface water (permanent or intermittent) or the 100 year flood plain should be a minimum of 100 m. Sites that contain, or are located within 100 meters of; water supply catchments or ground water recharge areas, coastal areas, are subject to tidal inundation or storm surge, wetlands, areas that may be seasonally inundated, or are likely to be flooded in a major rain event, water bodies (watercourses or open drains). Depending on the circumstances, high water Table conditions may also render a site unsuitable for use as a landfill facility. This minimizes the risk of polluting water with leachate. However, North Dakota Department of Health (2009) recommended a minimum distance of 200 feet (equivalent to about 60 meters) to the nearest surface water. However Bagchi (1994) stated that a landfill should not be located within 100 feet (30.48 m) of any non-meandering stream or river, and at least 300 feet (91.44 m) from any meandering stream or river.

5. Groundwater: Major landfills are not encouraged where the interface between the engineered landfill liner and natural soils is within: 15 meters of unconfined aquifers
bearing groundwater with less than 3000 mg/L total dissolved salts, 5 m of groundwater with a water quality of between 3,000 and 12,000 mg/L total dissolved salts, 2 m of groundwater with a water quality of over 12,000 mg/L total dissolved salts. These separation zones apply to the seasonal high water Table (depth of drilling earth to get water) at the site. An extremely deep water Table region is suitable so that underground water is not contaminated by the leachate of the waste. North Dakota Department of Health (2009) explained that the bottom of disposal trench should be at least four feet above the water Table (equivalent to about 1.20 meters). In addition, Chang et al. (2008) recommended 50 meters buffer zone around water wells to prevent contamination from landfill due to leaching of pollutants.

6. Local Topography: Landforms in the vicinity of the disposal site should be considered since they may influence; the type of disposal method that can be utilized, the suitability of the site for construction of service facilities, surface water drainage management, groundwater conditions, soil erosion risk, access to the site, ability to screen the site from view, and the impact of winds on the site. Preference is given to a landform that is located in flat or undulating land. Other than on the site of a disused quarry, major landfills must not be sited in hilly areas, with ground slopes nominally greater than 10 percent. However, EPA (2007) recommended a slope less than 5 percent, and North Dakota Department of Health (2009) recommended 15 percent slope or less.

7. Soils: Soil structure should be suitable for construction of landfill cells and drainage works. The soil should also be of sufficiently low permeability to significantly slow the passage of leachate from the site. Sites in clay-rich environments are preferable, due to the low permeability, good workability and superior leachate retaining characteristics of these soils. Sufficient soil should be available to provide adequate covering for wastes.

8. Climate: Local climatic conditions should be considered when siting a waste disposal facility. For example; areas with heavy rainfall need extra care to avoid side effects of drainage and erosion, sites with prevailing winds require extra efforts to control litter and dust.

9. Unstable Areas: Major Landfills must not be located within 100 meters of an unstable area. Unstable areas can include poor foundation conditions, areas susceptible to mass
movement, soft sandy and collapsible soils, and Karst terrains. North Dakota Department of Health (2009) supplemented that environmentally sensitive or unstable areas do not provide safe, long-term waste disposal. Such areas include; wetlands, gravel pits, flood plains, and shallow water Table areas. All these are environmentally sensitive to surface water and groundwater pollution. Ravines, woody draws, and steeply sloping terrains are unstable areas subject to accelerated erosion, which may expose the waste.

10. Infrastructure: Although landfills should have suitable transport access, with power and water available, landfills should not be located within 100 meters of any major highways, city streets or other transportation routes. Twumasi et al. (2006) recommended a distance of 300 meters. However, it would be more cost efficient for landfills not to be located so far away in order to avoid high transportation costs, so Baban and Flannagan (1998) used a 50 meters buffer for roads.

11. Local Flora and Fauna: Sites that contain protected or endangered fauna and/or flora, or sensitive ecosystems are unsuitable for landfill facilities. Possible impacts on ecosystems, flora and fauna include the contamination of sensitive wetland areas by leachate. In addition, landfills often attract large numbers of birds, thus increasing the risk to public health by spreading scavenged items away from the landfill facility.

12. Distance from environmentally sensitive or protected areas: A landfill must not be located in close proximity to sensitive areas such as fish sanctuaries, mangrove areas and areas gazetted for special protection would be excluded. Therefore a 3,000 meters buffer is necessary to surround an environmentally sensitive area. However, EPA (2007) recommends that a buffer within the landfill of at least 500 meters width should be provided and maintained around the site. A lesser buffer within the landfill may be provided where it is considered compatible with the surrounding area and land uses so that there will be an effective buffer of 500 meters between the landfill and any potentially sensitive or incompatible land use.

13. Distance from urban areas: the landfill should be situated at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odor (Tagaris et al., 2003), noise, decrease in property value (Zeiss and Lefsrud, 1995), and health concerns, which may avoid contamination of freshwater aquifers through leaching (Nagar
and Mizra, 2002). Urban buffers may range from 150 meters (Lin and Kao, 1999) to 5 km (Zeiss and Lefsrud, 1995). According to EPA (2007) a landfill site should be located in an area which is at least 500 meters from an urban residential or commercial area.

14. Coastline areas: Despotakis and Economopoulos (2007) showed that landfills should located minimum 100 meter from coastline areas.

15. Population: Gaim (2004) recommended that areas with a population density less than 200 were regarded as suitable for landfills.

2.5.2. Implementation of GIS for Landfill Site Selection

Different tools and techniques are being developed for solid waste disposal site selection in developed countries. The Geographical Information System (GIS) can provide an opportunity to integrate field parameters with population and other relevant data or other associated features, which will help in selection of suitable disposal sites (Rahman, et al., 2008).

Vatalis and Manoliadis (2002) argued that site selection procedures can benefit from the appropriate use of GIS. Common benefits of GIS include its ability to: (i) capture, store, and manage spatially referenced data, (ii) provide massive amounts of spatially referenced input data and perform analysis of the data, (iii) perform sensitivity and optimization analysis easily, and (iv) communicate model results. Spatial feature extraction or classification is one of the GIS capabilities for searching suitable sites.

As the landfill site selection process depends on a variety of laws, regulations and factors, large volume of spatial data should be evaluated and processed. To overcome this difficulty, GIS is commonly used to select suitable sites for landfill (Baban and Flannagan, 1998; Allen et al., 2002).

There are several available softwares using GIS, however, one of the most popular that can be customized is ArcGIS Desktop. ArcGIS is a suite of GIS software systems. These systems serve GIS professionals with a spectrum of geographic data management, spatial editing, and cartographic visualization functionality. The ArcGIS Desktop systems contain a configuration of applications, such as ArcCatalog, ArcMap, ArcToolbox™, and ArcScene, and can support a variety of extension products such as ArcGIS Spatial Analyst, ArcGIS Geostatistical Analyst, ArcGIS 3D Analyst™ and others. The ArcGIS applications are engineered for ease of use and powerful geographic display, query, and analysis. By their design, they are generic
2.6. Recycling and Composting

In the future there should be more and more waste avoidance and recycling so that landfilling of waste can be steadily reduced. On the long term landfills are not the appropriate method for waste management (Stegmann 2005).

Solid waste is processed for recycling and/or to reduce its volume and pollution potential for landfill sites. The sustainability of a recycling sector depends on its cost-effectiveness; and this is mostly determined by the economic status of a society. In developed economies, there exists an organized method for collecting and processing some recyclables like paper, glass and metal through public and private participation. In the case of developing economies, where the percentage of recyclable fractions like paper, glass and metals is lower, their recovery and recycling has been performed mostly by small industry in a less organized manner (Shekdar 2009).

In recycling, waste materials are processed industrially and then reformed into new or similar products. Recycling includes pre-consumer waste, such as factory cuttings or shavings, as well as post-consumer waste items, including cardboard, newspapers, plastic bottles, and aluminum cans. Although recycling is often viewed as a resource conservation activity, it may offer greater return for many products in terms of energy savings.

A second means of recapturing value is through the use of the natural biodegradation process. In urban areas, the composting of leaf and tree waste alone can reduce landfill dependency by up to 12 percent. The segregation of yard waste from other organic (biodegradable) wastes is necessary to avoid contamination of the compost which might render the mulch or end product less desirable (Heimlich et al., 2003).

Composting is a controlled biological process that uses natural aerobic processes to increase the rate of biological decomposition of organic materials. Composting MSW reduces the volume of the waste, kills pathogens that may be present, decreases germination of weeds in agricultural fields, and destroys malodorous compounds. A second possible reason sometimes offered as to why some communities might want to explore MSW composting has to do with the difficulty of sitting a new landfill (Renkow and Rubin, 1998; Hargreaves et al., 2008).
2.7. Multi Criteria Decision Analysis (MCDA)

Decision Analysis is a set of systematic procedures for analyzing complex decision problems. These procedures include dividing the decision problems into smaller more understandable parts; analyzing each part; and integrating the parts in a logical manner to produce a meaningful solution. (Malczewski, 1999)

MCDA has undergone an impressive development during the last 30 years, in part because it is amenable to handling today’s complex problems, in which the level of conflict between multiple evaluation axes is such that intuitive solutions are not satisfactory. MCDA is not a tool providing the ‘right’ solution in a decision problem, since no such solution exists. The solution provided might be considered best only for the stakeholders who provided their values in the form of weighting factors, while other stakeholders’ values may indicate another alternative solution. Instead, it is an aid to decision-making that helps stakeholders organize available information, think on the consequences, explore their own wishes and tolerances and minimize the possibility for a post-decision disappointment. (Belton and Stewart, 2002)

2.7.1. Steps of Multi Criteria Decision Analysis

Decision making about proposals for future action should normally follow the sequence below stated by Lawrence et al. (2001). The following process might apply to the development of a policy, a program or a project.

- Identification of decision makers (DMs), actors, and stakeholders.
- Identification of criteria and objectives.
- Identification of alternatives and options for achieving the objectives.
- Selection of MCDA technique.
- Assignment of criteria performance values.
- Weighting the criteria.
- Ranking the alternatives.
- Sensitivity Analysis.
- Making a decision.
Chapter 2

2.7.2. Methods of Multi Criteria Decision Analysis

This chapter gives a broad overview of the full range of MCDA techniques currently available. However, it is neither necessary nor desirable to explore all these techniques in detail. Some are oriented towards issues which public sector decision makers are unlikely to encounter; some are complex and untested in practice; others lack sound theoretical foundations.

All MCDA approaches make the options and their contribution to the different criteria explicit, and all require the exercise of judgment. They differ however in how they combine the data. Formal MCDA techniques usually provide an explicit relative weighting system for the different criteria. The main role of the techniques is to deal with the difficulties that human decision-makers have been shown to have in handling large amounts of complex information in a consistent way. MCDA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. The following sections outline some of the best-known approaches (Clemen, 1996).

2.7.2.1. Simple Additive Weighting (SAW)

Simple additive weighting which is also known as weighted linear combination or scoring methods is a simple and most often used multi-attribute decision technique. The ranking of the alternatives is defined based on the weighted sum of the effect score. This method is especially suitable for problems with scores measured on a quantitative scale. The user has to indicate the relative importance (the weight) of the effects.

Triantaphyllou and Mann (1989) stated that the first step is that all effect scores are standardized. An appraisal score is then calculated for each alternative by first multiplying these standardized affect scores by its appropriate weight, followed by summing up the weighted scores of all effects. The final ranking of the alternatives is assessed based on the resulting appraisal scores for each alternative. The final scores and ranking are dependent on the standardization method being applied. By saving the MCDA results, the results of different calculations can be compared. In this way the influence of changes in weights,
weight methods and standardization procedures can be analyzed. The result of weighted summation is a ranking of the alternatives and an appraisal score for each alternative”.

The SWA method is the simplest MCDA method for handling cardinal data. Since it is easy to use and can be easily understood by the decision maker, this method is widely used in many fields. After the impact matrix has been defined, linear transformation is applied to normalize it. For each alternative, a utility value $U_i$ is determined by multiplying the normalized impact value of each alternative by its importance weight. Then the summation of these products is taken. Mathematically, the utility function can be written as

$$U_j = \sum_{i=1}^{n} w_i r_{ij}, \quad j = 1, 2, \ldots, m, \quad eq (2.1)$$

Where $w_i$ is the importance weight of the attributes and $r_{ij}$ is the normalized impact matrix. After the utility values are computed for each attribute, the alternative with the highest score (i.e. the highest weighted average) is chosen as the most preferable alternative for the decision maker (Malczewski, 1999).

**2.7.2.2. Analytical Hierarchy Process (AHP)**

The AHP developed by Saaty (1980) is a technique for analyzing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles: decomposition, comparative judgment and synthesis of priorities.

AHP is a well-known technique that breaks down a decision-making problem into several levels in such a way that they form a hierarchy with unidirectional hierarchical relationships between levels. The top level of the hierarchy is the main goal of the decision problem. The lower levels are the tangible and/or intangible criteria and sub-criteria that contribute to the goal. The bottom level is formed by the alternatives to evaluate in terms of the criteria. AHP uses pair wise comparison to allocate weights to the elements of each level, measuring their relative importance with Saaty’s 1-to-9 scale, and finally calculates overall weights for evaluation at the bottom level. The method also calculates a consistency ratio (CR) to verify the coherence of the judgments, which must be about 0.10 or less to be acceptable. AHP is conceptually easy to use; however its strict hierarchical structure cannot address the
complexities of many real-world problems (Aragones-Beltran et al., 2010).

2.7.3. Multi Criteria Decision Analysis in Environmental Planning

Environmental planning and decision-making are essentially conflict analyses characterized by sociopolitical, environmental, and economic value judgements. Several alternatives have to be considered and evaluated in terms of many different criteria, resulting into a vast body of data that are often inaccurate or uncertain. To complicate the process further, there are typically a large number of decision-makers (DMs) with conflicting preferences. The different points of view of various interest groups also should be considered in the process. Therefore, a single, objectively best solution does not generally exist, and the planning process can be characterized as a search for acceptable compromise solutions (Lahdelma et al., 2000).

A fundamental difficulty in planning MSWM system is the need to simultaneously account for conflicting objectives. Planners must develop the best practicable and environmentally sustainable waste management strategies, which can be very difficult. The different objectives are not all related to economic costs, and must therefore be considered in a proper multi-objective framework. Generally speaking, the objectives are partly economic and partly environmental (Minciardi et al., 2008).

The necessity of using a multi-objective framework to consider the MSW management problem arises from the difficulty of finding simple trade-offs between economic and environmental objectives. A realistic model of the decision process has to take into account the interactive features that generally characterize the process. This interaction takes place whenever the decision maker has to evaluate a certain solution and then express the preference trade-offs. The difficulty lies in correctly involving the decision maker (not necessarily a technician) and possibly iteratively interacting with the decision maker. This becomes particularly important when there are social and political issues separate from the technical aspects, which can be taken into account only through interaction with the decision makers (Costi et al., 2004).

Different MCDA methods aim at supporting such complex planning and decision processes by providing a framework for collecting, storing, and processing all relevant information. The core of the selected MCDA method is the decision model, which is a formal specification of
how different kinds of information are combined together to reach a solution. MCDA methods are used in environmental planning and decision-making processes in order to clarify the planning process, to avoid various distortions, and to manage all the information, criteria, uncertainties, and importance of the criteria. MCDA methods can alleviate the problems caused by limited human computational power. Intuitive or adaptive choices are replaced by a justified and jointly accepted model (Lahdelma et al., 2000).

The type of the model selected should suit the type of problem and the available data. As the considered waste management problem is complex and has several different decision-making levels, the model chosen for this study was based on multi criteria decision Analysis. A variety of multi-criteria methods such as ELECTRE, TOPSIS and AHP have been used in dealing with environmental problems (Morrissey and Browne, 2004).

Different approaches have been proposed to solve multi-objective problems based on MCDA models. Some authors have addressed the problem from a multi objective approach, in which the set of feasible alternatives is considered infinite. Recent versions of the method can be found in Alumur and Kara (2007), Emek and Kara (2007) or Colebrook and Sicilia (2007). A different approach to the problem comes from the use of MCDA techniques, which consider a finite and relative small set of alternatives, yet the number of criteria involved in the process is high. MCDA techniques incorporate both quantitative and qualitative criteria to a decision problem. Cheng et al. (2002) use MCDA techniques for supporting decisions of solid waste management (simple weighted addition method, weighted product method, TOPSIS, cooperative game theory and ELECTRE). In a later work these authors integrate MCDA and inexact mixed integer linear programming (IMILP) methods to support the selection of an optimal landfill site (Cheng et al., 2003). PROMETHEE methods have been used by Queiruga et al. (2008) for selecting potential locations of recycling plants for treatment of waste electrical and electronic equipment; Khalil et al. (2004) for site selection for sustainable on-site sewage effluent disposal, Martel and Aouni (1992) for site selection of an airport, Vuk et al. (1991) for the selection of a communal waste disposal facility site. ELECTRE methods have been used by Norese (2006) for locating an incinerator and a facility to store ashes and other wastes in Italy; and Rey et al. (1995) for the location of a stabilized-waste storage facility. Fuzzy TOPSIS has been used by Yong (2006) for plant location and Chu (2002a,b)
for facility location and plant location. Recently other techniques combining GIS and fuzzy multi criteria decision-making have been applied for landfill siting (Chang et al., 2008).

AHP techniques have been used by Dey and Ramcharan (2008) for the site selection of limestone quarry operations to support cement production in Barbados; by Gemitzi et al. (2007), Kontos et al. (2003), and Sener et al. (2006) for ranking potential MSW landfill areas; and by Wang et al. (2009) combined with spatial information technologies for landfill site selection. AHP and TOPSIS have been used by Oenuet and Soner (2008) for solid waste transshipment site selection in Turkey.

Lahdelma et al. (2000) defined the problems setting in multi criteria decision analysis is typically one of the following:

1. Choose one or more best alternatives. This problem setting is most frequent in MCDA literature. However, in real environmental problems, the DMs often dislike the idea that some MCDA method would make the decision for them.

2. Complete or partial ranking of the alternatives. In real environmental problems, the DMs often require a ranking of the alternatives even in cases where the final decision is to choose the best alternative. This approach gives the DMs more freedom to choose the second, third, etc., best alternative if they for some reason want to.

3. Acceptability analysis of the alternatives. The result is a description of what kind of preferences would give the best rank, or any specific rank, for each alternative. This approach allows maximum freedom for the DMs.

2.7.4. DEFINITE Software Package

DEFINITE (decisions on a finite set of alternative) is a decision support software package that has been developed to improve the quality of decision making and it is developed at the Institute for Environmental Studies of the Free University of Amsterdam, Netherlands. DEFINITE is, in fact, a whole toolkit of methods that can be used on a wide variety of problems. If you have a problem to solve, and you can identify alternative solutions, then DEFINITE can weigh up the alternatives for you and assess the most reasonable. The program contains a number of methods for supporting problem definition as well as graphical methods to support representation. To be able to deal with all types of information DEFINITE
includes multi criteria methods, cost-benefit analysis and graphical evaluation methods. Related procedures such as weight assessment, standardization, discounting and a large variety of methods for sensitivity analysis are also available. A unique feature of DEFINITE is a procedure that systematically leads an expert through a number of rounds of an interactive assessment session and uses an optimization approach to integrate all information provided by the experts to a full set of value functions. DEFINITE supports the whole decision process, from problem definition to report generation. Its structured approach ensures that the decisions arrived at are systematic and consistent. DEFINITE offers a suite of multi-criteria techniques with a variety of options to import raw data and weights, and standardize the estimates for the achievement/satisfaction scores to ensure they are commensurate. This note reports the use of the four techniques that comprise the Multi Criteria Analysis (MCA) section of DEFINITE. The four techniques are: (i) Weighted Summation method, (ii) Electre II method, (iii) Regime method, and (iv) Evamix method (Janssen et al., 2001).
Chapter (3)

Study Area
3.1. Characteristics of the Study Area

Gaza Strip, shown in Figure (3.1), is located along the coast of the eastern Mediterranean Sea stretches over a distance of approximately 45km from Beit Hanoun city in the north to Rafah city in the south. Its width varies between 7 and 12km and the total area is about 365 km$^2$. 

Figure 3.1: Gaza Strip Governorates
Administratively, Gaza Strip is divided into five governorates: North, Gaza, Middle, Khan Younis and Rafah governorate in the south bordering with Egypt. Each governorate consists of municipalities that varied in number depending on the number of towns or villages and the population of each (Khalaf, 2005).

3.1.1. Topography

Topography refers to the altitude of the land surface. Gaza strip is a coastal foreshore plain gradually sloping westward toward the sea allowing for surface run-off to reinfiltrates the soil. The topography of the area is flat, where the altitude of the Gaza Strip land surface ranges between zero meters at the shore line to about 90 meters above mean sea level in some places. The height increases towards the east from 20 to 90 meter above the sea level (ARIJ- Part II, 2001).

3.1.2. Population

Population size is always a relevant factor in estimating majority of municipal services. Municipal Solid waste total generations are mainly dependent on per capita generation. For proper solid waste management plan and sustainability, it is mandatory to predict in some manner the future population based on statistics. The estimated population is around 1.5 million inhabitants that mean the area is highly populated due to the high growth rate (MoP, 2010).

3.1.3. Meteorological Conditions

3.1.3.1. Rainfall

Generally; the climate of Palestine is of East Mediterranean type ; identified as being hot and humid in summer and cold in winter. The US Environmental Agency has classified regions into arid and non-arid regions based on rainfall of 12.5 in/yr (312.5 mm/yr) to be the reference (Qrenawi, 2006). The Gaza Strip area is classified as a semiarid region since the average annual rainfall is about 13.83 in/yr (351.4 mm/yr). The nearest meteorological station to Gaza landfill is Gaza south (Mogragah) station at a coordinate of 31° 27.54’ N & 34° 27.03’ E while Dear Al Balah landfill is Dear Al Balah station at a coordinate of 31° 23.50’ N & 34° 22.77’ E (PMO, 2008).
3.1.3.2. Temperature

The area has a Mediterranean dry summer sub topical climate with mild winter; this is because of its locations as transitional zone between semi-humid Mediterranean climate and arid desert climate.

The highest mean annual temperature is 30.85 °C in August, while the lowest mean annual temperature is 13.50 °C in January, with the mean annual temperature of 19.90 °C (PMO, 2008).

3.1.3.3. Wind Speed

The wind velocity with northwest direction at 2 meter above the surface in the summer is about 1.5 m s\(^{-1}\), which is less than that is during winter months where velocity reaches values of 2.8 m s\(^{-1}\) (DHaeyer, 2000).

3.2. Status of Solid Waste in Gaza Strip

SWM is a growing issue that has caused environment pollution especially in urban localities of the Gaza Strip. The state of SWM in Gaza Strip has much improved over the last decade. But still, many challenges face Palestinian authorities, in terms of improving waste management, including: (ARIJ, 2007)

- Rapid population growth and increased solid waste production.
- Inadequate solid waste management.
- Persistent public ignorance on sensible waste management procedures.

3.2.1. Solid Waste Production and Composition

It’s estimated that the total daily solid waste produced in Gaza Strip is about 1,300 tons/day (MoP, 2010). Waste production was 0.6-1.0 kg/c/d, and waste density at collection points was 0.4 kg/l. Solid waste in Gaza consists mainly of household waste, building debris, agricultural wastes, industrial waste, medical wastes, and car workshops. A report issued by ministry of planning 2010 mentioned that the composition of the solid waste is estimated that 65%, of the household solid waste consist of organic material, sand 10%, plastic 12%, Glass 3%, Metals 5% and others 5% (MoP, 2010).
3.2.2. Collection and Disposal of Solid Waste

It is mostly municipalities that provide collection services in the large towns, and villages either formally or informally. Also UNRWA provides collection and disposal service for refugees camps. In some areas of Gaza City where a house-to-house collection service is provided using donkey carts, from which the waste is transferred to a skip container. Most cities are served by rear-loading compactor trucks which empty wheeled bins with a capacity of about one m$^3$. A new system, which is used in conjunction with crane-tipper trucks, is a house-to-house collection using a small agricultural tractor, which has an attachment at the rear to enable it to carry one 1m$^3$ container. When full, the container can be left at the roadside for a crane tipper to pick up and empty it (Coad, 1997). Currently, there are three landfills shown in Figure 3.1 in Gaza Strip; in south, middle, and Gaza. In Gaza Governorate, the disposal site covers at least 140 dunum directly east of Gaza City and adjoining the Green Line with Israel. This site receives wastes from both Gaza Governorate and Northern Governorate under agreement. Groundwater is about 80 meters below surface, with sand and clay layers forming the sub-surface. There is a special cell constructed and designed for the disposal of hazardous waste and it is double lined by polyethylene, it is used for the moment for the disposal of expired medical wastes only.

In the Middle Governorate, the landfill is located east of Deir El Balah city and covers approximately 60 dunum and also adjoins on the Green Line with Israel. This landfill receives wastes from both Middle Governorate and Khan Younis Governorate under Joint Service Council agreement. The landfill is lined with asphalt and equipped to recirculate leachate. Groundwater is about 60 meters below surface. The surface layer (approximately 15 meters deep) is sand, below which there is a clay layer of about 20 meters that in turn is underlain by a mixture of sand and clay to the groundwater level.

In Rafah Governorate a waste disposal site of approximately 27 dunum is located near to Sofa crossing border. This site receives waste from different communities of Rafah Governorate including different municipalities. The site is not lined but has leachate recirculation abilities and a weighbridge (Nassar and Jaber, 2007).

3.2.3. Composting and Recycling

Two other waste volume reduction strategies (recycling and composting) have not been
implemented to any significant degree at the national level in Gaza Strip. This is despite their promise for not only reducing volume but also for conserving natural resources and saving energy used in manufacturing new goods. Pilot composting programs were started in conjunction with the landfill system in the Gaza Strip. They have been suspended due to damage caused to facilities by Israeli gun fire and the danger posed to workers in charge of these facilities. Additional obstacles are presented by the unwillingness of residents on the individual and community level to allow composting plants to be built near them. The population of Gaza Strip is very dense, and the prospects are slim for finding locations to build waste management facilities where no one objects (UNEP, 2003).

The recycling sector in the Gaza Strip will probably grow quite slowly because there is no established pattern to follow. Currently, a very small fraction of solid wastes is recycled, mainly steel scrap and a small amount of organic.

El-Hawi et al. (2002) stated that the total MSW recycling is 9,068 tonne/year out of 215,000 tonne/year (a recycling rate of 4.21 per cent). Metals 5830 tonne, organics 1419 tonne, Paper and card 1080 tonne, Plastics 432 tonne, glass 200 tonne and cloth 107.

In Gaza City 100% of waste collected, minus perhaps between 2% and 5% of plastic content collected for recycling, goes into Gaza landfill. Palestinian Friends of the Environment (PEF) has conducted a couple of small composting projects in Khan Yunis as pilot projects and therefore has a level of experience of compost production in the Gaza environment. One or two INGOs have planned projects in SWM, but have tended to rely on equipment and vehicles as part of the solution, none of which are currently allowed into Gaza and as a result these projects are currently stalled (Morris-Iveson, 2009).

Recycling, too, has not been institutionalized on a national level. Some instances of recycling occur within the private sector, such as return-of-deposit schemes on glass bottles. The success of these programs depend upon the willingness of consumers to participate and, more importantly, upon the initiative of the companies to arrange for pickup of items and set up channels for reimbursement of suppliers. Thus far, many companies have not invested in such activities. Because the industrial sector in Gaza Strip is so small, a natural alternative could be, simply, to export recyclable material to Israel or Egypt. Both countries have already well-established recycling programs (UNEP, 2003).
There appears to be only one waste recycling stream operating, that of medium density plastic, under the coordination of the Palestinian Federation of Industries. The two plastic recycling industries visited operate based on plastic inputs from both individuals (largely through scavenging at municipal dumpsites and locally) and direct purchase from companies discarding plastic-based furnishings. Purchase from individuals covers around 70% of plastic input required at the Mahani Brothers Company in Jabalya. The output from this factory is plastic pipes, sold primarily to the Water Board. The factory runs at a production level of 700 kg of piping per day, and can produce gauges between 16 mm and 110 mm. Regular power cuts (estimated at an average of 2 to 3 hours per day) and the lack of plastic inputs means that the factory uses only 2 of its 8 machines. Another use of recycled plastic is at the Modern Industry Company in Khan Yunis, which again relies on discarded and purchased plastic inputs. This factory produces children’s toys and runs at around 50% capacity. There are around 20 such factories in Gaza, producing pipes, plastic containers and water tanks (Morris-Iveson, 2009).

3.2.4. Institutional and Organizational Arrangements

The Ministry of Local Government (MoLG) is the main coordinating leading ministry in line ministries of concern for solid waste management within the occupied Palestinian Territories (OPT), having overall responsibility and surveillance for the relevant functions of local government agencies. The regional solid waste councils and municipalities are responsible for the construction of solid waste treatment facilities, under the supervision of the ministry of Local Government. The Ministry of Planning (MoP) is responsible for the overall planning and fund affording in coordination with other line ministries, while the Environmental Quality Authority (EQA) is responsible for implementing the law at the national level, licensing of sites, environmental monitoring, provision of expertise and ensuring environmental protection (MoP 2010).

Morris-Iveson (2009) illustrated that the management of waste falls within the remit of the Municipal Councils, bodies which do not have the funding or equipment to fulfill this responsibility adequately. This effort is supplemented by INGOs and LNGOs, though these are few. SWM activities consist exclusively of waste collection from households, communal areas, market places and hospitals, transferring this waste to a central waste
transfer station (in reality an unmanaged dumpsite in the city centre) and from there onto larger vehicles for transfer to the landfill. Actually, this abundance of authoritative agencies has added to the confusion.

3.2.5. Legal Framework

Palestinian Authority inherited a mix of legislation from previous systems which, in terms of environmental protection, is weak, piecemeal and sector-based. Further work is still needed to develop coherence in this area.

Environmental Law No 7 (1999) regulates all environmental issues however law enforcement has not been effectively implemented. This law includes the protection of natural resources, forestry, archaeological and tourist sites, and drinking water, and the control of sewage, marine pollution, air pollution, industry, fishing, urban development, municipal and hazardous waste disposal. It also covers environmental planning and enforcement and incorporates the ‘polluter pays’ principle. However, it lacks many specifics, such as environmental quality standards, regulatory standards and economic measures.

A legal framework for an effective solid waste management has not been adopted by the Palestinian Authority, whilst the Environment Law (Articles 7, 8, 9 and 10 for non-hazardous and Articles 11, 12 and 13 for hazardous wastes) provides a framework through which decrees should be issued to provide a legal framework for the sector.

At a national level, there is an absence of leadership through which to focus resources and capacity in the sector. The Environment Law No. 7 of 1999 provides the EQA with important authorities which, if implemented, could correct many of the deficiencies associated with the existing waste management system. However, this requires, first, enactment of implementing regulations/decrees that address all aspects of waste management and which must be sensitive to the financial and political constraints that prevail. EQA lacks the capacity to undertake these initiatives itself both in terms of technical knowledge and in terms of the integration of different waste management components into an effectively operating waste management system (EC, 2006).
3.2.6. Impact of Waste on Environment

Failure to appropriately manage and dispose of waste can negatively affect the quality of the environment in many ways, as well as the people’s quality of life, including the deterioration of ground water quality; air pollution; deterioration of nature and biodiversity; and landscape and aesthetic distortion of the visual environment.

The open discharge of solid waste and wastewater on the ecosystem pose great threats to the current and future quality of groundwater and may present several risks to human health.

The solid waste dumping sites are not covered or lined from the bottom to protect the groundwater and surface water. The precipitation that falls into the ground, coupled with any disposed liquid waste, results in the subsequent formation of leachate.

Pollution of the atmosphere and deterioration of air quality: The uncontrolled burning of solid waste in the open dumping emits acidifying and greenhouse gases (CH$_4$ and CO$_2$). The biological degradation of the remaining unburned organic waste adds to their emissions by generating landfill gases. Moreover, the burning of medical waste may pollute the air with various heavy metals, particularly cadmium and mercury, along with dioxins that form through burning Polyvinyl chloride (PVC) materials. Air pollution is associated with a variety of health problems, especially respiratory diseases and mortality (ARIJ, 2007).
Chapter (4)

Methodology
Chapter 4

4.1. Introduction

The adopted methodology explained hereafter depends on many approaches that were used in an integrated manner to achieve the objectives of this research. The study depends on the data which were collected from both the primary and secondary sources. Secondary data were collected from the review of many previous studies which are concerned in the SWM. Since the secondary data were not sufficient to achieve the objectives of the study, primary data were collected through:

1. Interviews with many of the SWM experts and stakeholders in Gaza Strip.
2. Conducting a field work to classify the solid waste stream into predefined primary components.
3. An assessment sheet (questionnaire) to evaluate the available landfilling options in Gaza Strip according to predefined criteria and then, to choose the feasible option.
4. Using GIS technology to determine the suitable locations for landfills.

Furthermore, this chapter will describe in depth the details of the methodologies and approaches used to achieve the aim of the study. Figure (4.1) shows that there are three main methodologies and two sub methodologies which integrated together to achieve the objectives of the study, thus the overall aim of the study is achieved.

Firstly the approach followed to describe the MSW composition for the study area is illustrated in section 4.2; this approach depends on a field work. Hereafter, the approach of determining the optimal number of landfills is presented in section 4.3; this approach relies on structured interviews, questionnaire, and using DEFINITE model for MCDA. Finally, the approach applied to select the best locations for a landfill site is introduced in section 4.4; this approach counts mainly on using GIS tools.

This chapter will describe the steps of these methodologies and define the elements of them in details. However, the results will be presented and analyzed in Chapter 5.
4.2. The Solid Waste Composition Approach

To achieve the first objective of this study, a field work was conducted in three sites which approximately all solid waste in Gaza strip reach them namely, Gaza landfill, Dier-Elbalah landfill and Rafah landfill during the period from the end of October 2010 to the mid of November 2010.

Since the security situation in Gaza strip was unsafe during the sampling period, the Rafah landfill located on green line border was excluded and the study took place instead in Rafah transfer station located in Tel-Sultan area.

4.2.1. Pre-Sort Site Assessment

Prior to initiating the actual sorting events, it was critical to conduct site assessments at each of the solid waste facilities. The purpose of the site assessments were two-fold promote staff
support and cooperation for the sorting events and to initiate the gathering of data to develop the sampling and sorting plan for each facility.

4.2.2. Sampling and Sorting Events

Sampling was carried out at those disposal sites (landfills) according to international standard ASTM D 5231-92(2003). The determination of the mean composition of MSW was based on the collection and manual sorting of a number of samples of waste over a selected time period covering one week for each site as shown in Figure (4.2). Therefore, three sampling weeks were carried out.

Vehicle loads of waste were designated for sampling, and a sorting sample was collected from the discharged vehicle load. The sample was sorted manually into waste components. The weight fraction of each component in the sorting sample was calculated by the weights of the components. The mean waste composition was calculated using the results of the composition of each of the sorting samples.

Figure 4.2: Field Sorting Process
Vehicles for sampling were selected randomly during each day of the one-week sampling period, as to be representative of the waste stream. According to ASTM D5231-92, for a weekly sampling period of $k$ days, the number of vehicles sampled each day should be approximately $n/k$, where $n$ is the total number of vehicle loads to be selected for the determination of waste composition. A weekly period is defined as 6 days.

Based on ASTM D5231-92, the number of sorting samples (that is, vehicle loads ($n$) required to achieve a desired level of measurement precision) is a function of the component(s) under consideration and the confidence level. The governing equation for $n$ is as follows:

$$n = \left(\frac{t^* s}{e x}\right)^2$$  \hspace{1cm} (eq. 4.1)

where $t^*$ is the student t statistic corresponding to the desired level of confidence, $s$ the estimated standard deviation, $e$ the desired level of precision, and $x$ is the estimated mean. Suggested values of $s$ and $x$ for waste components are listed in Table (4.1) Values of $t^*$ are given in statistical Tables.

<table>
<thead>
<tr>
<th>Component</th>
<th>Standard Deviation ($s$)</th>
<th>Mean ($\bar{x}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newsprint</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Corrugated</td>
<td>0.06</td>
<td>0.14</td>
</tr>
<tr>
<td>Plastic</td>
<td>0.03</td>
<td>0.09</td>
</tr>
<tr>
<td>Yard waste</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>Food waste</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>Wood</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Other organics</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Ferrous</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.004</td>
<td>0.01</td>
</tr>
<tr>
<td>Glass</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>Other inorganics</td>
<td>0.03</td>
<td>0.06</td>
</tr>
</tbody>
</table>

1.00

The tabulated mean values and standard deviations are estimates based on field test data reported for MSW sampled during weekly sampling periods at several locations around the United States.
Each sorting sample weighed 91–136 kg and was prepared properly (mixed, coned and quartered) from each discharged MSW vehicle load using a front-end loader with at least a 1 m$^3$ bucket. After sampling, hand sorting applied for the classification of MSW into seven categories. Each material category is then weighed. The complete list of material categories and their definitions are included in the Table (4.2).

**Table 4.2: Descriptions of Waste Component Categories**

<table>
<thead>
<tr>
<th>category</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>Office paper, computer paper, magazines, glossy paper, waxed paper, newsprint and corrugated</td>
</tr>
<tr>
<td>Plastic</td>
<td>All plastics</td>
</tr>
<tr>
<td>Food waste</td>
<td>All food waste except bones</td>
</tr>
<tr>
<td></td>
<td>Yard waste (Branches, twigs, leaves, grass, and other plant material)</td>
</tr>
<tr>
<td>Other organics</td>
<td>wood, textiles, rubber, leather, and other primarily burnable materials not included in the above component categories</td>
</tr>
<tr>
<td>Metals</td>
<td>Ferrous (Iron, steel, tin cans, and bi-metal cans), and aluminum.</td>
</tr>
<tr>
<td>Glass</td>
<td>All glass</td>
</tr>
<tr>
<td>Other inorganics</td>
<td>Rock, sand, dirt, ceramics, plaster, non-ferrous non-aluminum metals (copper, brass, etc.), and bones</td>
</tr>
</tbody>
</table>

### 4.2.3. Data Review and Entry

Upon completing the sampling and sorting of the materials, the data sheets (see Appendix A) were reviewed to ensure the following:

- individual entries were legible;
- generator area was clearly identified;
- specific comments on unusual aspects of a sample were comprehensible; and
- a minimum of 91 kg of materials were sampled and sorted for each sample.

### 4.3. The Multi Criteria Decision Analysis Process

Due to the complex nature of the factors that are related to SWM, the development of a decision support system is essential to:
Evaluate and examine the scenarios based on characteristics that are related to solid waste management (technical, environmental, financial, social, etc…), using the method of multi-criteria analysis.

Define the best solution.

The proposed methodology for the selection of the best landfilling system is based on the typical development of a MCDA process. The evaluation process using MCDA has been applied through the following steps and as shown in Figure (4.3):

4.3.1. Establishment of the Decision Context

Good decisions need clear objectives. These should be specific, measurable, agreed, realistic and time-dependent.

4.3.2. Identification of Decision Makers and Stakeholders

The stakeholders consist of all the different people associated with the planning and decision process.

First, based on a general problem statement, the various stakeholders are identified. The stakeholders typically include the DMs, various interest groups affected by the decision, experts in the appropriate fields, and planners and analysts responsible for the preparations and managing the process.

In this stage, the stakeholders who can help in criteria formulation and scoring were determined to be mainly from Palestinian entities which concern and deal with solid waste. All of them were selected from different locations such as the ministries of the Palestinian Authority, universities, municipalities, EQA, private sector, international organizations and others.

It is important that all stakeholders or their representatives have the opportunity to participate in this phase so that all different points of view are taken into account.

Briefly those experts were representatives of related institutions as governmental bodies, municipalities, joint councils, academic institutions, and nongovernmental organizations.
Problem Definition

Stakeholders’ determination

Defining the alternatives

Identification of evaluation criteria

Weighting of criteria

Alternatives assessment

Multi-criteria Analysis

Final Conclusion

Figure 4.3: Multi-Criteria Decision Analysis Methodology
4.3.3. Determination of the Options to be Appraised

Once the objectives and stakeholders are defined, the next stage is to identify options that may contribute to the achievement of these objectives.

Firstly, the thinking was oriented to evaluate three alternatives expressing the number of landfills needed in Gaza Strip. But after getting the feedback from some experts this mode of thinking turned away and replaced by new type of cerebration which focus on the type of landfilling articulated by two alternatives named centralized landfill and decentralized landfills.

4.3.4. Formulation of the Criteria for Assessment of Each Option

The next stage is to decide on how to compare different options’ contribution to meeting the objectives. This requires the selection of criteria to reflect performance in meeting the objectives. Each criterion must be measurable, in the sense that it must be possible to assess, at least in a qualitative sense, how well a particular option is expected to perform in relation to the criterion.

The criteria consist typically of measures for technical feasibility, cost effectiveness, probable impacts on different population groups, various environmental impacts, etc. In fact to do this pace, two successive steps were taken as follows:

1. In order to outline the criteria, the objectives of the overall task were defined at first, and a preliminary classification of them was made. A preliminary list of criteria was then drafted on this basis as shown in Table (4.3).

2. Then this list was submitted to some experts through structured interviews with them in order to review it. For more clarification, the experts had the ability to suggest new main criteria or sub-criteria. Also they could delete any unimportant criteria. Moreover, they might transfer any sub- criteria from a main criterion to another. To avoid duplication, the experts were empowered to merge any similar criteria to an appropriate criterion. Finally the outcome of this process shown in Table (4.4) was adopted and used later in assessing the alternatives.
<table>
<thead>
<tr>
<th>Main criteria</th>
<th>Sub-criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a) Air pollution</td>
</tr>
<tr>
<td>1. Environmental Indicators</td>
<td>b) Ground water pollution</td>
</tr>
<tr>
<td></td>
<td>c) Land contamination</td>
</tr>
<tr>
<td></td>
<td>d) Aesthetic</td>
</tr>
<tr>
<td></td>
<td>e) Noise</td>
</tr>
<tr>
<td></td>
<td>f) Odors &amp; nuisance</td>
</tr>
<tr>
<td></td>
<td>a) Investment cost</td>
</tr>
<tr>
<td>2. Economic &amp; Engineering Indicators</td>
<td>b) Operation and maintenance cost</td>
</tr>
<tr>
<td></td>
<td>c) Transportation cost</td>
</tr>
<tr>
<td></td>
<td>d) Land use</td>
</tr>
<tr>
<td></td>
<td>e) Fundability</td>
</tr>
<tr>
<td></td>
<td>f) Potential for implementation</td>
</tr>
<tr>
<td></td>
<td>g) Technical complexity</td>
</tr>
<tr>
<td></td>
<td>h) Reliability</td>
</tr>
<tr>
<td>3. Management Improvements Indicators</td>
<td>a) Waste coverage</td>
</tr>
<tr>
<td></td>
<td>b) Leachate treatment</td>
</tr>
<tr>
<td></td>
<td>c) Gas control</td>
</tr>
<tr>
<td></td>
<td>d) Recycling applicability</td>
</tr>
<tr>
<td>4. Political / Social Indicators</td>
<td>a) Security</td>
</tr>
<tr>
<td></td>
<td>b) Compliance with current solid waste</td>
</tr>
<tr>
<td></td>
<td>strategies</td>
</tr>
<tr>
<td></td>
<td>c) Compatibility with agreements</td>
</tr>
<tr>
<td></td>
<td>d) Land availability and ownership</td>
</tr>
<tr>
<td></td>
<td>e) Public acceptance</td>
</tr>
</tbody>
</table>
Table 4.4: Final Criteria

<table>
<thead>
<tr>
<th>Main criteria</th>
<th>Sub-criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a) Air pollution</td>
</tr>
<tr>
<td></td>
<td>b) Ground water pollution</td>
</tr>
<tr>
<td></td>
<td>c) Land contamination</td>
</tr>
<tr>
<td>1. Environmental Indicators</td>
<td>d) Aesthetic</td>
</tr>
<tr>
<td></td>
<td>e) Noise</td>
</tr>
<tr>
<td></td>
<td>f) Odors &amp; nuisance</td>
</tr>
<tr>
<td></td>
<td>g) Land use</td>
</tr>
<tr>
<td></td>
<td>a) Investment cost</td>
</tr>
<tr>
<td>2. Socio - Economic Indicators</td>
<td>b) Operation and maintenance cost</td>
</tr>
<tr>
<td></td>
<td>c) Transportation cost</td>
</tr>
<tr>
<td></td>
<td>d) Closure cost</td>
</tr>
<tr>
<td></td>
<td>e) Land availability and ownership</td>
</tr>
<tr>
<td></td>
<td>f) Public acceptance</td>
</tr>
<tr>
<td></td>
<td>g) Public health</td>
</tr>
<tr>
<td>3. Engineering Indicators</td>
<td>a) Waste coverage</td>
</tr>
<tr>
<td></td>
<td>b) Leachate treatment</td>
</tr>
<tr>
<td></td>
<td>c) Gas control</td>
</tr>
<tr>
<td></td>
<td>d) Recycling applicability</td>
</tr>
<tr>
<td></td>
<td>e) Suitability for future expansion</td>
</tr>
<tr>
<td></td>
<td>f) Infrastructure requirements</td>
</tr>
<tr>
<td>4. Political / Legal Indicators</td>
<td>a) Security</td>
</tr>
<tr>
<td></td>
<td>b) Compliance with local SW strategies</td>
</tr>
<tr>
<td></td>
<td>c) Compatibility with agreements</td>
</tr>
<tr>
<td></td>
<td>d) Fundability</td>
</tr>
</tbody>
</table>

The following paragraph will introduce the meaning of each criterion in order to explain the aim of putting it.
4.3.4.1. Environmental Indicators

This main criterion contains criteria which reflect the impact on environmental indicators by each alternative as following.

a) Air pollution

This criterion is a measure of how negatively each option affects the air since it is possible to arise from landfills pollutant gases.

b) Ground water pollution

Also this criterion has to be evaluated according to each option because it is a measure of the influence of leachate produced from wastes on groundwater.

c) Land contamination

Like the previous criterion, this one is a measure of leachate effects on soil in the area of landfills presence.

d) Aesthetic

This criterion is a measure of the negative effects of each alternative on the aesthetic in the area of study.

e) Noise

Because of operation practices and traffic of waste transfer vehicles, this criterion is considered as a measure of those factors related to each option.

f) Odors

This criterion indicates how each alternative can affect the smelling in the neighboring areas.

g) Land use

This measures the degree to which an option fits with designated use for the location as given in regional plan. Furthermore, it measures the impact of each alternative on land use in the surrounding areas.

4.3.4.2. Socio-Economic Indicators

The social and economical factors are very interrelated, so that they grouped in one main criterion. The description of each one is shown below.
a) Construction cost
This criterion gives a general judgment by experts on which alternative requiring less construction cost.

b) Operation and maintenance cost
The same as above criterion, this criterion represent the operation and maintenance costs needed for each alternative relatively.

c) Transportation cost
This important criterion brings out the expenditures needed for collecting and transferring the waste to any alternative.

d) Closure cost
This criterion measures the relative difference of cost when closing each alternative at the end of its design period or in case of need to do that.

e) Land availability and ownership
This criterion is very essential inasmuch as it not only measures the ability to find the appropriate land required for each alternative but also it measures the possibility to own it.

f) Public acceptance
This criterion is a measure of the public’s attitude or willingness to embrace an option and to make use of it.

g) Public health
This criterion may be used as a general measure of the expected impact on public health and hygiene based on use of any alternative.

4.3.4.3. Engineering Indicators
In other words this main criterion can be called the technical indicators. Apparently, most of the involved criteria express the positive effect of each alternative on them.

a) Waste coverage
This criterion measures the ability of each alternative to hold efficiently the produced waste.
b) Leachate treatment

This indicator is a measure of which alternative can exploit more effectively the resulting leachate. The judgment should take into consideration the quantities of this leachate in both alternatives.

c) Gas control

This measures the degree to which an option can participate in facilitating the use of gas.

d) Recycling applicability

This criterion considers the influence of implementing the recycling technologies in each option.

e) Suitability for future expansion

This measure to what extend it is practical and reasonable to expand the area of each alternative.

f) Infrastructure requirements

This criterion may be appropriate in some cases where the options being considered require other infrastructure not directly related to the project be in place. Example may be the need for better roads for the routine delivery of supplies.

4.3.4.4. Political/legal Indicators

a) Security

This criterion is used as a general measure of the effect of security situations when use any alternative.

b) Compliance with current solid waste strategies

Extent to which the option meets local goals and strategies in respect of SWM in the Gaza Strip.

c) Compatibility with agreements

This criterion considers whether or not the option fits in with rights and other local, regional, and international laws and agreements.
d) Fundability

Fundability is a measure of the ability of securing financial support for capital and recurring costs to fund the option. It is primarily a function of the amount of money needed.

### 4.3.5. Weighting of Criteria

This process means assigning a weight for each criterion on account of reflecting their relative importance to the decision. Determining the weights is, however, quite controversial and is basically accomplished by decision-makers through reviewing the criterion and their relative importance concerning the objective to which they contribute.

That was done by conducting structured interviews with decision makers and experts from various concerned institutions.

Conceptually, this weighting was assigned to both main criteria and sub-criteria (see Appendix B) in order to achieve a classification of the evaluation criteria by priority. The stakeholder survey questionnaire was designed to measure and evaluate the options of landfilling mode in Gaza Strip.

The period of surveying assessment took more than one month, in during several correspondences were addressed, eventually the data were collected from concerned institutions in Gaza Strip, analyzed and results are presented in the next chapter.

A numerical scale was used to measure the relative importance between criteria so as to be the weights sum of main criteria sum up to one and the weights sum of sub-criteria in each main criterion also equal one. Formally, a set of weights is defined as follows: \( w = (w_1, w_2, ..., w_j, ..., w_n) \) and \( \sum w_j = 1 \).

The weight values assigned to the criteria account for two factors:

- Changes in the range of variation for each evaluation criteria.
- Different degrees of importance being attached to these ranges of variation.

### 4.3.6. Scoring the Alternatives

In this stage, the alternatives (options) and effects (criteria) are organized in a table, and the score of each alternative with respect to the criteria should be defined according to a specified scale as shown in Table (4.5). The respondents make an assessment of the expected
performance of each option against the criteria. Then the assessment of the value associated with the consequences of each option for each criterion was made.

Conceptually, it is possible to carry out the comparison of the alternatives directly at the assessment level.

<table>
<thead>
<tr>
<th>ID</th>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- -</td>
<td>large negative effect</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>small negative effect</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>no effect</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>small positive effect</td>
</tr>
<tr>
<td>5</td>
<td>++</td>
<td>large positive effect</td>
</tr>
</tbody>
</table>

4.3.7. Analysis of Response

In this research DEFINITE, (decisions on a finite set of alternatives), is used as a software for applying the multi criteria analysis as illustrated in Figure (4.4). DEFINITE is a decision support software package that has been developed to improve the quality of environmental decision making.

The problem definition stage enables the users to set up the problem, including definition of alternatives and criteria. The alternatives could be desalination, or wastewater treatment, whereas the criteria could be the cost, and availability of technology.

Several types of multi-criteria analyses are provided, including weighted summation approaches, pair-wise comparison of alternatives as ELECTRE, regime method and Evamix methods. The user is prompted to rank the criteria in the order of importance, and to rank series of simplified test alternatives, each defined on specified criteria.
Besides, a sensitivity analysis was conducted taking into account other preferences or weights that affect the overall ordering of the option and taking into consideration the advantages and disadvantages of the selected options, then comparing the different pairs of options.

### 4.4. The Generic Site Selection Process

Most of the landfill sites in Palestine are selected randomly, and waste is burned and not treated, which impacts nature and human (Mahamid and Thawaba, 2010).

Landfill site selection can generally be divided into two main steps: the identification of potential sites through preliminary screening, and the evaluation of their suitability based on environmental impact assessment, economic feasibility, and engineering design, and cost comparison (Chang et al, 2008).

This research only covers the first step in a comprehensive way so that candidate sites for an appropriate landfill area in the Gaza Strip are determined by using the geographic information systems. While the second step will be left to other researchers, inasmuch as it requires further studies and more efforts to be attained. However, a candidate site will be recommended by the researcher based on his point of view.

The methodology is a logical as well as systematic part of the study to guide scientific
investigation. A method involves a process or technique in which various stages or steps of collecting data or information are explained. The methodology of this study covers some sequential steps, which, if properly implemented, should ensure against nuisances and adverse long-term effects. Detailed methodology is also graphically presented in Figure (4.5).

4.4.1. Definition of Restriction Criteria

Before the spatial analysis was performed, limitation and factors criteria must be identified according to the local regulations, international practice as well as from the related literature that are suitable with the study area. Hence, they were outlined based on the evaluation on the environmental, social, and engineering-economic issues. Criteria used for the preliminary screening should be pragmatic so that areas of environmental significance are excluded. The issue of optimum criteria and appropriate methodologies is vital in most developing countries since site-planning rules are not as well established as developed countries.

The presented method starts with the identification of evaluation criteria or parameters needed for landfill sitting. Since Gaza Strip has a small area which doesn’t exceed 365 km$^2$, a loose scenario was considered to decrease the restrictions on landfill site selection.

Actually, not all of the data sources required to carry out analyses on the study areas may currently be used. For example, there is no flood risk in Gaza Strip at the present time. Therefore, based on literature guidelines and taking into consideration the loose scenario, there were 11 importance criteria identified for marking out the suitable locations of landfill in Gaza Strip. These criteria are:

- Site Capacity: A site should provide at least 20 years of use in order to; minimize costs for site establishment and closure, smooth running of operations, and provision of adequate
time for acquiring the next site.

- **Local Topography:** areas with slope less than 15% will be considered suitable for a landfill.

- **Soils:** Soil with medium, relatively low, and very low permeability are considered fairly suitable and optimal to site a landfill respectively. Specifically, the waste disposal site should be constructed on clay-rich soils, with a minimum thickness of 5 meters and permeability lower than 0.05 meters/day.

- **Adjacent Land Uses or Land cover:** To limit the risks to public health and impacts on the areas surrounding the landfill buffer zones between the landfill and sensitive areas are provided to be 50 meters from regional roads, 200 meters from industrial developments, 1500 meters from urban residential or commercial area.

- **Airports:** The distance from an airport assigned to be 3.0 km.

- **Surface Water:** The distance between the areas dedicated for waste disposal and the nearest surface water or the 100 year flood plain is taken 60 m.

- **Groundwater:** A buffer area is established around all of the water wells of a distance 50m. Considering underground water contamination, depth of water Table must be taken in to consideration as a highly effective factor. Zones with deep enough water Table depth will be considered optimal while zones with relatively deep and shallow water Table are introduced as fairly suitable and unsuitable respectively.

- **Unstable Areas:** Major Landfills must not be located within 100 meters of an unstable area.

- **Distance from environmentally sensitive or protected areas:** A landfill must not be located in close proximity to sensitive areas. Therefore a 500 meters buffer is necessary to surround an environmentally sensitive area.

- **Distance from urban areas:** According to lin and Kao (1999), a landfill site could be located in an area which is at least 150 meters from an urban residential or commercial area.

- **Coastline areas:** Despotakis and Economopoulos (2007) show that landfills should located minimum 100 meter from coastline areas.
These criteria were divided into two categories namely constraint and factor criteria. Constraint criteria represent the unsuitable areas according to the regulations, which prohibit landfill site from being placed within these areas that may have conflict with the regulations and/or could harm the environment. While, Factors criteria were used to evaluate the potential areas for landfill based on its suitability.

### 4.4.2. Data Collection

Data availability is of prime importance when using GIS. In the current study, a comprehensive body of secondary information related to environmental, socio-cultural, and economic factors was collected and produced in a digital format from different sources, such as Palestinian Water Authority (PWA), and MoP. All the data layers are derived and prepared from related maps by scanning, geocoding and digitizing the relevant information. Consequently, 13 input map layers including topography, water wells, urban centers and villages, roads (regional and main), railways and infrastructures, airport, valleys, industrial areas, soil type, land use, protected areas, water level and coastal line are evaluated and prepared to be used in the analysis in GIS environment.

### 4.4.3. Analysis of Data

GIS plays a major role in determining the suitable locations for a landfill site according to predefined criteria based on scientific standards and measurements. Specifically, Arc Map 10.0 was used for imaging and analysis of spatial data and different digital maps.

Numerous intermediate or analysis map layers were created using GIS map analysis approaches. The latter included buffer zoning, neighboring computation, and geo-processing tools (overlay, intersection, union, clipping, etc...). While the intermediate map analysis allowed the exclusion of areas not satisfying the specific sitting criteria, the geo-processing tools constituted the most commonly used GIS function in selecting the sites satisfying all the required conditions.

In this study, the approach was to utilize models that combine and integrate maps to determine an optimal landfill sitting. Accordingly, six major GIS spatial operations were performed to achieve the set of objective for this project. These are buffering, overlaying, dissolving, classification, clipping, and querying.
Buffering

It is a spatial analysis known as proximity analysis, generating zones of a given distance around a feature theme. It forms a polygon around a point, line or polygon theme by locating its boundaries at a specified distance. GIS can create buffer zones around selected features.

Overlay

Overlay was performed to identify areas that meet all the set criteria and to show areas that do not meet the criteria. GIS can overlay different pieces of information.

Dissolving

It is used to create a new coverage by merging adjacent polygons, lines, or regions that have the same value for a specified item.

Classification

The goal of classification is to assign each cell in the study area to a known class (supervised classification) or to a cluster (unsupervised classification). The main use of it in the study is to classify the soil types, topography, and water level.

Clip

Clip uses the clipping region as a cookie cutter; only those input coverage features that are within the clipping region are stored in the output coverage. This process helped in obtaining study area maps of all the parameters.

Query

This command is used to answer the question of ‘what is and where is’ in GIS. The land use was queried to get the open space while the elevation was queried to get the suitable elevation.

The utilization of GIS for a preliminary screening is normally carried out by classifying an individual map, based on selected criteria, into exactly defined classes or by creating buffer zones around geographic features to be protected. All map layers are then intersected so that the resulting composite map contains two distinct areas. For example, if screening criteria involve the provision of a protective buffer around certain types of spatial objects, the area outside the intersected boundary is considered suitable and that inside is unsuitable. The two
distinct classes separated by a sharp boundary reflect the representation of, and GIS operations on, geo-referenced data based on a binary true or false Boolean logic.

Geographical features required for the analysis could be extracted by using Arc GISs software. For example, to obtain GIS data sets of buffer zone, the land in the Gaza Strip was classified by creating buffer zones around geographic features to be protected using literature values widely used in landfill selection process.

Once all the candidate sites have been identified, they must all be compared and technically evaluated. Unsuitable sites must be eliminated and the best sites must be short listed for further consideration. The short listed sites are then ranked in order of suitability. The ranking process is, however, controversial and is often open to criticism because it may be seen as subjective, which in some instances is the case, therefore both this step and the following step will be left for further studies.

The top-ranking site is then subjected to a more detailed investigation by means of a Feasibility Study. The Feasibility Study may comprise many administrative and technical aspects, which depend on local legislation. It should, however, include a preliminary Geohydrological Investigation, as well as a preliminary Environmental Impact Assessment (EIA).

**4.4.4. Presentation of Results**

Once the data are analyzed, the results will be presented and the final outcome will be articulated. Detailed description of results is articulated in chapter 5.
Chapter (5)

Results and Discussion
Chapter 5

5.1. Introduction

This chapter will show the results of each component of this research. Accordingly, in the beginning the composition of MSW will be introduced in section 5.2. Subsequently, the potential of recycling materials will be defined in section 5.3. After that the findings of the optimal number of landfills and all the elements of its methodology will presented in section 5.4. Hereafter, the required area of the central landfill will be computed in section 5.5. Then the best location results of the landfill will be showed in section 5.6.

5.2. Solid Waste Composition Results in Gaza Strip

This section constitutes of the computation of required samples, composition of MSW in Gaza landfill, composition of MSW in Middle landfill, composition of MSW in Rafah transfer station, overall composition of MSW in Gaza Strip, and the comparison of this results with others.

5.2.1. Number of Samples Determination

The number of samples in each site was calculated according to equation (4.1) taking into consideration a 95% confidence level and assuming food waste as a govern component which mean that standard deviation (s) equals to 0.03 and estimated mean (x̄) equals to 0.1, in addition a 10% of precision (e) is desired. Therefore 38 samples were needed to be sorted in each site so that it was taken 40 samples for classification, thus 6-7 samples were sorted each day in each site. A total of 10 samples were taken from Deir El-Balah landfill during the week (i.e. approximately 2 samples each day) because of the unsafe security situation there.

5.2.2. Gaza Landfill Results

Gaza landfill covers at least 140 dunums east of Gaza City (Juhr El-Diek area) and bordering the Green Line with occupied Palestinian territories. The site receives daily waste of about 900-1000 ton wastes from both Gaza Governorate and Northern Governorate. Since there are about 852,472 inhabitants in the both governorates (MoP 2010), the per capita production of waste almost equal to 1 kg/capita/day.

Forty samples were collected and analyzed in this site during six days from vehicles coming from various locations covering all areas disposing in this landfill. All of samples were sorted
in the same site day by day. Moreover, samples weights were ranged between 91 kg to 123.5 kg with an average of 106.2 kg.

The waste composition for the waste stream entering Gaza landfill is shown in Table (5.1). The percentage composition of waste combined from all locations was 45% organic, 15% paper (most of them are corrugated), 12% plastic, 9% metal, 9% glass and 10% other waste (most of them are sand and debris). Indeed, organics were the largest composition and glass was the smallest composition for all locations.

In fact the percentages of components shown in Table (5.1) can be translated into quantity manner such that it can be said that Gaza governorate and North governorate produce daily about 450 tons organics, 150 tons paper, 120 tons plastic, and 280 tons of other waste (metal, glass, and others). Consequently, there is a clear potential for recycling and composting.

Table 5.1: Composition of MSW Components in Gaza Landfill (weight basis)

<table>
<thead>
<tr>
<th>Component</th>
<th>average weight per sample (kg)</th>
<th>s.d. (kg)</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>15.6</td>
<td>5.0</td>
<td>14.8</td>
</tr>
<tr>
<td>Plastic</td>
<td>12.9</td>
<td>4.2</td>
<td>12.2</td>
</tr>
<tr>
<td>Food Waste</td>
<td>22.4</td>
<td>5.3</td>
<td>21.2</td>
</tr>
<tr>
<td>Other Organics</td>
<td>25.3</td>
<td>4.5</td>
<td>23.7</td>
</tr>
<tr>
<td>Metals</td>
<td>9.7</td>
<td>5.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Glass</td>
<td>9.3</td>
<td>4.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Other Inorganics</td>
<td>10.9</td>
<td>6.4</td>
<td>10.2</td>
</tr>
<tr>
<td>Total</td>
<td>106.2</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

s.d. = standard deviation

Furthermore, it is shown in Table (5.2) that most of samples were taken from Gaza governorate (about 85%) inasmuch as it has larger area and more population than north governorate and this is similar actually to the percentage of vehicles entering the landfill from this governorate. In spite of that the samples were covered all areas disposing in Gaza landfill.
Table 5.2: Distribution of Samples by Districts in Gaza Landfill

<table>
<thead>
<tr>
<th>Area</th>
<th>Governorate</th>
<th>No. of trucks</th>
<th>Trucks Percentage %</th>
<th>Collection company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheikh Redwan</td>
<td>Gaza</td>
<td>4</td>
<td>10</td>
<td>Contractor</td>
</tr>
<tr>
<td>Sheja’ia</td>
<td>Gaza</td>
<td>6</td>
<td>15</td>
<td>Contractor</td>
</tr>
<tr>
<td>Rimal</td>
<td>Gaza</td>
<td>3</td>
<td>7.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Beach camp</td>
<td>Gaza</td>
<td>4</td>
<td>10</td>
<td>UNRWA</td>
</tr>
<tr>
<td>Zahra’ city</td>
<td>Gaza</td>
<td>4</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Yarmouk transfer station</td>
<td>Gaza</td>
<td>2</td>
<td>5</td>
<td>Municipality &amp; Contractor</td>
</tr>
<tr>
<td>Beit-Hanoon</td>
<td>North</td>
<td>2</td>
<td>5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Tel El-Hawa</td>
<td>Gaza</td>
<td>1</td>
<td>2.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Juhr Al-Deik</td>
<td>Gaza</td>
<td>3</td>
<td>7.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Sabra</td>
<td>Gaza</td>
<td>3</td>
<td>7.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Beit-Lahia</td>
<td>North</td>
<td>2</td>
<td>5</td>
<td>Contractor</td>
</tr>
<tr>
<td>Asqola</td>
<td>Gaza</td>
<td>1</td>
<td>2.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Shaa’f</td>
<td>Gaza</td>
<td>1</td>
<td>2.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Shifa’</td>
<td>Gaza</td>
<td>1</td>
<td>2.5</td>
<td>Municipality</td>
</tr>
<tr>
<td>Nusser</td>
<td>Gaza</td>
<td>1</td>
<td>2.5</td>
<td>Contractor</td>
</tr>
<tr>
<td>Jabalia</td>
<td>North</td>
<td>2</td>
<td>5</td>
<td>UNRWA &amp; Municipality</td>
</tr>
</tbody>
</table>

5.2.3. Dier El-Balah Landfill Results

This landfill is located east of Deir El Balah city and covers approximately 70 dunums and also bordering the Green Line with Israel. The landfill receives wastes from both Middle Governorate and Khan Younis Governorate under Joint Service Council (JSC) agreement. In addition it is recorded that about 300 tons reached the landfill every day which means that the
Chapter 5

Analysis of results and discussion

per capita production is 0.6 kg/capita/day, this low value may return in one hand to the wrong practice of some municipalities which prefer to use illegal dumpsite than send the waste to the landfill, thus they don’t pay fees for using the landfill. In other hand many of the areas using the landfill are rural which known of low waste production especially in the east of Khan Yuonis governorate.

Ten samples only were taken in this site during six days from vehicles coming from various locations covering all areas disposing in this landfill. The landfill administration limited the number of samples to ten because the security situation there was extremely dangerous. All of samples were sorted in the same site day by day. Moreover, samples weights were ranged between 96.5 kg to 107 kg with an average of 101 kg.

The waste composition for the waste stream entering Deir El-Balah landfill is shown in Table (5.3). The percentage composition of waste combined from all locations was 50% organic, 13% paper (most of them are corrugated), 11% plastic, 9% metal, 4% glass and 13% other waste (most of them are sand and debris). Indeed, organics were the largest composition and glass was the smallest composition for all locations.

Table 5.3: Composition of MSW Components in Middle Landfill (weight basis)

<table>
<thead>
<tr>
<th>Component</th>
<th>average weight per sample (kg)</th>
<th>s.d. (kg)</th>
<th>weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>13.1</td>
<td>2.8</td>
<td>13.0</td>
</tr>
<tr>
<td>Plastic</td>
<td>11.1</td>
<td>2.7</td>
<td>10.9</td>
</tr>
<tr>
<td>Food Waste</td>
<td>21.6</td>
<td>3.9</td>
<td>21.3</td>
</tr>
<tr>
<td>Other Organics</td>
<td>28.8</td>
<td>5.8</td>
<td>28.5</td>
</tr>
<tr>
<td>Metals</td>
<td>8.9</td>
<td>4.4</td>
<td>8.8</td>
</tr>
<tr>
<td>Glass</td>
<td>4.4</td>
<td>2.0</td>
<td>4.3</td>
</tr>
<tr>
<td>Other Inorganics</td>
<td>13.4</td>
<td>6.7</td>
<td>13.2</td>
</tr>
<tr>
<td>Total</td>
<td>101.3</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

s.d. = standard deviation
In fact the percentages of components shown in Table (5.3) can be translated into quantity manner such that it can be said that Dier El-Balah governorate and Khan Younis governorate produce daily about 149 ton organics, 39 ton paper, 33 ton plastic, and 79 ton other waste (metal, glass, and others). Accordingly, there is a clear potential for recycling and composting.

Furthermore, it is shown in Table (5.4) that fifty percentages of samples were taken from Khan Younis governorate and this is similar actually to the percentage of vehicles entering the landfill from this governorate. In spite of that the samples were covered all areas disposing in this landfill.

Interestingly, although there were fewer samples taken from Dier El-Balah landfill, the results are similar to Gaza landfill.

<table>
<thead>
<tr>
<th>Area</th>
<th>Governorate</th>
<th>No. of trucks</th>
<th>Trucks Percentage %</th>
<th>Collection company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qarara</td>
<td>Khan Younis</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Khan younis</td>
<td>Khan Younis</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Khiza’a</td>
<td>Khan Younis</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Abassan Kabeera</td>
<td>Khan Younis</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Bani Suhaila</td>
<td>Khan Younis</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Wadi Salqa</td>
<td>Deir El-Balah</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Nusierat</td>
<td>Deir El-Balah</td>
<td>1</td>
<td>10</td>
<td>UNRWA</td>
</tr>
<tr>
<td>Buriej</td>
<td>Deir El-Balah</td>
<td>1</td>
<td>10</td>
<td>UNRWA</td>
</tr>
<tr>
<td>Mussader</td>
<td>Deir El-Balah</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
<tr>
<td>Deir El-Balah</td>
<td>Deir El-Balah</td>
<td>1</td>
<td>10</td>
<td>Municipality</td>
</tr>
</tbody>
</table>
5.2.4. Rafah Transfer station

Rafah waste disposal site which are approximately 27 dunums is located near to Sofa crossing border, where the security situation is very dangerous. Therefore the survey was conducted in Rafah transfer station located in Tel Sultan area in the west of Rafah which received solid waste from Rafah municipality only and other municipalities use the landfill directly. Actually, to get over this problem some vehicles from municipalities using the landfill were requested to the transfer station and they were unloaded in it so that some samples were taken from them.

Based on Rafah municipality records about 120 ton of solid waste are produced daily in Rafah governorate which has 192,778 inhabitants live in it (MoP, 2010). In other words the residents in Rafah governorate produce 0.62 kg/capita/day of solid waste. Fundamentally this low value may resulted from the wrong practice of some municipalities which prefer to use illegal dumpsite than send the waste to the landfill, thus they don’t pay fees for using landfill. Also some areas using this landfill are rural which known of low waste production especially in the east of Rafah governorate; in addition some recyclable materials are extracted and converted to recycling facilities.

Forty samples were collected and sorted during six days from vehicles coming from various locations covering all areas disposing in Rafah landfill. Moreover, samples weight was ranged between 93.5 kg to 126.5 kg with an average of 103kg.

The waste composition for the waste stream entering Rafah landfill is shown in Table (5.5). The percentage composition of waste combined from all locations within Rafah governorate was 49% organic, 15% paper (most of them are corrugated), 12% plastic, 7.5% metal, 4.5% glass and 12% other waste (most of them are sand and debris). Indeed, organics were the largest composition and glass was the smallest composition for all locations.

It can be concluded that Rafah governorate produces daily about 59 tons of organics, 18 tons of papers, 15 tons of plastics, and 29 tons of other wastes (metal, glass, and others). Accordingly, there is a clear potential for recycling and composting.
Chapter 5

Table 5.5: Composition of MSW Components in Rafah Transfer Station (weight basis)

<table>
<thead>
<tr>
<th>Component</th>
<th>average weight per sample (kg)</th>
<th>s.d.</th>
<th>Percent of weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>15.1</td>
<td>3.7</td>
<td>14.7</td>
</tr>
<tr>
<td>Plastic</td>
<td>12.7</td>
<td>3.5</td>
<td>12.3</td>
</tr>
<tr>
<td>Food Waste</td>
<td>24.5</td>
<td>3.9</td>
<td>24.0</td>
</tr>
<tr>
<td>Other Organics</td>
<td>26.0</td>
<td>4.2</td>
<td>25.2</td>
</tr>
<tr>
<td>Metals</td>
<td>7.6</td>
<td>4.2</td>
<td>7.4</td>
</tr>
<tr>
<td>Glass</td>
<td>4.8</td>
<td>2.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Other Inorganics</td>
<td>12.2</td>
<td>4.1</td>
<td>11.8</td>
</tr>
<tr>
<td>Total</td>
<td>102.9</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

s.d. = standard deviation

5.2.5. Overall Solid Waste Compositions in Gaza Strip

One-week field sorting events were conducted at each participating facility. A total of 90 samples were collected and sorted in this analysis. Knowing that the average weight of each sample was more than 100 kg then the total weight of samples was about 9,370 Kg.

Statistically, the results can be considered representative because the participating facilities manage approximately 100% of the Gaza strip waste. In addition, the samples were well distributed between the residential areas.

Depicted in Table (5.6) and Figure (5.1) are the results by each facility and weighted average of MSW composition in Gaza Strip.

It can be inferred also that Rafah governorate as well as Gaza and north governorates have same paper and plastic percentages. Additionally, there is a similar food waste percentage in Gaza, Deir El-Balah, and Khan Younis governorates.

Obviously, there is a significance difference in glass percentages between Gaza landfill from one side and both of Deir El-Balah landfill and Rafah transfer station from the other side. The glass percentage in Gaza landfill counted of about double the percentage of each landfill
which may be justified by the ample existence of glass importers and glass workshops in Gaza governorate.

Despite the mentioned differences between landfills, it is noted that there is inherent convergence of solid waste components percentages in all facilities which demonstrate the uniform pattern of standard living in all Gaza strip areas.

The average characteristics have been presented in Tables (5.6) and Figure (5.2). Also results indicated that food and other biodegradable materials comprised 47.5% (673 tons) of the total waste.

In Gaza strip, Organic wastes constitute the largest component in the waste stream by weight. These organic wastes comprise nearly half of the weight of waste which half of them are food waste and the rest are other organics such as babies’ diapers.

This is followed by paper which generally comprises nearly 14.5% (206 tons/day) of waste composition which most of it is cardboard. Plastic, being the third in components order, make up 12% (172 tons/day) of the waste stream. The category “plastic” included all grades of plastic bags, bottles, packaging, all-weather sheeting, and all grades of hard and soft plastics from toys, appliances, and many other sources. Paper and Plastic have a significant

Figure 5.1: Aggregate composition by major material category in each facility
percentages and this is somewhat surprising. Subsequent to plastic, metals represent about 8% (118 tons/day) of waste stream.

Table 5.6: Composition Percentages of MSW Components in Each Facility

<table>
<thead>
<tr>
<th>Component</th>
<th>Gaza</th>
<th>Deir Balah</th>
<th>Rafah</th>
<th>Average Weight %*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>14.8</td>
<td>13.0</td>
<td>14.7</td>
<td>14.5</td>
</tr>
<tr>
<td>Plastic</td>
<td>12.2</td>
<td>10.9</td>
<td>12.3</td>
<td>12.1</td>
</tr>
<tr>
<td>Food Waste</td>
<td>21.2</td>
<td>21.3</td>
<td>24.0</td>
<td>22.5</td>
</tr>
<tr>
<td>Other Organics</td>
<td>23.7</td>
<td>28.5</td>
<td>25.2</td>
<td>24.9</td>
</tr>
<tr>
<td>Metals</td>
<td>9.1</td>
<td>8.8</td>
<td>7.4</td>
<td>8.3</td>
</tr>
<tr>
<td>Glass</td>
<td>8.8</td>
<td>4.3</td>
<td>4.6</td>
<td>6.4</td>
</tr>
<tr>
<td>Other Inorganics</td>
<td>10.2</td>
<td>13.2</td>
<td>11.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

* weighted average based on the number of samples in each facility

The lowest percentage in waste components is glass which forms nearly 6.5% (91 tons/day) of the total components. Finally, the other inorganics materials comprise 11.5% (160 tons/day) of waste composition which most of them are sand and fine materials.

Figure 5.2: MSW Composition in Gaza Strip
5.2.6. Comparison with Other Local Studies

Results of this study were inconsistent with those previous studies reported in Ministry of Planning (MoP), 2010; Environmental Quality Authority (EQA), 2007; and METAP report, 2004. A comparison of the present study with other studies is presented in Table (5.7).

In contrast to the field survey, a study carried out by the Mediterranean Environmental Technical Assistance Programme (METAP, 2004) and funded by World Bank showed that only 1.5%, 2% of MSW could be paper and plastic respectively. Whereas organics reach in this study to 67%, while in the field survey it is about 50%. Furthermore, a total sand represents more than 25%. In summary, organics and sand represent the largest quantity in the waste which reaches 94% and the remaining 6% are paper, plastic, glass, and metals.

Another study reported in one of EQA publishing in 2007, imply that paper as same as plastic represent 8% of the waste components. The organics were 70% of the total, while glass and metal both contribute 6% and 3% respectively to the total waste generated. Therefore the other wastes comprise only 5%.

Table 5.7: Waste Composition Percentages by Local Studies

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>10.0</td>
<td>8.0</td>
<td>1.5</td>
<td>14.5</td>
</tr>
<tr>
<td>Plastic</td>
<td>12.0</td>
<td>8.0</td>
<td>2.0</td>
<td>12.1</td>
</tr>
<tr>
<td>Organic Waste</td>
<td>65.0</td>
<td>70.0</td>
<td>67.0</td>
<td>47.4</td>
</tr>
<tr>
<td>Metals</td>
<td>5.0</td>
<td>3.0</td>
<td>1.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Glass</td>
<td>3.0</td>
<td>6.0</td>
<td>1.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Other Inorganics</td>
<td>5.0*</td>
<td>5.0*</td>
<td>25*</td>
<td>11.3</td>
</tr>
</tbody>
</table>

* Others
** Sand

The recent report published by MoP in 2010 stated that organics waste form a significant proportion (65%). Ten percent of the solid waste was classed as paper and plastic account for 12% of the total. The remaining components were determined to be: metals (5%), glass (3%), and others (5%). These proportions were estimated by the committee preparing the report.
It is remarkable that in previous studies organics waste were approximately alike, since they account for more 65%. But in the field survey organics didn’t exceed 50% of the total waste. It is believed that these previous studies depend mainly on estimations not real surveys. Another reason for these discrepancies that the field survey was conducted in the disposal facilities which receive waste from residential, commercial, and even industrial areas, but previous studies limited their values on household waste. Moreover, there were clear differences in other components between the field survey and the previous studies as far as the differences among previous studies themselves. For instance percentages of plastic, paper, metals and glass have a slight dissimilarity between Mop 2010 and EQA 2007 and a wide divergence between each of them in one hand and METAP 2004 in the other hand.

It is apparently noticed that there is a decline trend in the percent of organics and increase in the percentage of plastics. This may be attributed to increase of the quantities of relief materials during the last period which may include large quantities of packaged items. Another reason that is considered a major source of plastics in Gaza Strip is the wide use of nylon and cans.

One explanation for these differences may be that the use of literature reported data for local planning is likely to lead to inaccurate estimates of local MSW quantities and composition. Besides that there was no reporting about number of samples taken, the selection criteria, sampling design and data analysis method, etc. in previous studies.

**5.2.7. Comparison with Other Regional and International Studies**

In developing countries the organic fraction is high and may reach up to 60%. Solid waste characterization and quantification is very helpful and economically feasible, since the method of handling, storage and processing of solid wastes at the source plays an important role in public health, aesthetics and the efficiency of the municipal solid waste system (Alavi Moghadam et al., 2009). In West Bank studies showed that in Ramallah and Jericho the composition of MSW is 41% organic and food wastes, 25% plastics, 16% paper and cardboard, 3% glass, 3% metals, 6% textiles, 4% other wastes, and 2% waste less than 10 mm diameter (Alkhateeb, 2009). While in Nablus district the composition is 63% organic material, 8% plastics, 3% metals, 3% glass, 10% paper and cardboard, 3% textiles 10% others and inert
Additional materials (Abu Zahra, 2006). Additionally, Al-Khatib et al. (2010) showed that the overall composition for Nablus district is 65.1% organic, 9.1% papers and cards, 7.6% plastic, 3.9% materials < 10mm, 3.1% textile, 2.9% glass, 2.8% metals, and 5.4% others. According to the most recent survey of solid waste composition in Israel, conducted in 2005 and published on ministry of environment website, organic materials are the main components of the waste stream, in terms of weight, constituting 40% of Israel’s solid waste, followed by paper and cardboard (25%), plastic (13%), metals (3%), glass (3%), textiles (4%), and others including disposable diapers (12%).

In Southeast Asian nations studies showed that in Indonesia the composition of MSW is 62% organic wastes, 6% paper and cardboard, 10% plastics, 9% glass, 8% metals and 4% others, while in Laos it is 46% organic wastes, 7% paper and cardboard, 10% plastics, 8% glass, 12% metals and 21% others, in Brunei it is 44% organic wastes, 22% paper and cardboard, 12% plastics, 4% glass, 5% metals and 13% others (SWM in Asia, 2000-2007 cited in Yen et al., 2009). In India, based on investigations performed by NEERI (1996) and Kanpur Municipal Corporation (1999), the percent distribution of solid waste are showing paper 4%, biodegradable 44.3%, inert (dust, ash, etc.) 39.2%, metals 0.01%, textiles 4.9%, plastics, leather and rubber 7.6%, others (stones, wood, etc.) 0.1% (NEERI 1996 cited in Zia and Devadas, 2008). In Turkey, the characterization percent profile of solid waste is showing cardboard 2.4%, food and yard 54.2%, metals 3%, glass 6.3%, nylon 9.4%, textile 1.9% and ash and others 5.9% (Tinmaz and Demir 2006). In Philippines studies showed that the solid waste composition as the following: food wastes 36%, papers and cardboard 12%, plastics 11%, textiles 3%, rubber and leather 3%, wood and yard wastes 12%, metals 8%, glass 6% and others 9% (JICA 1992 cited in by Bennagen et al. 2002). In Bangladesh, the composition of mixed MSW for Habibganj city illustrated that the percentages of food wastes 50%, fine dust 9.6%, plastics 10.3%, stones, bricks and earthward 14.3%, paper 6%, metals 1.5%, leather 2% and others 1.8% (Alam et al. 2007).

Clearly, the field survey findings are very close to most of the studies in the developing countries which reflect the similarity of consumption pattern in those countries.

5.3. Quantification of the Potential Recycling

Resource recovery can be an effective tool in managing waste streams. Resource recovery
includes any process that can recover energy and/or recyclable materials from collected MSW. Questions that arise include: how much waste can be recovered?, are the quantities generated feasible to be recovered?, what are the environmental benefits or costs?. The first step in developing an effective recycling or energy recovery program is to determine the composition of the solid waste generated at the source. In this chapter it is calculated how much waste can be recycled in Gaza Strip.

5.3.1. Recycling

5.3.1.1. Recycling rates

It is indicated from the composition study that the potential recyclables in Gaza Strip waste is as follows: fresh vegetables and fruits, wood, and yard waste (34.06%), papers and cardboards (14.52%), plastics (12.11%), metals (8.29%), and glass (6.43%). Based on these figures it can be concluded that 75.41% of the municipal waste can be recycled.

Valuable concerns shall be given to paper and plastic fractions as well as the organic and food wastes as a source for composting and soil enrichment, especially the study area has large areas for agriculture use.

Assuming that the recycle rate will be 10% as reported by (World Bank, 2003) and based on the yearly estimated MSW generation; the amount of materials that can be recycled is calculated in the Table (5.8) below:

<table>
<thead>
<tr>
<th>Potential recyclables</th>
<th>Food, wood, and yard waste</th>
<th>Papers and cardboards</th>
<th>Plastics</th>
<th>Metals</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling rate</td>
<td>34.06%</td>
<td>14.52%</td>
<td>12.11%</td>
<td>8.29%</td>
<td>6.43%</td>
</tr>
<tr>
<td>Average MSW generated per year</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily Recycled (Ton/day)</td>
<td>715,000</td>
<td>66.7</td>
<td>28.4</td>
<td>23.7</td>
<td>16.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>66.7</td>
<td>28.4</td>
<td>23.7</td>
<td>12.6</td>
</tr>
</tbody>
</table>
5.3.2. Success of recycling / composting

Zuilen (2006) stated that the success of recycling and composting depends on many factors. To increase the recycling rate, attention has to be paid to the following actions:

- Implementation of a best practice recycling program.

Collection of recyclables is seen as an integral part of a successful recycling strategy because it makes recycling accessible and easy for the average householder. This does not mean that everyone will take part in recycling. Collection must be efficient i.e. with minimum energy input, to maximize the environmental benefit of recycling.

- The government must place national waste recycling target.

Guidelines must be developed on how much recyclables must be recycled e.g. per year. Therefore a database of how much waste is generated and recovered is very important to make future plans.

- Recycling must be legalized

Making recycling mandatory would increase participation. This is an unpopular step, but it may be necessary to meet future recycling goals. Mandatory recycling tends to produce a negative attitude towards recycling, and may cause some persons to resist the program whenever possible. Mandatory recycling combined with incentives (e.g. deposit) can be a mean to increase recycling. This option requires funds to pay to the participants.

- Continuous public awareness

Normally, the best method to increase recycling is through education. Unless people see a benefit, there is little chance they will participate. One way to increase recycling is to increase individual participation by education programs. These programs must deal with different waste topics or insights and must occur on a regular basis.

- Finding markets for the material

The only way to increase recycling to meet future recycling goals is to find markets for recycled materials. A detailed market study is important to have insight in the economic feasibility, demand, and price fluctuations.

Finally, the development of technologies such as the landfill GIS model, in hand with new policies and waste management legislation, represent a step in the right direction for the
management of waste, and more specifically for landfill site selection in Gaza Strip. However, there is an urgent need, in line with government policy, to reduce the significant volumes of waste that we produce as a society. It will take time and a major commitment to reach a situation where waste prevention, waste reduction and waste recovery ultimately reduce the need for landfill and other waste disposal methods.

5.4. Optimal Number of Landfills for Gaza Strip

In an effort to get a comprehensive outcome of determining the optimal number of landfills needed for Gaza Strip, a wide range of stakeholders were participated in the multi criteria analysis questionnaire. Thus twenty eight questionnaires were distributed to all stakeholders by structured interviews to ensure hundred percent rate of response which really achieved in this study.

This section will deal with the results of the respondents’ preferences as well as the DEFINITE modeling results.

5.4.1. Respondents’ Organization Class:

Figure (5.3) indicates the distribution of the respondents’ organization, and the results show that eight of respondents were from academic institutions, distributed to six experts from Islamic University of Gaza (IUG) and the others from University College of Applied Science (UCAS) and Alaqsa university, five were from united nations institutions where three of them from United Nations Relief and Works Agency (UNRWA) and the rest from United Nations of Development Program (UNDP), six were from the main municipalities in Gaza Strip, six were from governmental and semi-governmental institutions distributed equally, two were from NGOs exactly from PEF, and finally one was from INGOs.

Fortunately, more than 90% of respondents are experts with high administrative levels in their institutions for instance they are classified to be managers, directors, chairmen and even deputy ministers.
5.4.2. Experience of the Respondents

Table (5.8) indicates the distribution of the respondents' experience which shows that 57% of the respondents have an experience more than 15 years in the field of SWM, and 25% of them have an experience between 10-15 years.

<table>
<thead>
<tr>
<th>Experience</th>
<th>No. of respondents</th>
<th>Percent %</th>
<th>Cumulative percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5 yrs</td>
<td>2</td>
<td>7.1%</td>
<td>7.1%</td>
</tr>
<tr>
<td>6-10 yrs</td>
<td>3</td>
<td>10.7%</td>
<td>17.8%</td>
</tr>
<tr>
<td>11-15 yrs</td>
<td>7</td>
<td>25.0%</td>
<td>42.8%</td>
</tr>
<tr>
<td>More than 15 yrs</td>
<td>16</td>
<td>57.2%</td>
<td>100 %</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>100%</td>
<td>----</td>
</tr>
</tbody>
</table>

5.4.3. Main Criteria Weights

In the past, the environmental factors wasn’t been considered as important as other factors in
infrastructure projects. In this study the aware of environmental factors is appeared evidentially, thus the environmental factors have the highest weight among all other factors with 31.5% as shown in Table (5.9). Likewise, the socio-economic factors are considered very important in the respondents’ judgment so that it ranks in the second class with 28%. Also, the political/legal factors seem to be very prominent; therefore its weight is 22.5% because the political situation in the study area is unstable. The lowest weight of the main criteria is the engineering one since most of the respondents believe that this factor can be attained provided that the others are attainable.

*Table 5.9: Main Criteria Weight*

<table>
<thead>
<tr>
<th>Main Criteria</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>31.5</td>
</tr>
<tr>
<td>Socio-Economic</td>
<td>28.0</td>
</tr>
<tr>
<td>Political/legal</td>
<td>22.5</td>
</tr>
<tr>
<td>Engineering</td>
<td>18.0</td>
</tr>
</tbody>
</table>

5.4.4. Sub Criteria Weights

The average weight for each criterion is calculated from the assigned criterion weight by respondents.

5.4.4.1. Environmental Indicators Weights

Obviously, the ground water pollution is the most important factor among the seven environmental factors from the respondents’ point of view. This, probably, because the ground water is the unique source of water in the study area so it needs a special care when choosing the landfill numbers.

Furthermore, the other factors were very close to each other which reflect the same importance of them. Nonetheless, the noise and aesthetic factors have the lowest weight since the landfills should be sit far away from roads and urban areas. All the weights of the environmental factors are presented in Table (5.10).
Table 5.10: Environmental Sub-Criteria Weight

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Weight%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground water pollution</td>
<td>28.0</td>
</tr>
<tr>
<td>Land use</td>
<td>15.5</td>
</tr>
<tr>
<td>Air pollution</td>
<td>14.5</td>
</tr>
<tr>
<td>Land contamination</td>
<td>13.0</td>
</tr>
<tr>
<td>Odors</td>
<td>11.5</td>
</tr>
<tr>
<td>Noise</td>
<td>9.0</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>8.5</td>
</tr>
</tbody>
</table>

5.4.4.2. Socio-Economic Indicators Weights

The operation and maintenance cost, transfer cost, land availability and ownership, and construction cost have together 70% of the total weight as shown in Table (5.11). Actually, these factors represent the most important constraints in choosing the landfill numbers.

The public acceptance and health have less attention and importance in the study area. And finally, the closure cost is considered the less important factor in the respondents’ opinions.

Table 5.11: Socio-Economic Sub-Criteria Weight

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Weight%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation &amp; maintenance cost</td>
<td>18.5</td>
</tr>
<tr>
<td>Transportation cost</td>
<td>17.5</td>
</tr>
<tr>
<td>Land availability and ownership</td>
<td>16.5</td>
</tr>
<tr>
<td>Construction cost</td>
<td>16.0</td>
</tr>
<tr>
<td>Public acceptance</td>
<td>12.0</td>
</tr>
<tr>
<td>Public health</td>
<td>12.0</td>
</tr>
<tr>
<td>Closure cost</td>
<td>7.5</td>
</tr>
</tbody>
</table>
5.4.4.3. Engineering (Technical) Indicator

Relatively, all sub-criteria presented in Table (5.12) have approximate weights inasmuch the respondents think that these technical issues should be implemented after the construction of the landfill.

Table 5.12: Engineering Sub-Criteria Weight

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Weight%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling applicability</td>
<td>18.5</td>
</tr>
<tr>
<td>Infrastructure requirements</td>
<td>18.5</td>
</tr>
<tr>
<td>Waste coverage</td>
<td>18.0</td>
</tr>
<tr>
<td>Suitability for future expansion</td>
<td>16.5</td>
</tr>
<tr>
<td>Leachate treatment</td>
<td>15.5</td>
</tr>
<tr>
<td>Gas control</td>
<td>13.0</td>
</tr>
</tbody>
</table>

5.4.4.4. Political/Legal Indicators

It can be seen from Table (5.13) that fundability as same as security are the most important sub-criteria in this main criteria. This high weight is due to the unstable political situation in the study area.

Table 5.13: Political/Legal Sub-Criteria Weight

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Weight%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundability</td>
<td>31.5</td>
</tr>
<tr>
<td>Security</td>
<td>29.5</td>
</tr>
<tr>
<td>Compliance with current S.W strategies</td>
<td>20.5</td>
</tr>
<tr>
<td>Compatibility with international laws and existing agreements</td>
<td>18.5</td>
</tr>
</tbody>
</table>

5.4.4.5. Final Weights of All Criteria

As a result of defining the main criteria and sub-criteria weights, a combination of those
weights gives the actual weight of each criterion as can be seen in Appendix C. These weights were calculated by summing up the weights to each criterion for all experts and then they were divided by the number of experts.

The results indicated that the actual weights range between 2% and 9%. This reflects that all criteria are important to be considered.

5.4.5. Score of Alternatives

Like the weights of both main criteria and sub criteria, each respondent assign to each alternative the appropriate score from his point of view according to the --/++ scale. After that the average of this score is calculated as shown in Appendix D.

5.4.6. Standardization of Scores

Before a multi-criteria method can be applied, for most methods, the effects Table needs to be standardized.

Scores from the various effects can only be compared if the measurement units are the same. Through the standardization procedure the measurement units are made uniform, and the scores lose their dimension along with their measurement unit.

The selected standardization method in this study is the goal method since it is the most suitable method for the used scale.

5.4.7. Multi Criteria Analysis

Next to the entry of all inputs, all methods available in the DEFINITE program, namely; weighted summation, Electre II, Regime, and Evamix, are used in this study in order to get the best option.

Each of the four techniques yields detailed output which can be included in a formal report. However, in this study we will offer a summary of the results for each technique as will introduced below.

5.4.7.1. Results of Weighted Summation Method

Weighted summation is a simple and frequently used evaluation method. As a first step all effect scores are standardized. An appraisal score is then calculated for each alternative by first multiplying these standardized effect scores by its appropriate weight, followed by
Chapter 5

summing the weighted scores of all effects. The final ranking of the alternatives is assessed based on the resulting appraisal scores for each alternative. (Janssen et al., 2001)

Figure (5.4) shows the result of the MCDA according to weighted summation method. This analysis compare between options in term of each main criterion and in term of all criteria together.

It appears that the centralized landfill option is preferred than the decentralized option in the total comparison. Moreover, the centralization is clearly considered preferable than the decentralization in terms of environmental factors and socio-economic factors as whole.

Although the centralized landfill exceeds the decentralized landfills also in not only the engineering factors but also the political/legal factors, there is a trivial difference between
them in each main criterion. So it can be concluded that, regarding to these two main criteria, the centralization and decentralization are almost alike. Otherwise, decentralization has an advantage in some sub criterion such that the transportation cost of waste. There is a consensus among all respondents that the decentralization can save a lot of expenditures for waste transferring.

5.4.7.2. Results of Electre II Method

The Electre method is based on a pairwise comparison of the alternatives, thus using only the interval character of the scores in the evaluation of the effects Table. The basic idea is to measure the degree to which scores and their associated weights confirm or contradict the dominant pairwise relationships among alternatives. (Janssen et al., 2001)

According to Electre II method the centralization also gets preferred than decentralization as shown in Figure (5.5).

![Figure 5.5: Results of Electre II Analysis](image)

5.4.7.3. Results of Regime Method

The Regime method can be seen as an ordinal generalization of pairwise comparison methods
such as the Electre method. The regime method is based on pairwise comparisons of the alternatives. The Regime method provides a probability Table as an intermediate result. The overall score of an alternative is calculated as the row average of the relative success indices. In addition, the Regime method does not standardize qualitative (ordinal and --/+++ ) effects. (Janssen et al., 2001)

The results of analysis are shown in the Figure (5.6). In this method it seems clearly that the centralization is more desirable than decentralization.

![Figure 5.6: Results of Regime Method](image)

5.4.7.4. Results of Evamix Method

The Evamix method is designed to deal with an effects Table with a mixture of qualitative and quantitative effects. The set of effects in the effects Table is divided into a set of ordinal effects and a set of quantitative effects. Dominance effects are calculated for both sets. The
Evamix method does not standardize qualitative (ordinal and ---/+++ ) effects. (Janssen et al., 2001)

Like other methods the centralization gets better results than decentralization in all comparisons as shown in Figure (5.7).

![Figure 5.7: Results of Evamix Method](image)

5.4.8. The Optimal Number of Landfills

The respondents were asked to determine the optimum number for landfills in Gaza Strip from their point of views. One of the respondents refused to ask this question because he believes that it's an urging case in Gaza strip, and it needs more discussion, however, the majority of experts suggested that one landfill would be efficient and enough to manage the produced waste in Gaza Strip. Nevertheless, those experts stipulated some requirements such
that the location of this landfill should be appropriate for all districts, transfer stations should be constructed to facilitate the transfer of waste, and adequate trucks with spare parts should be secured to transfer the waste.

On this basis building sanitary landfill is the best solution. But due to space limitations, it is also advisable to choose properly the best location for it and to attempt to reduce the volume of the waste stream as far as possible beforehand.

5.5. Sizing Procedure

In this section the required area for the central landfill is computed in case of zero recycling activities in one hand and in case of 10% recycling rate on the other hand.

The following assumptions were reported in MoP (2010): The average daily solid waste production per capita in Gaza Strip in 2010 was reported about 1300 ton/day and the average density in a landfill after compaction is between 800 and 1000 kg/m³. Besides, a 3% population increase per year and a constant average waste production per capita per year (1 kg/capita/day) are assumed.

5.5.1. Required Area Calculation

a) Current Waste Generation Per Day = 1300 tons
b) Estimated Waste Generation After 20 Years =  
\[ W \left( 1 + \frac{X}{100} \right)^n = 1300 \left( 1 + \frac{3.0}{100} \right)^{20} = 2350 \text{ tons} \]

c) Total Waste Generation in 20 Years =  
\[ T = \frac{1}{2} \left( W + W \left( 1 + \frac{X}{100} \right)^n \right) = \frac{1}{2} \left( 1300 + 2350 \right) \times 365 \times 20 = 13.3 \times 10^6 \text{ tons} \]

d) Total volume of waste in n years (\( V_w \)) (on the assumption of 1.0 t/m³ density of waste)  
\[ V_w = \frac{T}{1.0} \text{ (m}^3) \]
\[ \left( \frac{13.3 \times 10^6}{1.0} \right) = 13.3 \times 10^6 \text{ m}^3 \]
e) Total volume of daily cover in n years ($V_{dc}$) (on the basis of 15 cm soil cover on top and sides for lift height of 1.5 to 2 m)

$$V_{dc} = 0.1 \times V_w \text{ (m}^3\text{)}$$

$$= 0.1 \times 13.3 \times 10^6 = 1.33 \times 10^6 \text{ m}^3$$

f) Volume of Liner and Cover Systems.
Total volume required for components of liner system and of cover system (on the assumption of 1.5m thick liner system (including leachate collection layer) and 1.0 m thick cover system (including gas collection layer)

$$V_C = k \times V_w \text{ (m}^3\text{)}$$

($k = 0.25$ for 10 m high landfill, $0.125$ for 20 m high landfill and $0.08$ for 30 m high landfill.
This is valid for landfills where width of landfill is significantly larger than the height)

$$= 0.125 \times 13.3 \times 10^6 = 1.67 \times 10^6 \text{ m}^3$$

(g) Volume likely to become available within 10 years due to settlement / biodegradation of waste

$$V_S = m \times V_w$$

($m = 0.10$ for biodegradable waste; $m$ will for less than 0.05 for incinerated/inert waste).

$$V_S = 0.1 \times 13.3 \times 10^6 = 1.33 \times 10^6 \text{ m}^3$$

h) First Estimate of Landfill Volume

$$C_i = V_w + V_d + V_C - V_S \text{ (m}^3\text{)}$$

$$C_i = (13.3 + 1.33 + 1.67 - 1.33) \times 10^6$$

$$= 14.97 \times 10^6 \text{ m}^3$$

i) Likely Shape of Landfill is Rectangular in plan (length: width = 2:1)
Primarily above ground level, partly below ground level.

j) Possible Maximum Landfill Height = 20 m
k) Area Required = \( \left( \frac{14.97 \times 10^6}{20} \right) = 7.50 \times 10^5 \ \text{m}^2 \)

l) Total area required (including infrastructural facilities) (first estimate)

\[
A_i = 1.10 A_i + 0.4 \times 10^5 = \left( 7.50 \times 10^5 \times 1.10 \right) + 0.4 \times 10^5 = 8.65 \times 10^5 \ \text{m}^2
\]

The required area for a centralized landfill is about 900 dunum.

m) Assuming 10.0% recycling rate will decrease the area to about 11.0%. Thus the required area will be less than 800 dunum.

### 5.6. Results of Landfill Site Selection

#### 5.6.1. Introduction

The landfill site selection criteria model (spatial model) used in this study was developed basing on the information obtained from the review of the different criteria used in other countries to identify landfill sites, and also based on a loose scenario. The parameters used in this study for landfill site selection, are both spatial and non spatial factors.

The Spatial factors used include: soils, land use, topography, groundwater level, land ownership, valleys, airport, coastal line, residential and commercial areas, industrial lots, roads and railways, protected areas, and water wells. The Non-Spatial factors used include site capacity and shape, distance from generation sources, and population distribution.

In the following sections the results of applying GIS tool will be described in details.

#### 5.6.2. Study Area Boundary

Since all analyses over layers have to be limited to the extent of the study area, a boundary map (base map) was generated and used for future calculations.

The GIS model was applied to the Gaza Strip with a total area of about 365 km\(^2\) to be the initial landfill sitting research area as shown in Figure (3.1)

#### 5.6.3. Constraint Maps

Constraint (binary) maps are used to distinguish between lands that are suitable for landfill sitting and those lands that are restricted. The constraint maps are produced by merging each individual theme with the study area. This procedure creates a constraint map for each theme
containing only two classes represented by 1’s (for suitable land) and 0’s (for unsuitable land).

5.6.3.1. Coastline Buffer

Since the sea regions are used as recreational areas so a buffer of 100 m is implemented along side with the Gaza Strip coastline as shown in Figure (5.8). Therefore, about 4 km\(^2\) are excluded of the study area to be appropriate for a landfill site which represents 1.11% of the total area.

5.6.3.2. Surface Water Buffer

This criterion has a direct effect with land suitability for being used as landfill. In other words farther lands from valleys will get more preferences for being selected.

The surface water layer is constructed in order to create surface water constraint map with buffer zone around since they are not desirable region to build a landfill nearby.

A buffer distance of 30 m from the Gaza valley (Wadi Gaza) is considered for landfill location as also shown in Figure (5.8). Accordingly, the excluded area due to this criterion exceeds 1 km\(^2\) (0.29% of the total area).

5.6.3.3. Industrial Lots Buffer

By considering all the suggested safe distances in the literature, minimum distances for the study area are determined as 200 m for industrial areas. This distance is used to create buffer zones around industrial areas and excluded from the study area.

Applying this buffer removes more than 15 km\(^2\) from the study area which corresponds to 4.13% of the total area as shown in Figure (5.8).

5.6.3.4. Urban Areas Buffer

The urban constraint map is created in order to define a limit around urban areas that would protect the population from landfill hazards, such as scavenging animals and strong odor. The built up areas as same as urban development areas are buffered by 150 m, thus an area more than 137 km\(^2\) is rejected as suitable landfill site. Actually, this area is the largest excluded area since it represents 37.66% of the total area as depicted in Figure (5.9).
Figure 5.8: Industrial, Surface Water, and Coastline Buffers
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Figure 5.9: Urban Areas Buffer
5.6.3.5. Protected Areas Buffer

No landfill site is allowed to be built within the protected land at a buffer distance of 500 m as shown in Figure (5.10). Incidentally, in Gaza Strip the protected areas comprise three main regions namely, national park, mawasi, and natural reserve. Depicted in Figure, implementing a 500 m buffer around those areas eliminated about 79 km$^2$ from the total area. In other words, the second higher area (21.68%) is excluded due to this criterion.

Figure 5.10: Protected Areas Buffer
5.6.3.6. Airport Buffer

A buffer of 3000 m is established around the airport so that the unsuitable area is determined and computed to be 34.5 km$^2$. Indeed, this area represents accurately 9.44% of the total area.

5.6.3.7. Roads Buffer

Landfill location must be close to roads network in order to facilitate transportation and consequently to reduce relative costs. However, aesthetically and logically a buffer of 50 meter has been considered from each side of both regional and main roads in this study. Accordingly, two zones of suitability are determined and considered in further analysis. Hence, the eliminated area is 32.5 km$^2$ which constitute 8.89% of the total area.

5.6.3.8. Railways Buffer

The railroads constraint map is produced in order to establish buffer around them. Given that building on railroads is not a desirable place to situate a landfill site, the buffer distance of 100 is employed. The excluded areas due to airport buffer, roads, and railways can be seen in Figure (5.11).

5.6.3.9. Water Wells Buffer

To protect groundwater from probable contamination a 50 m buffer is implemented not only to municipal wells but also to legal agricultural wells. Likewise, this criterion excludes sporadic areas about 27 km$^2$ from the total area. Exactly 7.39% is excluded from the study area due to this criterion as presented in Figure (5.12).

5.6.3.10. Final Constraint Overlay Map

Once all the map layers satisfying the criteria were developed, an overlay map was obtained representing the final landfill suitable areas. Consequently, this procedure created a constraint map for each theme containing only two classes represented by suitable land and unsuitable land. The above mentioned constraint maps (layers) were combined using overlay function to create the final constraint map depicted below in Figure (5.13).

According to the final constraint overlay map, the results of the loose scenario gave a total unsuitable area of 268 km$^2$, which corresponds to 73.42% of the total area. In other words, the remaining area to be examined represents around 25% of the total area. Afterwards, this
area will be decreased due to considering other factors.

Figure 5.11: Airport, Main Roads, and Railways Buffers
Figure 5.12: Water Wells Buffers
Figure 5.13: Final Constraint Map
5.6.4. Factor Maps

Factor maps illustrate suitability of a specified feature that ranges from the unsuitable locations to the suitable locations. The goal of producing the factor maps is to reduce the suitable locations into specific locations.

5.6.4.1. Suitable Sites With Sufficient Capacity

After having selected the most suitable areas for waste disposal, the next condition to be met is that the suitable areas are large enough for storing the waste for a prolonged period. In order to be able to use the site for a longer period and according to landfill size requirements the minimum area should be 1,000 donum.

Specifically, the scattered areas less than the required area or their shape inadequate for sitting a landfill sum up about 10.98 km$^2$. These excluded lands increase the unsuitable areas to 279 km$^2$ so that 76.46% of the total area is considered unsuitable areas as appear in Figure (5.14).

5.6.4.2. Land Use

This criterion concerns with natural features that may be exposed by the threats imposed because of landfill adjacency. Land use for Gaza Strip is defined beforehand through clear regional planning. Any area selected as a landfill site must therefore comply with existing plans. Parameters like port, recreational areas, and agricultural potential areas have been taken in to consideration and consequently they converted to the unsuitable areas as shown in Figure (5.14).

The available land use map was queried to get open lands which are not currently in use or its use can be adequate for landfills. The application of this criterion excluded an overall area of about 15.4%, of the total study area. Therefore, the eliminated area exceeds 56.32 km$^2$. Additionally, the total excluded areas are 335.4 km$^2$ that constitute around 92% of the total area.

Then the candidate sites are projected on the land use map of the study area as shown in Figure (5.15).
Figure 5.14: Candidate Sites
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Figure 5.15: Land Use Map
5.6.5. Available Areas by Area Characteristics

The results obtained from the previous operations show that the available areas for landfill sitting are less than 30 km² divided to seven candidate areas. In the next step a query was done to find the areas that meet the following conditions:

5.6.5.1. Soil Characteristic

Soil characteristics of geologic structure, soil type will affect the waste leachate containment characteristics of a site. Table (5.14) shows the soil types in Gaza Strip and its scale value for the permeability and its infiltration rate of waste leachate containment according to (Khalaf, 2005).

Table 5.14: Classification and Characteristic of Different Soil Types in Gaza Strip

<table>
<thead>
<tr>
<th>Local Classification</th>
<th>Texture</th>
<th>Permeability (cm/sec)*</th>
<th>Permeability Description*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loess soil</td>
<td>Sandy loam (6% clay, silt 34%, sand 58%)</td>
<td>0.0141 - 0.0423</td>
<td>Moderately rapid</td>
</tr>
<tr>
<td>Dark brown</td>
<td>Sandy clay loam (25% clay, 13% silt, 62% sand)</td>
<td>0.0014 - 0.0042</td>
<td>Moderately slow</td>
</tr>
<tr>
<td>/ reddish brown</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loess</td>
<td>Sandy clay loam (23% clay, 21% silt, 56% sand)</td>
<td>0.0014 - 0.0042</td>
<td>Moderately slow</td>
</tr>
<tr>
<td>Sandy loess soil</td>
<td>The top layer is sandy loam (14% clay, 20% silt, 66% sand). The lower profile is loam (21% clay, 30% silt, 49% sand)</td>
<td>0.0042 - 0.0141</td>
<td>Moderate</td>
</tr>
<tr>
<td>Loessial sandy soil</td>
<td>Sandy loam (17.5% clay, 16.5% silt, 66% sand)</td>
<td>0.0141 - 0.0423</td>
<td>Moderately rapid</td>
</tr>
<tr>
<td>Sandy loess soil over loess</td>
<td>Top layer is loamy sand (9% clay, 4% silt, 87% sand). Deeper profile is sand (7.5% clay, 0% silt, 92.5% sand)</td>
<td>&gt; 0.0423</td>
<td>Rapid</td>
</tr>
</tbody>
</table>


According to the characteristics of geological texture of the region, this criterion categorizes the whole area in to two distinct classifications; soils having high rate of permeability (loess soil, and sandy regosol) are considered unsuitable for being used as a landfill while soils with medium and relatively low rate of permeability (sandy loess soil over loess, loessial sandy...
soil, sandy loess soil, and dark brown/reddish brown) are considered fairly suitable and optimal to site a landfill respectively. Figure (5.16) illustrates the soil type in the candidate sites.

Figure 5.16: Soil Type Map
5.6.5.2. Topography

The topographical features of the study area are flat and the contour surfaces are very less, therefore the slope requirement of the study area are satisfied as shown in Figure (5.17).

*Figure 5.17: Topography Map*
5.6.5.3. Depth of Underground Water Table

Considering underground water contamination, depth of water Table shown in Figure (5.18) must be taken into consideration as a highly effective factor. This criterion categorizes the whole area into two zones; zones with deep enough water Table depth will be considered optimal while zones with relatively deep and shallow water Table are introduced as unsuitable.

Figure 5.18: Water Level Map
5.6.5.4. Land Ownership

Figure (5.19) shows the type of land ownership in Gaza Strip. Clearly, there are four main types of ownership in the study area namely, Waqf, private, governmental, Bier sheba’ (another type of private).
5.6.6. Alternatives of Landfill Location

The seven candidate sites shown in the above mentioned Figures are projected in the soil characteristic map, topography map, water Table level map, and land ownership map in order to compare between them based on these factors and other factors.

Henceforth, these sites will be compared due to the above mentioned characteristic as presented in Table (5.15). It is very clear that the candidate site distributed in the east of three governorates as follows, three in Gaza governorate, one in middle governorate, and three in Khan Younis governorate. Also, the characteristics of them are very close to each other.

Table 5.15: Candidate Sites Characteristics

<table>
<thead>
<tr>
<th>characteristic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governorate</td>
<td>Gaza</td>
<td>Gaza</td>
<td>Gaza</td>
<td>Middle</td>
<td>Khan Younis</td>
<td>Khan Younis</td>
<td>Khan Younis</td>
</tr>
<tr>
<td>Area (km$^2$)</td>
<td>1.60</td>
<td>3.11</td>
<td>3.51</td>
<td>3.69</td>
<td>5.66</td>
<td>5.44</td>
<td>9.00</td>
</tr>
<tr>
<td>Soil type</td>
<td>Loess soil + Dark brown / reddish brown</td>
<td>Loess soil + Dark brown</td>
<td>Loessial sandy soil</td>
<td>Loessial sandy soil + Dark brown</td>
<td>Sand loess soil over loess</td>
<td>Sand loess soil over loess</td>
<td></td>
</tr>
<tr>
<td>Ownership</td>
<td>Private + Waqf</td>
<td>Private</td>
<td>Private</td>
<td>Beir sheba’</td>
<td>Beir sheba’</td>
<td>Private</td>
<td>Beir sheba’</td>
</tr>
<tr>
<td>Topography (m)</td>
<td>51-60</td>
<td>21-70</td>
<td>11-60</td>
<td>41-70</td>
<td>51-90</td>
<td>61-100</td>
<td>51-70</td>
</tr>
<tr>
<td>Water Table depth (m)*</td>
<td>50-60</td>
<td>20-65</td>
<td>10-55</td>
<td>45-70</td>
<td>50-90</td>
<td>55-90</td>
<td>45-65</td>
</tr>
</tbody>
</table>

* Approximate ranges

Furthermore, the largest area available for landfill site can be found in Khan Younis governorate where about 9.0 km$^2$ are suitable to sit a landfill there. Contrarily, the smallest available area is in Gaza governorate with 1.60 km$^2$. However, this small area is more than the required area.

Apparently, the soil type in all sites, except parts from the first site, has relatively low
permeability. Regardless, this means that all sites are suitable for sitting a landfill taking in consideration that areas with dark brown / reddish brown and sandy loess soil are more suitable.

Presently neither governmental lands nor Waqf lands are in the candidate sites. On the other hand the available ownership either private or Bier sheba’ which is also private. This will require a negotiation with owners to attain the preferred land.

As stated before, the topography in general is flat at all candidate sites. However, some sites have gradual differences in the whole area. Comparatively, the first, fourth, and seventh sites seem to be more suitable than others.

Likewise, the water Table is considered relatively far in the all candidate sites excepting some regions in the second and third sites.

In addition, the existing landfills are either very close to these sites or inside these sites. For instances Gaza landfill is adjoins the second candidate site and Middle landfill is located at east north of fourth landfill. Also Rafah landfill is located at the edge of the east south of the seventh site as shown in Figure (5.20).

5.6.7. Final Site Selection

As a result the mentioned candidate sites can be suggested as a suitable list of land to the Local Authority but, this is not a final result as further step needs to be applied in order to narrow down these suitable areas.

Eventually, from the researcher point of view, the fourth site is considered the most suitable site for a landfill location. This conclusion is based on the importance of this site location because it is in middle distance between all solid waste generation centers. For more clarification, the centre of this site away from north and Gaza governorates, middle governorate, Khan Younis governorate, and Rafah governorate by 17km, 5km, 7km, and 15km respectively.

Undoubtedly, this site still need further studies to gather comprehensive details to all factors before making the final decision.
Chapter 5

Analysis of results and discussion

Figure 5.20: Existing Landfills and Candidate Sites Relation
Chapter (6)

Conclusion and Recommendations
6.1. Achievements

The primary aim of this research is to develop a baseline for landfilling planning in order to manage the produced solid waste in the study area during the following twenty years. Therefore, the main achievements of this research can be summarized as follows:

- An updated MSW composition for the study area is obtained so that it can be used for further applications and researches in the field of solid waste.
- Potential of recycling and materials recovery is determined in order to reduce the solid waste quantities. Accordingly, many negative impacts of solid waste can be solved or decreased, for instance the required area of landfills will be decreased if the recycling rate is increased.
- Many MCDA techniques are used through DEFINITE model to determine the optimal number of landfills needed in the study area. Hence, it can be integrated with other SWM approaches to manage the future produced quantities effectively.
- Afterwards, the required area of the needed landfills is calculated in two cases. In the first hand if there are no recycling activities and in other hand if ten percent recycling rate is practiced.
- GIS tool is implemented to find the most suitable locations for landfills sites. Several useful maps are produced in order to study the candidate sites and to find the best location.

6.2. Conclusion

The main conclusions drawn from the current research are the following:

- Organic wastes comprise nearly half of the weight of waste which half of them are food waste and the rest are other organics such as babies’ nappies. This is followed by Paper which generally comprises nearly 14.5% of waste composition which most of it is cardboard. Plastic, being the third in components order, make up 12% of the waste stream. Paper and Plastic have a significant percentages and this is somewhat surprising. Subsequent to plastic, metals represent about 8% of waste stream. The lowest percentage in waste components is glass which forms nearly 6.5% of the total
components. Finally, the other inorganics materials comprise 11.5% of waste composition which most of them are sand and fine materials.

The potential recyclables in Gaza Strip waste is as follows: fresh vegetables and fruits, wood, and yard waste (34.06%), papers and cardboards (14.52%), plastics (12.11%), metals (8.29%), and glass (6.43%). Based on these Figures it can be calculated that 75.41% of the municipal waste can be recycled.

The environmental indicators and the socio-economic indicators are considered the most important indicators for determining the optimal number of landfills.

According to the MCDA and based on the stakeholders feedbacks it is found that one landfill would be efficient and enough to manage the produced waste in Gaza Strip. But some requirements are required for that such that the location of this landfill should be appropriate for all districts, transfer stations should be constructed to facilitate the transfer of waste, and adequate trucks with spare parts should be secured to transfer the waste.

The required area for a centralized landfill to manage the full produced MSW is about 900 dunum. However, assuming 10.0% recycling rate will decrease this area to about 11.0%. Thus the required area will be less than 800 dunum.

The results obtained from implementing a loose scenario of sitting criteria and using GIS show that the available areas for landfill sitting are less than 30 km$^2$ divided to seven candidate areas.

In conclusion, the mentioned candidate sites can be suggested as a suitable list of lands to the local authority but this is not a final result as further step needs to be applied in order to narrow down these suitable areas.

Because of its location in middle distance between all solid waste generation centers, the fourth site is considered the most suitable site for a landfill location. For more clarification, the centre of this site away from north and Gaza governorates, middle governorate, Khan Younis governorate, and Rafah governorate by 17km, 5km, 7km, and 15km respectively.
6.3. Recommendations

- Many problems in SWM have been identified by many researchers, so the coming researches should focus on finding solutions for these problems.

- The researcher recommends that additional studies should be done on the characteristics of MSW like seasonal variations, laboratory experiments, volume of MSW components, etc…

- Valuable concerns shall be given to paper and plastic fractions as well as the organic and food wastes as a source for composting and soil enrichment, especially that the study area has large areas for agriculture use.

- Studies should be done to conduct recycling plans for potential recyclables. These plans could contain the required recycling techniques for each material, feasibility studies, cost benefit analysis, the responsibilities of all stakeholders, and etc…

- Detailed investigations should be required for choosing the best location specifically by conducting MCDA based on experts’ opinions and field studies.

- Government and researchers should integrate the efforts toward an integrated solid waste management taking into consideration the results obtained in this study.
References
References


References


References

Environment Protection Agency (2007), EPA Guidelines for Environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste), Environment Protection Authority.


References


Triantaphyllou, E., Mann, St., (1989). An Examination of Effectiveness of Multi Dimensional Decision Making Methods: A Decision Making Paradox, Pennsylvania University, USA. Elsevier Publisher, B.V. 0167-6236/89.


Appendices
Appendices

Appendix A

Waste Composition Data Sheet

Day/Date: _____________________  Collection Company: ______________
Site: _______________________  Vehicle Type: ______________
Weather: ________________  From: ________________
Recorded By: ________________

<table>
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<tr>
<th>Component</th>
<th>Weight (Kg)</th>
<th>Weight percentage (%)</th>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yard Waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food Waste</td>
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<td></td>
</tr>
<tr>
<td>Glass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Inorganics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
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</table>

Notes:___________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________


Appendices

Appendix B

Questionnaire of Multi Criteria Decision Analysis

Selecting the Optimum Number of Landfills Required for Gaza Strip Solid Waste

Islamic University of Gaza
Deanery of Graduate Studies
Department of Civil Engineering

Dear Sir:

I am a master student of civil engineering, department of Infrastructure management-at the Islamic University of Gaza.

This study is a part of master research in solid waste management at the Islamic University of Gaza (IUG) supervised by Dr. Jehad Hamad.

This questionnaire aims to evaluate the landfilling system needed for disposing Gaza Strip solid waste according to a set of criteria.

Kindly, I wish you can fill this questionnaire based on your experience and judgment in the field of solid waste management.

All data will be used just for academic study and it will be kept confidentially.

I appreciate your participation.

Researcher: Ahmed Abdalqader
Mobile No.: 0598915330
Email: aalqader@gmail.com
Notes:
- For “Main Criteria Weight”: each main criterion will be weighted by percentage (from 1 – 100%), so that the total main criteria weights equals 100%.
- For “Sub-Criteria Weight”: each sub-criterion will be weighted by percentage (from 1 – 100%), so that the total main criteria weights equals 100%.
- For “Rating”: (1) refers to worst case or least preferred, and (5) refers to best case or most preferred.

<p>| | | |</p>
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<th></th>
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<td>-</td>
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</tr>
<tr>
<td>2</td>
<td>-</td>
<td>small negative effect</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>no effect</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>small positive effect</td>
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<tr>
<td>5</td>
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<td>large positive effect</td>
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## Alternatives

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<td>1 2 3 4 5</td>
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<td>-- - 0 + ++</td>
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<tr>
<td>Ground water pollution</td>
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<td></td>
<td></td>
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<td>Land contamination</td>
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<td></td>
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<td>Odors</td>
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<td>Noise</td>
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<tr>
<td>Land use</td>
<td></td>
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<td><strong>2-Socio-Economic indicator</strong></td>
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<td>Operation &amp; maintenance cost</td>
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<td>Transportation cost</td>
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<td>Land availability and ownership</td>
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<td>Public health</td>
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<td></td>
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<tr>
<td><strong>3-Engineering indicator</strong></td>
<td>%</td>
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<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
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<td>Waste coverage</td>
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<tr>
<td>Leachate treatment</td>
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<td>Gas control</td>
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<tr>
<td>Recycling applicability</td>
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<tr>
<td>Suitability for future expansion</td>
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<tr>
<td>Infrastructure requirements (transfer station, collection system of waste, etc…)</td>
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<tr>
<td><strong>4-Political/ legal indicator</strong></td>
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<td>1 2 3 4 5</td>
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<td>Compatibility with international laws.</td>
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</table>
Islamic University of Gaza
Deanery of Graduate Studies
Department of Civil Engineering

1. Name:---------------------------------------

2. Telephone:------------------------------------

3. Firm:------------------------------------------

4. Job Title:--------------------------------------

5. Organization Class: ( ) NGO ( ) Governmental ( ) Private
   ( ) Municipal ( ) Academic ( ) Other----------

6. Years of Experience: ( ) 0-5 ( ) 5-10 ( ) 10-15 ( ) More than 15.

7. In your opinion, the optimum number of landfills in Gaza Strip:
   ( ) 1 ( ) 2 ( ) 3
### Appendix C

#### Actual Weights of Criteria

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### Appendices

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### Effect Table

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## Appendices

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### Political/legal

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