T.R.
VAN YUZUNCU YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF CIVIL ENGINEERING

FUTURE SOLID WASTE GENERATION QUANTITY DETERMINATION AND LANDFILL SITE SELECTION BY USING GIS AND MULTI CRITERIA DECISION ANALYSIS A CASE STUDY OF SULAYMANIYAH CITY/IRAQ

M.Sc. THESIS

PREPARED BY: Luqman Hamad ABDALLA
SUPERVISOR: Assoc. Prof. Dr. Serkan KEMEC

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ACCEPTANCE and APPROVAL PAGE

This thesis entitled "**Future solid waste generation quantity determination and Landfill site selection by using GIS and multi criteria decision analysis a case study of Sulaymaniyah city/iraq**" presented by Luqman Hamad ABDALLA under supervision of Prof. Dr.Serkan KEMEÇ in the department of Department of Civil Engineering has been accepted as a M. Sc. thesis according to Legislations of Graduate Higher Education on 15/03/2018 with unanimity / ~~majority~~ of votes members of jury.

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Member: Assist. Prof. Dr. Mahmut ÇAVUR Signature:

This thesis has been approved by the committee of The Institute of Natural and Applied Science on ...30../.....3..../...2018. with decision number ..2018/17-I

Signature

....

Director of Institute

THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition, all kinds of information that does not belong to me have been cited appropriately in the thesis prepared by the thesis writing rules.

Signature

Luqman Hamad ABDALLA

ABSTRACT

FUTURE SOLID WASTE GENERATION QUANTITY DETERMINATION AND LANDFILL SITE SELECTION BY USING GIS AND MULTI CRITERIA DECISION ANALYSIS A CASE STUDY OF SULAYMANIYAH CITY/IRAQ

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M.Sc. Thesis, Civil Engineering Department
Supervisor: Assoc. Prof. Dr.Serkan KEMEÇ
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The City of Sulaymaniyah is situated in the north of Iraq. It covers a jurisdiction of around 1889.5-km2 and inhabitants population of 702882 people according to census taken in 2016. The process of landfill site selection is reflected as a complex work linked to various factors and regulations. Landfill technique is among the easiest and inexpensive management systems which are incorporated in sustainable solid waste management. The objective of the study was to select landfill site for the city that is environmentally sound, socially acceptable and economically feasible in Sulaymaniyah city. The city of Sulaymaniyah is located in a place there is no landfill site which meets both environmental and scientific standards. Thus, in this study sixteen criteria were designated. The criteria used in the process are: urban center, type of soil, elevation, archaeological sites, roads, slope, military area, water wells, rivers, villages, agricultural land use, roads, electrical power line, industrial sites, wind direction and airport. The above standards were applied in the Geographical Information System (GIS) that shows a high potential to manage and analyse various data. Moreover, the Multicriteria Decision Analysis methods AHP (analytical hierarchy process) method was used to derive the weightings of criteria through using a matrix of pair-wise comparison. After that the weighted linear combination (WLC) method was used to obtain the suitability index map for candidate landfill sites. Two suitable candidate sites for landfill were selected for Sulaymaniyah city, where all these sites satisfied the scientific and environmental criteria which were adopted in this study. The areas of the selected sites were adequate to accommodate solid waste from 2020 until 2032.

Keywords: AHP, GIS, Iraq, Landfill, Sulaymaniyah.

ÖZET

GELECEK KATI ATIK ÜRETİM MİKTARININ HESAPLANMASI VE CBS VE ÇOK ÖLÇÜTLÜ KARAR VERME ANALİZİ İLE ÇÖP DEPOLAMA ALANI YER SEÇİMİ SÜLAYMANİYE / IRAK ÖRNEĞİ

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Süleymaniye şehri Irak'ın kuzey kesiminde yer alır. yaklaşık 1889.5 km2'lik bir alanı kapsamaktadır ve 2016 yılında yapılan nüfus sayımına göre nüfusu 70.2882 kişidir. Uygun bir çöp depolama alanı seçme süreci, çeşitli faktörlere ve düzenlemelere bağlı olarak karmaşık bir çalışma olarak yansıtılıyor. Depolama tekniği, sürdürülebilir katı atık yönetiminde yer alan en kolay ve ucuz yönetim sistemlerindendir. Çalışmanın temel amacı, Süleymaniye şehrinde çevreye duyarlı, sosyal açıdan kabul edilebilir ve ekonomik olarak uygulanabilir bir çöp depolama alanını seçmektir. Süleymaniye şehri, hem çevresel hem de bilimsel standartlara uygun bir çöp toplama alanına sahip değildir. Bu çalışmada on altı kriter belirlenmiştir. Bu süreçte kullanılan kriterler şunlardır: şehir merkezleri, toprak tipi, yükseklik, arkeolojik alanlar, yollar, eğim, askeri üs, su kuyuları ve nehirler gibi su toplama alanları, köyler gibi yerleşim alanları, tarım arazisi kullanımı, ulaşım araçları yollar, elektrik hattı, rüzgar yönü, sanayi siteleri ve havaalanı. Yukarıdaki standartlar, çeşitli verileri yönetme ve analiz etme konusunda yüksek bir potansiyele sahip olan Coğrafi Bilgi Sistemi'nde (CBS) ortamında uygulanmıştır. Ayrıca, çok ölçütlü karar verme analızı(ÇÖKVA) metotları (AHP) analitik hiyerarşi prosesi yöntemi, çift-bazlı karşılaştırma matrisi kullanılmıştır (ölçütlerin ağırlıklarını türetmek için kullanılmıştır). Bundan sonra, aday depolama alanları için uygunluk indeksi haritasını elde etmek için ağırlıklı doğrusal kombinasyon (ADK) yöntemi kullanıldı. Bu alanların tamamının bu çalışmada benimsenen bilimsel ve çevresel kriterleri yerine getirdiği Süleymaniye kenti için depolama sahası için iki uygun aday alan seçilmiştir. Seçilen alanların alanları, 2020'den 2032 yılına kadar katı atıkları depolamaya yeterlidir.

Anahtar kelimeler: AHP, CBS, Irak, Depolama alanı, Süleymaniye.

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LIST OF ABBREVIATIONS

Some abbreviations used in this study are presented below, along with descriptions**.**

Abbreviation	Description
Pr_i	Priority vector
AHP	Analytical hierarchy process
CI	Consistency Index
CR	Consistency ratio
DEM	Digital elevation model
DMs	Decision-makers
Egi	Eigenvalue
GIS	Geographic Information Systems
GPS	Global positioning system
GRSW	Generation rate of solid waste for each year
GRW	Generation rate of solid waste
GRWA	Average generation rate of solid waste
IMILP	Inexact mixed integer linear programming
MCDA	Multicriteria decision analysis
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
OWA	Ordered Weighted Average
P	Population
Qs	Quantity of solid waste
RGI	Rate of increment for waste generation rate
RI	Random index
SAW	Simple Additive Weighting
SMCDA	Spatial Multicriteria Decision Analysis
Ui	Utility value

Abbreviation	Description
UTM	Universal transverse Mercator
WGS	World Geodetic System
WHO	World Health Organization

1. INTRODUCTION

Solid wastes could be defined as non-gaseous and non-liquid products of human activities, regarded as being useless (Babayemi and Dauda, 2009). Its origin is mainly from households, construction and municipal (Munier, 2005). The generation and management of municipal solid wastes are the problems facing both developing and developed countries. Generation of municipal solid waste has become an increasing public health and environmental problem everywhere in the world, mainly in developing countries. Fast expansion of urban, industrial and agricultural activities spurred by quick population growth has created vast amounts of liquid wastes and municipal solid that contaminate the environment and destroy resources (Dauthy et al., 2005). In many countries with growth of population and the increasing demand for food and other essentials, there has been increased in the amount of municipal solid waste being generated creating its management and dumping problematic (Asadi et al., 2005). Municipal solid waste management has long been a universal environmental problem. This is because of the quick growth of urbanization and population that reductions the non-renewable resources and dumping of toxic waste and arbitrarily, because of this major environmental issues posing stress to the arrival of human being (Allen et al., 1997). The most collective problems related with inappropriate management of municipal solid waste include fire hazards, foul odor, transmission diseases, atmospheric and water contamination, aesthetic pain and economic victims (Jilani, 2002).

The process of landfill siting is the complex tasks related to municipality solid waste management systems because it is subject to municipal and government funding, rising environmental awareness, public health concerns, increasing population densities, reduced land availability for landfills and increasing social and political resistance to the instituting of landfill sites (Lin and Kao, 1999). Identifying landfill sites is a difficult process where need many factors to be taken into consideration. Illustrations of such factors include geomorphologic features, environmental and social factors and technical parameters. Waste dumping sites must preserve the ecology in the surrounding area and biophysical environment (Erkut and Moran, 1991; Lober, 1995; Siddiqui et al., 1996). Economic factors, which include the development and operation costs as well as cost of acquiring land, must also considered (Erkut and Moran, 1991; Yesilnacar and Cetin, 2008). Transportation costs, owing to the distance from solid waste production centers and distance from main roads, are also an important factor (Wang et al., 2009).

Iraq, an Arabian country with a population of over 32 million, is experiencing rapid economic growth. This, along with a growing population, led to an increase in individual incomes and instability created by sectional conflicts, worsening solid Waste Management issues. Repeated wars in Iraq have also created constant instability and as a result the country has not been able to keep up with the ongoing scientific progress of more developed countries and has become isolated.

In 2016, Sulaymaniyah city with 702882 persons produced 220635 (tonnes) of solid waste with the municipal solid waste generation of 0.86 kg/(capita. day) (Sulaymaniyah directory of municipality), It means that about (60.5) tonnes waste is daily produced in Sulaymaniyah (Sulaymaniyah directory of Municipality). There is an absence of modern, efficient waste handling and disposal infrastructure as well as a general lack of interest in/awareness of health and environmental issues. Unfortunately, the hallmarks of landfill sites in Iraq are groundwater contamination, surface water pollution, spontaneous fires, large-scale greenhouse-gas emissions and increasing numbers of insects and rodents in/ around the site area (Alnajjar, 2013).

This research uses the concepts of geographic information systems (GIS) and a spatial multi-criteria decision analysis (SMCDA) to be used in the selection of landfill siting because there are powerful, integrated tools to solve the problem of landfill site selection. Decision makers often use (MCDA) Multi Criteria Decision Analysis to handle large quantities of complex information. GIS and AHP are powerful integrated tools used to solve the problem of landfill site selection. AHP is a multi-criteria decision making approach and was developed by Thomas Saaty in 1980 to unify these multi-criteria in the process of making decision. The decision problem was broken down into a hierarchy (Tree) of interrelated decision elements. Input data was then collected by pair wise comparisons of decision elements. The “eigenvalue” method was used to estimate the relative weights of decision elements. Then it was aggregated to arrive at a set of ratings for the decision alternatives. This method can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objective criteria and sub-criteria (Ersoy and Bulut, 2009). GIS plays a significant role in a landfill siting. GIS allows data to be displayed and managed efficiently from variety of sources, and it reduces the time and cost in the siting process. GIS may also be used for identifying routes for transporting waste to transfer stations and then to a landfill site and vice versa (Kontos et al., 2003; Delgado et al., 2008; Moeinaddini et al., 2010).

1.1. Case Study

Sulaymaniyah one of the most famous cities of Iraq. Sulaymaniyah is a very young city. Ibrahim Pasha Baban founded it in 1784. Sulaymaniyah is a city in the north Iraq. The Azmer Range, Goyija Range and the Qaiwan Range in the northeast, Baranan Mountain surround Sulaymaniyah city in the south and the Tasluja Hills in the west. between latitudes (35°46'25" - 35°14'11") North and longitudes (45°41'49" - 45°1'39") East, as displayed in (figure1.1) The study area has a surface area of 1889.5 km2. The average elevation of 736.12 meters above sea level. The city has a semiarid climate with very hot dry summers and cool wet winters. The total average annual rate of precipitation is 668.5 mm. The population of Sulaymaniyah City is approximately 702882 number of people. The main land cover types of the mentioned area are pastures, fallow lands, agriculture, water and residential areas. Economic growth in recent years has led to a remarkable increase in population and consequently in solid waste generation.

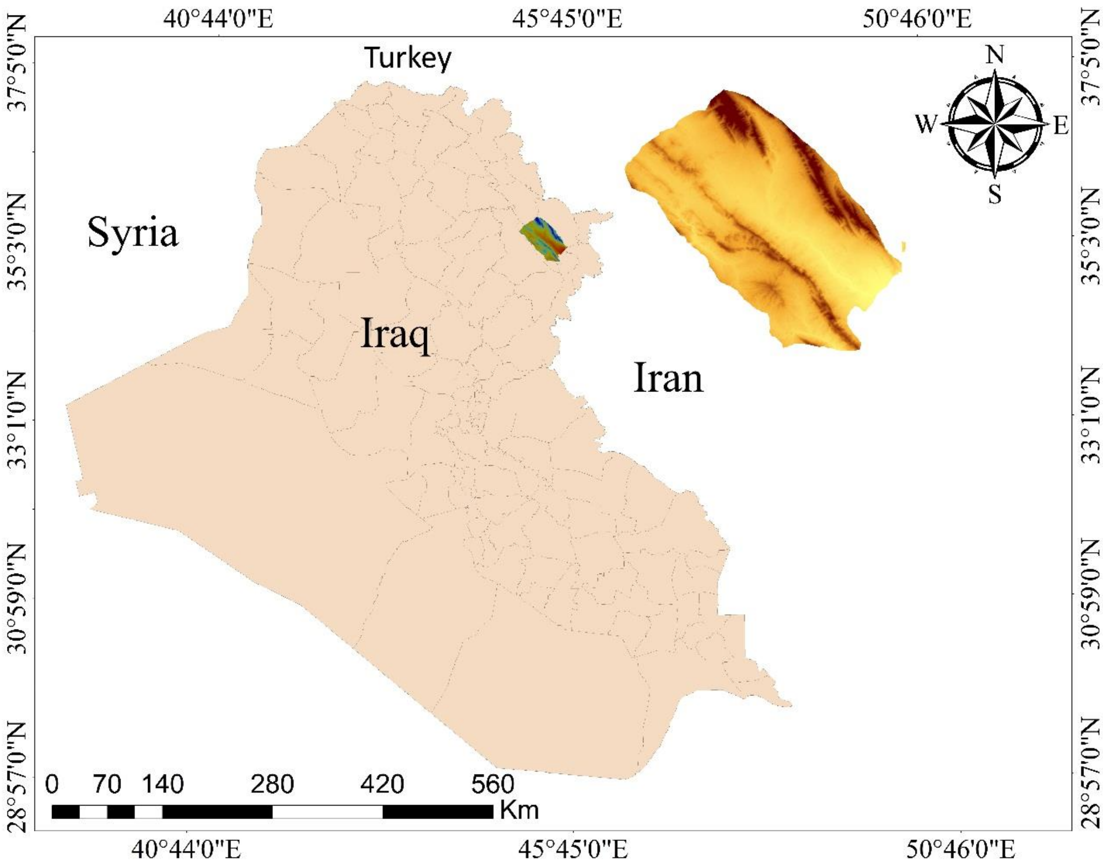


Figure1.1. Location Map of study area.

1.2. Statement of the Problem

As a consequence of population growth and development activities, high amounts of household and municipal solid wastes are generated. The population of a Sulaymaniyah city is growing due to both natural increase and through immigration of people from rural areas to city. High rate of wastes are facing problem of their disposal and have very high potential effect to pollute environment such as surface water, ground water, soil and air. Public health is also highly affected by the uncontrolled solid waste generation and disposal. In Iraq most of the diseases are related to poor environmental sanitation and water contamination. It is obvious that lack of suitable waste disposal site, public latrine and general sanitary mechanisms in the vicinity can affect the community's economic and social activities directly or indirectly (Tsegaye, 2006).

The increased wastes from the growing population and development activities have to be reduce via waste reduction, recycling and reuse techniques. Despite these solid waste management systems, collecting and depositing in safe sites by landfill technique is the primary means of waste disposal (Gizachew, 2011). This is due to the difficulty or the impossibility of managing all solid wastes through waste reduction, recycling and reuse. The solid waste disposal system should be in an environmentally sound and socially acceptable way so as to protect the environment and safeguard public health.

The major sources of solid wastes in the city are commercial institutions such as hotels, restaurants. Due to no landfill sites, people are forced to dispose the wastes from home or other areas like commercial institutions such as bars, hotels, restaurants, etc irregularly. These causes sanitary conditions of the area deteriorate and certainly will have high potential environmental and human health risk. This irregular removal of wastes serves as a cause for different diseases causing and transmitting agents as well. So the people are at risk in their day to day activities because of this problem. Therefore, solid waste disposal system should be an environmentally sound and socially acceptable way to protect the environment and safeguard public health. However, the traditional and manual method used to select suitable landfill site is inaccurate, tedious, time consuming and costly.

Although, in Iraq on most parts of the area had been already conducted researches concerning on landfill sites selection. Earlier, the municipality of a city was tried to select solid waste disposal site. However, they did not fully utilize GIS and multi criteria decision analysis and were unable to consider many of these factors.

The current waste disposal system of the city is open dump system and the site is filled out, causing many dangerous problems to the agricultural lands quality residents, and also to health. The most important feature of this problem is inappropriate landfill site that it has a low distance to Tanjaro river and residential areas. That is why, the research need to conduct in order to select solid waste landfill site for the city by considering ecological, environmental, economical and social factors. Using to method to estimate the future expectations of the quantities and the cumulative quantities of solid waste in study area to determine the required landfill site area. The study focused on integrating GIS and MCDA to provide appropriate information about geographic data to assist in selecting suitable solid waste disposal site using different factors. Therefore, the present study employs GIS, multi-criteria decision analysis for appropriate landfill site selection for Sulaymaniyah city, and that this project comes up with the solutions for previously stated problems.

1.3. Objectives of Research

The detailed objectives of this study include:

1. A comprehensive assessment of the reality of solid waste management in Sulaymaniyah city and the current locations of waste disposal sites in Sulaymaniyah city.

2. Estimation of future expectations of the quantities and the cumulative quantities of solid waste in study area.

3. Estimation of the required area for landfill siting in Sulaymaniyah city.

4. Set the most important criteria for landfill siting in in Sulaymaniyah city that conform to the international criteria. These criteria will be use as a reference to enable planners and decision makers to apply them in other similar areas in Iraq when selecting a new landfill site.

5. Identifying a suitable candidate site for landfill through using the GIS (geographic information system) and AHP (analytical hierarchy process) method Sulaymaniyah city based on the selected criteria.

1.4. Scope of the Study

Presently, there are no landfill site in Sulaymaniyah City that follows the scientific and environmental criteria which are usually applied in the selection of landfill sites. There are irregular waste disposal sites or dumping sites which are distributed throughout the cities of the Governorate. These sites caused many environmental problems in those areas. The main aim of this research is to select the best landfill sites in Sulaymaniyah city that conform to international and environmental criteria. To achieve this goal important criterion that can affect the environment were considered. Then, GIS technique and multi-criteria decision-making method (AHP) were used to define the best suitable sites.

1.5. Thesis Layout

The study has five chapters. The first chapter contains the introduction part with background of the study, descriptions of the study area, statement of the problem, objectives of the study, Scope of the Study. Chapter Two, is related to literature review. The focus area of the literature reviews are explaining terms, concepts related to the subject matter. This section is emphasized different scholars ideas around the global regarding causes and consequences of landfill. Chapter Three, deals with the methodology. Chapter Four, deals with results and discussion of the study. Chapter Five presents conclusion of the research work.

2. LITERATURE REVIEW

Municipal Solid Waste (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).

Municipal Solid Waste (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.

MSW 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).

2.1. Methods of Solid Waste Disposal

As a result of increasing population growth with subsequently increasing solid waste production, the need for solid waste disposal will remain a growing issue (Al-Meshan, 2005). The term waste disposal in the solid waste management system refers to the final function for any element, where there is no other option for dealing with it, and no additional value exists (Guangyu, 2016). There are many methods for dealing with various types of waste and they can be disposed of in the following ways:

a. Open Dumps

The use of open dumps is considered an antiquated method and includes all kinds of solid waste, which is deposited into open dumps untreated, uncovered and not segregated (http://edugreen.teri.res.in/explore/solwaste/disposal.htm).

b. Dumping into Sea

This method is applied in coastal cities. The waste is dumped in places far away (15- 30) km from the coast. It is very expensive and also it is not friendly to the environment (http://theconstructor.org/environmental-engg/methods-of-solid-waste disposal/4721/).

c. Recovery of Phosphorus from Sewage

This method converts the sludge that results from sewage into phosphorus. The Swedish Government proposed recycling of 60% of all phosphorus by 2015 (Swedish Environmental Protection Agency, 2005).

d. Incineration

The incineration method is based on burning remaining waste material in large furnaces after segregating material through a recycling process (http://edugreen.teri.res.in/explore/solwaste/disposal.htm).

e. Biological treatment (Composting)

In this method, recyclable food (degradable waste) is converted into composting as a base for fertilizers and for soil cultivation using biological treatment under special conditions. The biological treatment also involves biological decomposition of organic matter into biogas under anaerobic conditions (Swedish Environmental Protection Agency, 2005).

f. Waste to Energy (Recover Energy)

In this method, non-recyclable waste is converted into fuel, electricity and usable heat using different processes (http://theconstructor.org/environmental-engg/methods-of solid-wastedisposal/ 4721/).

g. Material recovery

It includes manufacturing materials, recycling materials and construction materials, which can be reused for specific purposes (Swedish Environmental Protection Agency, 2005).

h. Waste Minimization

It means reducing the quantity of waste, which is sent to landfills through recycling old materials (http://www.conserve-energy-future.com/waste-management-and-waste-disposalmethods.php).

i. The Bottom Line

This method is used in the remediation of biomedical waste generated in the special waste disposal systems used in health care facilities (http://www.conserve energy future.com/waste-management-and-waste-disposal-methods.php).

j. Landfills

Landfills are usually situated in or near urban areas (source of waste generation) for waste storage. The waste must be disposed into it at regular time. At the end of every day, after compressing the waste the pit is covered with a layer of soil in order to prevent the breeding of rats and flies. The area of landfill is covered with a thick layer of mud when the operational life of the landfill has ended. The site of landfill can be developed into a park or a parking area (Al-Meshan, 2005). The main problem with landfill sites is contamination of groundwater, soil and surrounding area when water leaches from landfills. In order to reduce the environmental impact in developed countries, the rate of minimization of various wastes that go to landfills is achieved through increasing materials recovery, incineration of organic materials for the purpose of energy production, recovery of phosphorus from sewage, recycling of household waste, etc. (Swedish Environmental Protection Agency, 2005).

k. Sanitary Landfills

The sanitary landfill is built to protect the environment and human health. The design of sanitary landfills must take into account the control of leachate and harmful gases. The leaching problem is solved using layers of bentonite clay, synthetic liners that comprise plastic geomembranes, geotextiles, geo-grids and geo-mats and collection pipes for leachate. The harmful gases are controlled using methane collection vents. Thus the process of constructing sanitary landfills is considered very costly (Şener, 2004).

2.2. Quantities of Generated Waste

In literature, the status of solid waste management, many researchers in different countries have documented quantities of waste and generation rates of solid waste. The Comprehensive Scope Evaluation Report (2010) states that the total generated waste in Multan/Pakistan was 611 tonnes/day, and the generation rate of all waste was 0.41 kg/(capita. day).

(Annepu, 2012) studied the actuality of the solid waste in 366 of India's cities, which represented 70% of urban population in India. In this study, the quantity of generated solid waste was 188,500 tonnes/day, and the generation rate of solid waste was 0.5 kg/(capita. day). The composition of municipal solid waste in India's cities includes 51% organics, 17.5% recyclable as well as 31% of inert materials.

In USA, the (Center for Sustainable Systems 2015) found that the annual generation rates of municipal solid waste were 4.40 kg/(capita. day) in 2013, whilst the total generation quantity of municipal solid waste in 2013 was 254.1 million tonnes. (Hoornweg and Bhada-Tata, 2012) showed that the waste generation projections for 2025 in the regions of (East Asia, Organization for Economic Co-operation and Development Countries. Latin America and the Caribbean, South Asia, South Africa and Sub-Saharan Africa, Middle East and North and Africa and Eastern and Central Asia) are about (680, 636, 266, 207, 161, 135 and 130) million tonnes/year respectively. The average projected solid waste generation rates in these regions in 2025 are (1.5, 2.1, 1.6, 0.77, 0.85, 1.43 and 1.5) kg/(capita. day) respectively.

In Sweden, the (Swedish Environmental Protection Agency 2005) found that the waste quantity (excluding mining waste) in 2005, going to landfill could be reduced by 50% compared with 1994. According to this study, about 1 million tonnes of household waste that was sent to landfill was reduced using recycling and recovery processes between 1994-2004, where only 9% of household waste has been sent to landfill during 2004. The waste quantity of manufacturing industries, which was going to landfill, decreased from 4.4 to 2.6 million tonnes between 1994-2004. Waste from the pulp and paper industry, which was sent to landfill, was reduced from 1.25 million tonnes in 1994 to 0.82 million tonnes in 2004. Presently, just 1% of all household waste is being sent to landfill (https://sweden.se/nature/the-swedish-recycling-revolution/).

(Dahlén and Lagerkvist, 2007) compared the quantity of household waste that was collected in 35 Swedish municipalities in 2005. They found a wide difference in generation rate of household waste in these cities ranging from 140 to 320 kg/(capita. day).

According to the (Swedish Environmental Protection Agency, 2012), Europe as a whole is generating about 3 billion tonnes of waste in each year, and Sweden represents a high percentage of the production of this waste. The generation rates of household waste in 2008 were about 500, 800 and 300 kg/(capita. year) in Sweden, Ireland and the Czech Republic respectively. Sweden is the sixth largest generator of waste per capita per year. Sweden produced 100 million tonnes of waste in 2008.

(Abou-Elseoud, 2008) studied, through the Report of the Arab Forum for Environment and Development (Tolba and Saab, 2008), the annual generation rates of solid waste and the quantity of solid waste generated in different Arab countries in 2006. In (Total Arab countries, Egypt, Sudan, UAE, Saudi Arabia, Kuwait, Jordan, Syria, Tunisia, Morocco and Mauritania), annual generation rates of solid waste were: 0.7, 0.63, 0.6, 1.2, 1.4, 1.4, 0.9, 0.5, 0.6, 0.33 and 0.9 kg/(capita. year) respectively. While the quantities of solid waste generated were 81.3, 16.4, 7.95, 1.85, 12.1, 1.56, 1.84, 3.41, 2.22, 3.8 and 1 million tonnes/year.

In Iraq, (Alsamawi et al., 2009) studied the estimation of municipal solid waste generated in Baghdad for the five years from the year 2006 to the year 2010. They found the waste generation rates 0.63 kg/(capita. day) in 2006 and 0.74 kg/(capita. day) in the year 2010. According to this study, Iraq was placed in the class of middle-income countries. (Aziz et al., 2011) found the solid waste generation rate of Erbil Governorate in northern Iraq was 0.654 in 2011. The percentages of weight of food, plastic, paper, metal, glass, and cloth were 79.34, 6.28, 5.9, 3.6, 3.42 and 1.45%, respectively as components of domestic solid waste.

(Al-Rawi and Al-Tayyar, 2012) found the generation of solid waste in Mosul city was 0.647 kg/(capita. day) in 2010, and it will and it will reach 1.1 kg/(capita. day) in 2028with the rate of increment for waste generation rate of Mosul city.

2.3. 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).

2.3.1. Site selection criteria for landfills

In the last decades, many states and organizations were issued with regulations for site selection criteria for landfill in the name of environmental protection. Some of these regulations did not provide specific constraints (buffer zone) or distances around these criteria. Therefore, many researchers suggested new criteria suitable for each study area based on the criteria of previous studies and the opinions of experts.

The World Health Organization (WHO) has a set of general criteria for selecting sites for landfill without determining buffer zones or distance from/around each criterion (Sloan, 1993). These criteria are soil profile and its characteristics, rechargeable areas, natural resources, structure type, historic areas, cultural resources, natural hazards, and built-up areas. The WHO recommended that these criteria are considered essential and should be applied to create satisfaction, participation and approval amongst the population.

The Environment Protection Authority (Australia EPA, 2016) based on (NSW

Department of Urban Affairs and Planning, 1996) has set out restrictive criteria for landfill siting including the following:

a) 250 m as buffer zones from landfill sites to "national parks, historic and heritage areas. Conservation areas, wilderness areas, wetlands, littoral rainforests, critical habitats, scenic areas, scientific areas and cultural areas".

b) 40 m as suitable buffer zones from landfill sites to "a permanent or intermittent water body or in an area overlying an aquifer that contains drinking water quality groundwater that is vulnerable to pollution".

c) 250 m as proper buffer zones from landfill sites to “a residential zone or dwelling, school or hospital not associated with the facility".

d) 1000 m as buffer zones from landfill sites to residential zones, schools and hospitals. This figure will be adopted in the case of a landfill that will receive more than 50,000 tonnes.

e) Landfill sites should not located within "a karst region or with substrata that are prone to land slip or subsidence".

f) Landfill sites should not be located within "specially reserved drinking water catchments".

g) Landfill sites should not situated within a way of major flood event.

Environmental Regulatory Practice, (Department of Environment and Heritage Protection, 2013) in the Queensland Government (a state that comprises the northeastern part of Australia) inserted some buffer distances to landfill sites to protect the environment from these sites. These buffer distances are: 100 m from landfill sites to the floodplain, surface waters and unstable areas, 500 m from landfill sites to a sensitive place to avoid noise, dust and odor, 1,500 m from an aerodrome (piston-engine propeller-driven aircraft) to a landfill site and 3,000 m from an aerodrome (jet aircraft).

In Sweden, sanitary landfills were built in 1970 to control the problem of odours, winds and open fires in the waste through the construction of cover systems for designated dumpsites. To control groundwater contamination, the liner system was developed in 1980 as one of the main components of landfill sites. Meeting all the requirements for the establishment of a new sanitary landfill takes about three to five years because of strong local opposition. Several local councils in Sweden have decided to collaborate in the establishment of regional sanitary landflills in order to solve this problem. The site selection for sanitary landfills is a complex problem, where there are many difficulties facing decision makers and planners selecting sites for sanitary landfills in urban areas. The reduction of the waste quantities contributes to solving the difficulties of siting sanitary landfills through using various methods such as: treatment, financial incentives, product control, separation at source, etc.

In 1990, about 400 sanitary landfills were operating and about 300 of these were subjected to a survey according to the Environment Protection Act. 270 of these sanitary landfills have undergone control programmes for ground and surface water. (Carra and Cossa, 1990). There are four categories of environmental impacts (water contaminates impact, air emission impact, ecological impact and human health impact) which should be taken into consideration when planning site selection for modern landfills in Sweden (Hsiao, 2001). (Luthbom and Lagerkvist, 2003) mentioned that there are no guiding principles in Sweden as for selecting sites for landfill or for weighting criteria; however there are many systems to support multi-criterial evaluations. They suggested setting suitable criteria and weighting for each criterion to suit local conditions and regulations based on five categories of criteria for landfill siting according to the Swedish EPA regulations.

European landfill siting regulations recommend that a landfill site must be situated on a site that does not pose a danger to the environment (Swedish Environmental Protection Agency, Handbook (2004:2)). Landfilling of waste with guidelines to the Ordinance (2001:512) (Item 18 of the Ordinance (2001:512) on the Landfill of Waste); Environmental Protection, the landfill regulations (Northern Ireland) 2003 No. 496 (item No. 5 and 8 (3) a(i)). Environmental Protection, the landfill (Scotland) Regulations 2003 (No. 5 and 10 (3) a(i)). the Environmental Permitting Guidance (England and Wales) Regulations 2010 based on (Official Journal of the European Communities, 1.7.1999, L182/11)). Accordingly, five categories of criteria are usually considered. They are: The site boundary of a landfill should be located at suitable distances from residential and recreational areas, water bodies, waterways, other agricultural sites and urban sites.

a) Avoid selecting a landfill site in areas of groundwater, coastal water and nature protection zones.

b) Taking into account the geological and hydrogeological conditions of a landfill site area.

c) Avoid selecting a landfill site in areas that are located within the risk of flooding, subsidence, landslides and avalanches.

d) Avoid selecting a landfill site in areas that should be under protection (for natural or cultural heritage).

Corrective measures should be taken in cases where the landfill site does not meet the requirements mentioned above. The appropriate distances between the waste facility and the built environment should be 500 m (Swedish Environmental Protection Agency, 2005). Recycling stations should be located at a distance no more than 300 m from any residential area (as a rule) (Sweden sverige, 2015).

2.3.2. 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 GIS software's will be used, 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 and serve a broad audience of users (Daneshvar et al., 2003).

2.4. 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). In general, MCDA problems involve six components (Keeney and Raiffa, 1976; Pitz and McKillip, 1984):

- A goal or a set of goals the decision maker want to achieve,
- The decision maker or a group of decision makers involved in the decision making process with their preferences with respect to the evaluation criteria,
- A set of evaluation criteria (objectives and/or physical attributes)
- The set of decision alternatives,
- The set of uncontrollable (independent) variables or states of nature (decision environment)
- The set of outcomes or consequences associated with each alternative attribute pair.

MCDA techniques can be used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities (Dodgson, 2000). There are many MCDA approaches, which differ in how they combine and utilize the data. MCDA approaches can be classified on the basis of the major components of Multicriteria decision analysis. Three different classifications can be made as (Figure 3.1):

- Multi objective decision-making (MODM) versus Multi attribute Decision Making (MADM)
- Individual versus group decision maker problems, and
- Decisions under certainty versus decisions under uncertainty

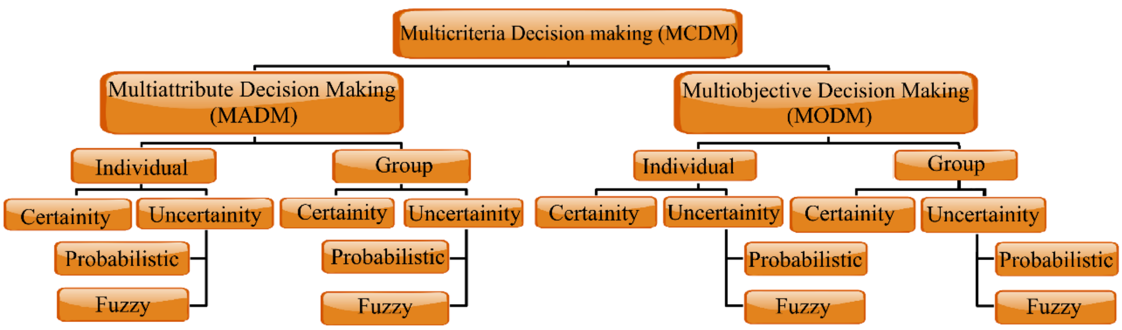


Figure 2.1. Classification of Multicriteria decision problems (Malczewski, 1999).

The distinction between MADM and MODM is based on the evaluation criteria, which are the standards of judgments, or rules on which the alternatives are ranked according to their desirability. Criterion is a general term and includes both the concepts of attributes and objectives.

An attribute is a measurable quantity whose value reflects the degree to which a particular objective is achieved. An objective is a statement about the desired state of the system under consideration (Chankong and Haimes, 1983). It indicates the directions of improvement of one or more attributes. Objectives are functionality related to, or derived from a set of attributes (Malczewski, 1999).

There might be formal relationship between objectives and attributes, but usually the relationship is informal. To assign an attribute to a given objective, two properties which are comprehensiveness and measurability should be satisfied.

An attribute is comprehensive if its value sufficiently indicates the degree to which the objective is met. And it is measurable if it is reasonably practical to assign a value in a relevant measurement scale. The ratio, interval, ordinal and binary scales are suitable for measurement of attributes, whereas nominal scale is not since it does not allow an ordering of the alternatives (Janssen, 1992). MADM problems require that choices be made among alternatives described by their attributes. The set of attributes is given explicitly and multi attribute problems have a finite set of feasible alternatives. Unlike MADM, MODM problems require that means-ends relationships be specified, since they deal explicitly with the relationship of attributes of alternatives to higher level objectives. MODM involves designing the alternatives and searching for the best decisions among an infinite or very large set of feasible alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions (Malczewski, 1997) (Table 3.1).

Table2.1. Comparison of MODM and MADM Approaches (Hwang and Yoon,1981; Starr and Zeleny, 1977).

	MODM	**MADM**
Criteria defined by:	Objectives	Attributes
Objectives defined:	Explicitly	Implicitly
Attributes defined:	Implicitly	Explicitly
Constraints defined:	Explicitly	Implicitly
Alternatives defined:	Implicitly	Explicitly
Number of alternatives	Infinite (large)	Finite (small)
Decision maker's control	Significant	Limited
Decision modeling paradigm	Process-oriented	Outcome-oriented
Relevant to:	Design/search	Evaluation/choice
Relevance of geographical data structure	Vector-based GIS	Raster-based GIS

Both MADM and MODM problems can be further classified as individual and group decision making depending on the goal-preference structure. If there is a single goal preference, the problems is considered as individual decision making regardless of the number of decision makers involved in the process. However, if the individual or interest groups are characterized by different goal preferences, the problem becomes the group decision making (Malczewski, 1997).

The other classification depends on the certainity of the decision. If the decision maker has perfect knowledge of the decision environment and the amount of knowledge available is enough, then the decision is considered as decision under certainity. However, most of the real world decisions involve some aspects that are unknown and difficult to predict. This type of decisions is referred as decisions under uncertainity. The decisions under uncertainity can be further subdivided into fuzzy and probabilistic decision making (Eastman, 1993). The probabilistic decisions are handled by probability theory and statistics. And the outcome of a stochastic event is either true or false. However, if the situation is ambiguous, the problem is structured as the degree of how much an event belongs to a class. This type of problems is handled by fuzzy set theory (Zadeh, 1965). spatial multi-criteria decision analysis (SMCDA) to be used in the selection of landfill siting because there are powerful, integrated tools to solve the problem of landfill site selection.

2.4.1. Steps of spatial multicriteria decision analysis (MCDA)

Any spatial decision problem can be structured into three major phases:

- Intelligence which examines the existence of a problem or the opportunity for change,
- Design which determines the alternatives
- Choice which decides the best alternative (Simon, 1960). The major elements involved in spatial decision making process are discussed below.

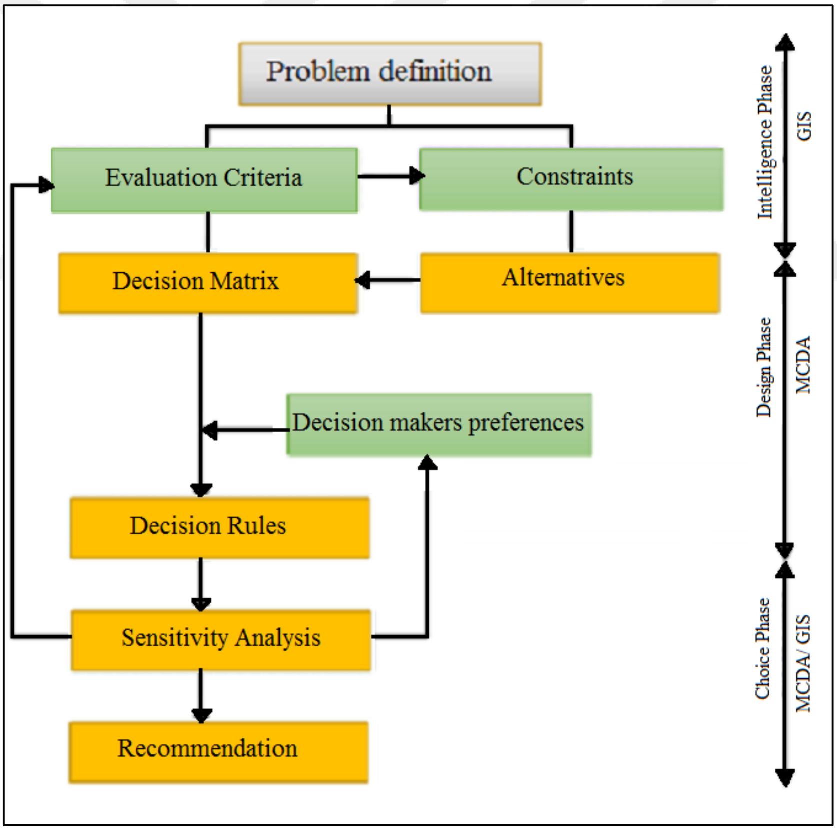


Figure 2.2. Framework for spatial Multicriteria decision analysis (Malczewski, 1999).

2.4.1.1. Problem definition

A decision problem is the difference between the desired and existing state of the real world. It is a gap which is recognized by a decision maker. Any decision making process begins with the recognition and the definition of the problem. This stage is in the intelligence phase of decision making and it involves searching the decision environment for conditions, obtaining, processing and examining the raw data to identify the problems. The GIS capabilities for storage, management, manipulation and analysis are used in this stage which provides major support (Malczewski, 1999).

2.4.1.2. Evaluation criteria

After the determination of the problem, the set of evaluation criteria which includes attributes and objectives should be designated (Keeney and Raiffa, 1976). This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problem and measures for achieving those objectives which are defined as attributes. Because the evaluation criteria are related to geographical entities and the relationships between them, they can be represented in the form of maps which are referred as attribute maps. GIS data handling and analyzing capabilities are used to generate inputs to spatial decision making analysis (Malczewski, 1999).

2.4.1.3. Spatial decision alternatives

Decision alternatives can be defined as alternative courses of action among which the decision maker must choose. A spatial decision alternative consists of at least two elements (Malczewski, 1999) action (what to do?) and location (where to do it?). The spatial component of a decision alternative can be specified explicitly or implicitly (Malczewski, 2006). The second case holds when there is a spatial implication associated with implementing an alternative decision. The set of spatial decision alternatives may be discrete or continuous. In the first case, the problem involves a discrete set of pre-defined decision alternatives. Spatial alternatives are then modeled through one or a combination of the basic spatial primitives, namely point, line, or polygon. The second case corresponds to a high or innate number of decision alternatives, often denned in terms of constraints. For practical reasons, the set of potential alternatives is often represented in a \discretized" form where each raster represents an alternative. Alternatives may be constructed as a collection of raster.

2.4.1.4. Constraints

A constraint (or admissibility criterion) represents natural or artificial restrictions on the potential alternatives. Constraints are often used in the pre-analysis steps to divide alternatives into two categories: \acceptable" or \unacceptable". An alternative is acceptable if its performance on one or several criteria exceeds a minimum or does not exceed a maximum. In practice, constraints are often modeled through elementary Multicriteria methods like the conjunctive or disjunctive aggregation procedures. With the conjunctive method, a minimal satisfaction level g_j is associated with each criterion gj . If the performance of an alternative with respect to different criteria is equal or better to these minimal satisfaction levels $(i.e., g_j(a_i) \geq g_j, \forall j \in F)$, the alternative is considered as acceptable. Otherwise, the alternative is considered as unacceptable. With the disjunctive method, the alternative is considered acceptable as soon as at least one satisfaction level is exceeded.

2.4.1.5. Quantification

The evaluation of alternatives may be quantitative or qualitative. Several methods require quantitative evaluations. In the literature, there are some totally qualitative methods such as the median ranking method. Other methods, such as the ELECTRE family of methods Figueira et al., 2005, involve the two types of evaluations. When most of criteria are qualitative, quantitative criteria may be converted into qualitative ones and a qualitative method is used. Otherwise, a quantification method (i.e., assignment of numeric values to qualitative data) is applied; the scaling approach is the most used one. Application of a quantification method requires the definition of a measurement scale. The most used measurement scale is the Linker-type. This scale is composed of approximately the same number of favorable and unfavorable levels. An example with five levels is: very unfavorable, unfavorable, neuter, favorable, very favorable. Other more detailed measurement scales may also be used. The quantification procedure consists of constructing a measurement scale like the one with five points mentioned above. Then, numerical values are associated with each level of the scale. For instance, the numbers 1, 2, 3, 4 or 5 may be associated with the five point scale from very unfavorable to very unfavorable.

2.4.1.6. Standardization

The evaluation of alternatives may be expressed according to different scales (ordinal, interval, ratio). However, a large number of multicriteria methods (including practically all the utility function-based methods) require that all of their criteria are expressed in a similar scale. Standardizing the criteria permits the rescaling of all the evaluation dimensions between 0 and 1. This allows between and within criteria comparisons. There are a large number of standardization procedures. In all of them, standardization starts from an initial vector

$(g_j(a_1), g_j(a_1); \dots., \; g_j(a_m))$ to obtain a standardized vector $(r_{1j},\; r_{2j}, \dots., r_{mj})$ with $0 \; \leq r_{ij} \; \leq \; 1; \; \forall j \; \in \; F$ and $i \; = \; 1, \dots, n$ (n is the number of alternatives). The most used standardization procedure in the GIS-based multicriteria decision making is the linear transformation procedure. It associates with each alternative ai and for each criterion gj the percentage of the maximum over all alternatives:

$$r_{ij} = \frac{g_j(a_i)}{max_i g_j(a_i)}, i = 1,2, \dots, n: j \in F.$$

2.4.1.7. Pre-analysis of dominance

In the absence of any preferential information, the only possible operation on the performance table is to eliminate the dominated alternatives. Let a and b be two alternatives from A and F a family of criteria. The alternative a dominates the alternative b in respect to F, noted $a \vartriangle b$, if and only if:

$$gg_j(a) \geq g_j(\text{b}); \; j \; \in \; F$$

with at least one strict inequality. Then, an alternative a from A is said to be efficient or admissible or Pareto optimal if and only if there is no other alternative b in A such that: b∆a.

2.4.1.8. Criterion weights

A weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration. Assigning weights of importance to evaluation criteria accounts for (i) the changes in the range of variation for each evaluation criterion, and (ii) the different degrees of importance being attached to these ranges of variation (Kirkwood, 1997). There are four different techniques when assigning the weights: Ranking, Rating, Pairwise Comparison and Trade of Analysis Methods (Table 2.1).

Table 2.2. Comparison of the methods used in estimating weights (Pitz and McKillip, 1984; Schoemaker and Waid, 1982; Kleindorfer et al.,1993).

Methods/ Feature	**Ranking**	**Rating**	**Pairwise Comparison**	**Trade-off Analysis**
No. of judgments	n	n	n(n-1)/2	<n
Response scale	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes
Underlying theory	None	None	Statistical/ heuristic	Axiomatic/ deductive
Ease of use	Very easy	Very easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximations	Not precise	Quite precise	Quite precise
Software availability	Spreadsheets	Spreadsheets	Expert Choice	Logical Decision
Use in a GIS environment	Weights can be imported from spreadsheet	Weights can be imported from spreadsheet	Component of IDRISI	Weights can be imported from LD

2.4.1.8.1. Ranking methods

This is the simplest method for evaluating the importance of weights which includes that every criterion under consideration is ranked in the order of decision maker's preferences. Due to its simplicity, the method is very attractive. However, the larger the number of criteria used, the less appropriate is the method. Another disadvantage is lack of theoretical foundation.

2.4.1.8.2. Rating methods

The method requires the decision maker to estimate weights on the basis of a predetermined scale. One of the simplest rating methods is the point allocation approach. It is based on allocating points ranging from 0 to 100, where 0 indicates that the criterion can be ignored, and 100 represents the situation where only one criterion need to be considered. Another method is ratio estimation procedure which is a modification of the point allocation method. A score of 100 is assigned to the most important criterion and proportionally smaller weights are given to criteria lower in the order. The score assigned for the least important attribute is used to calculate the ratios. Again the disadvantage of this method like ranking method is the lack of theoretical foundation. And also the assigned weights might be difficult to justify.

2.4.1.8.3. Pairwise comparison method

The method involves pairwise comparisons to create a ratio matrix. It take pairwise comparisons as input and produced relative weights as output the pairwise comparison method involves three steps:

(1) Development of a pairwise comparison matrix: The method uses a scale with values range from 1 to 9. The possible values are presented in (Table 2.2).

Table 2.3. Scale for pairwise comparison (Saaty, 1980).

Intensity of importance	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

(2) Computation of the weights: The computation of weights involves three steps. First step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix). Then, computation of the average of the elements in each row of the normalized matrix should be made which includes dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared.

(3) Estimation of the consistency ratio: The aim of this is to determine if the comparisons are consistent or not. It involves following operations:

a) Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows,

b) Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously,

c) Compute lambda(λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

$CI = (\lambda - n)/(n-1)$

d) Calculation of the consistency ratio (CR) which is defined as follows:

CR = CI / RI

Where RI is the random index and depends on the number of elements being compared (Table 2.3, Figure 2.2). If CR< 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if CR $\geq$ 0.10, the values of the ratio indicates inconsistent judgments.

Table 2.4. Random inconsistency indices (RI) for n=1,2,.....,15 (Saaty, 1980).

n	RI	n	RI	n	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

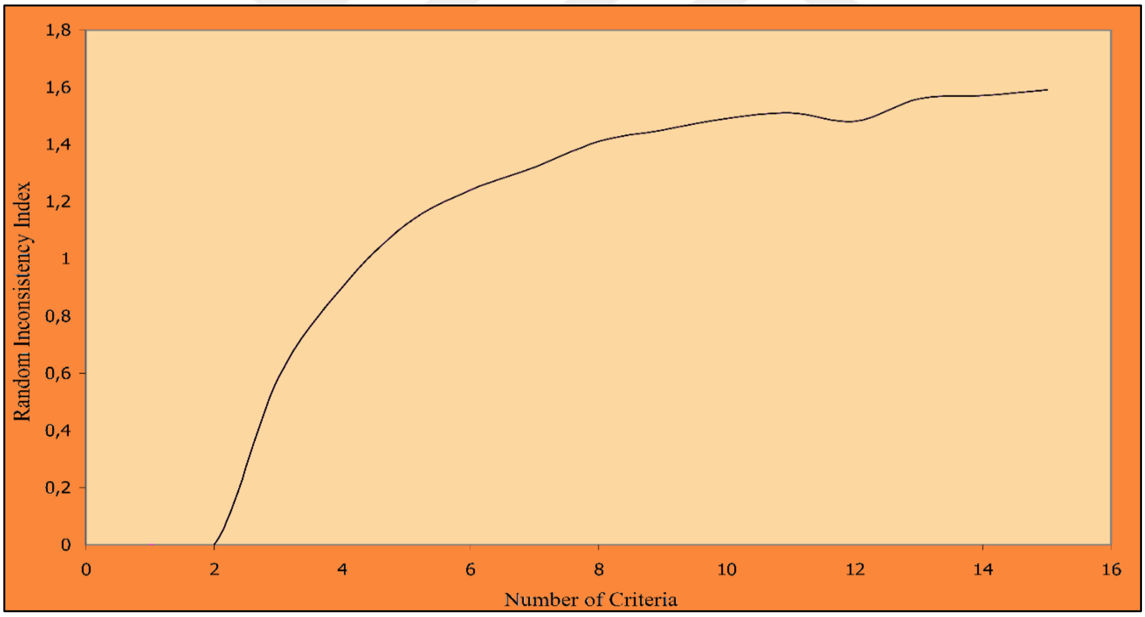


Figure 2.3. The graph of random inconsistency indices vs. number of criteria.

The advantages of this method can be summarized that only two criteria have to be considered at a time, it can be implemented in a spreadsheet environment (Kirkwood, 1997) and it is incorporated into GIS based decision making procedures (Eastman, 1993; Janskowski, 1995). On the other hand, the relative importance of evaluation criteria is determined without considering the scales on which the criteria are measured. Another disadvantage is that if you have many criteria, the amount of pairwise comparisons that should be made will be very large.

2.4.1.8.4. Trade-off analysis method

In this method, decision maker is required to compare two alternatives with respect to two criteria at a time and assess which alternative is preferred. Trade-offs define unique set of weights that will allow all of the equally preferred alternatives in the trade-offs to get the same overall value/utility. There is an assumption in this method that the trade-offs the decision maker is willing to make between any two criteria do not depend on the levels of other criteria (Malczewski, 1999).

The weakness of this method is the decision maker is presumed to obey the axioms and can make fine grained in difference judgments. On the other hand, the method can be implemented within the spreadsheet environment (Kirkwood, 1997).

2.4.1.9. Preference structure and preference parameters

When comparing two alternatives a and b, the decision maker will generally have one of the three following reactions:

- preference for one of the two alternatives,
- indifference between the two alternatives or
- impossibility to compare the alternatives.

These situations are generally denoted as follows:

- aPb if a is preferred to b (bP a if it is the opposite),
- aIb if there is indifference between a and b, and
- aRb if there is an incomparability.

The binary relations of preference P, indifference I, and incomparability R are respectively the sets of tuples (a; b) such that aPb, aIb, aRb. It is generally admitted that I is reflexive and symmetric, P is asymmetric, and R respectively and symmetric. The three relations (I; P;R) constitutes a structure of preference over A if and only if they have the properties mentioned above and only one of the following situations holds (Vincke, 1992): aPb, bP a, aIb, aRb. Preference models require the definition of one or several thresholds, called preference parameters. The most used preference parameters are the indifference, preference and veto thresholds. These three parameters are used essentially within the outranking relation-based decision rules. The first two parameters for modeling imprecision and uncertainty in the decision maker's preferences. The latter is often used to compute the discordance index.

2.4.1.10. Decision rules

To compare alternatives in A, it is necessary to aggregate the partial evaluations (i.e., with respect to each criterion) into a global one by using a given decision rule (or aggregation procedure). As mentioned earlier, within the discrete family, there are usually two aggregation approaches:

- Utility function-based approach, and
- Outranking relation-based approach.

The basic principle of the first family is that the decision maker looks to maximize a utility function $U(a) = U(g_1(a), g_2(a), \dots \dots, g_m(a))$ aggregating the partial evaluations of each alternative into a global one. The simplest and most often used utility function has an additive form: $U(a) = \sum_{j \in F} u_j(g_j(a))$; where uj are the partial utility functions. Within this form, the preference P and indifference I binary relations are defined for two alternatives a and b as follows:

$$aPb \Leftrightarrow U(a) \text{ and } aIb \Leftrightarrow U(b)$$

In contrast with the first family, the second one uses partial aggregation procedures. Different criteria are aggregated into a partial binary relation S, with aSb used to indicate that \a is at least as good as b". The binary relation S is called an outranking relation. The most well known method in this family is ELECTRE Figueira et al., 2005.To construct the outranking relation S, for each pair of alternatives (a; b), a concordance index $C(a, b) \in [0,1]$ measuring the power of criteria that are in favor of the assertion aSb and a discordance index $ND(a, b) \in [0.1]$ measuring the power of criteria that are opposed to aSb are computed. Then, the relation S is defined as follows:

$$\begin{cases} C(a, b) \geq \hat{c} \\ ND(a, b) \leq \grave{d} \end{cases}$$

where ĉ and $\grave{d}$ are the concordance and the discordance thresholds, respectively. Often an exploitation phase is needed to extract from S information on how alternatives compare to each other. At this phase, the concordance C(a; b) and discordance ND(a; b) indices are used to construct an index $\sigma(a,b) \in [0,1]$ representing the credibility of the proposition aSb, $\forall(a,b) \in A \times A$. The proposition aSb holds if $\sigma(a,b)$ is greater or equal to a given cutting level, $\lambda \in [0.5,1]$.

In the continuous formulation of a multicriteria problem, decision rules implicitly define the set of alternatives in terms of a set of objective functions and a set of constraints imposed on the decision variables. Here, multi objective mathematical programming is often used. A multi objective mathematical program is a problem where the aim is to find a vector $x \in R^p$ satisfying constraints of type

$$h_i(x) \leq 0: (i = 1,2, \dots \dots \dots, n)$$

respecting eventual integrity conditions and optimizing the objective functions:

$$z_j(x), j = 1,2, \dots \dots., m.$$

The general form of a multi objective mathematical program is as follows:

$$\begin{cases} Optimize\ \ [z_1(x), z_2(x), \dots \dots z._m\ (x)] \\ h_t(x) \leq 0 \quad (i = 1,2, \dots..n) \\ x \in X \end{cases}$$

A multi objective mathematical program is in fact a multicriteria decision problem where:

- $A\ = \{x: h_i(x) \leq 0, \forall_i\} \subset R^p$ is the set of decision alternatives, and
- $F = \{z_1(x), z_2(x), \dots, z_m(x)\}$ is a set of criteria where each criterion is expressed by an objective function in terms of the decision variables.

2.4.1.11. Sensitivity/robustness analysis

The analysts should examine, through sensitivity analysis, the stability of results with respect to the variation of different parameters. Sensitivity analysis is the base for robustness analysis. There are several proposals to enhance GIS-based multicriteria decision making with sensitivity analysis procedures (Feick and Hall, 2003). Robustness analysis in multicriteria decision making is a relatively recent research topic. Proposals for enhancing GIS-based Multicriteria decision making with robustness analysis are still lacking.

2.4.1.12. Final recommendation

The final recommendation in Multicriteria analysis may take different forms, according to the manner in which a problem is stated. (Roy, 1996). identifies four types of results corresponding to four ways for stating a problem:

- choice: selecting a restricted set of alternatives,
- sorting: assigning alternatives to different predefined categories,
- ranking: classifying alternatives from best to worst with eventually equal positions
- description: describing the alternatives and their follow-up results.

2.4.2. 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 system16 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).

2.4.2.1. 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 Ui 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

$$U_j=\sum_{i=1}^{n} Wi*r_{ij} \ , \qquad j = 1,2,\ldots\ldots,m. \qquad eq(2.1)$$

Where wi is the importance weight of the attributes and rij 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).

2.4.2.2. Analytical hierarchy process (AHP)

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

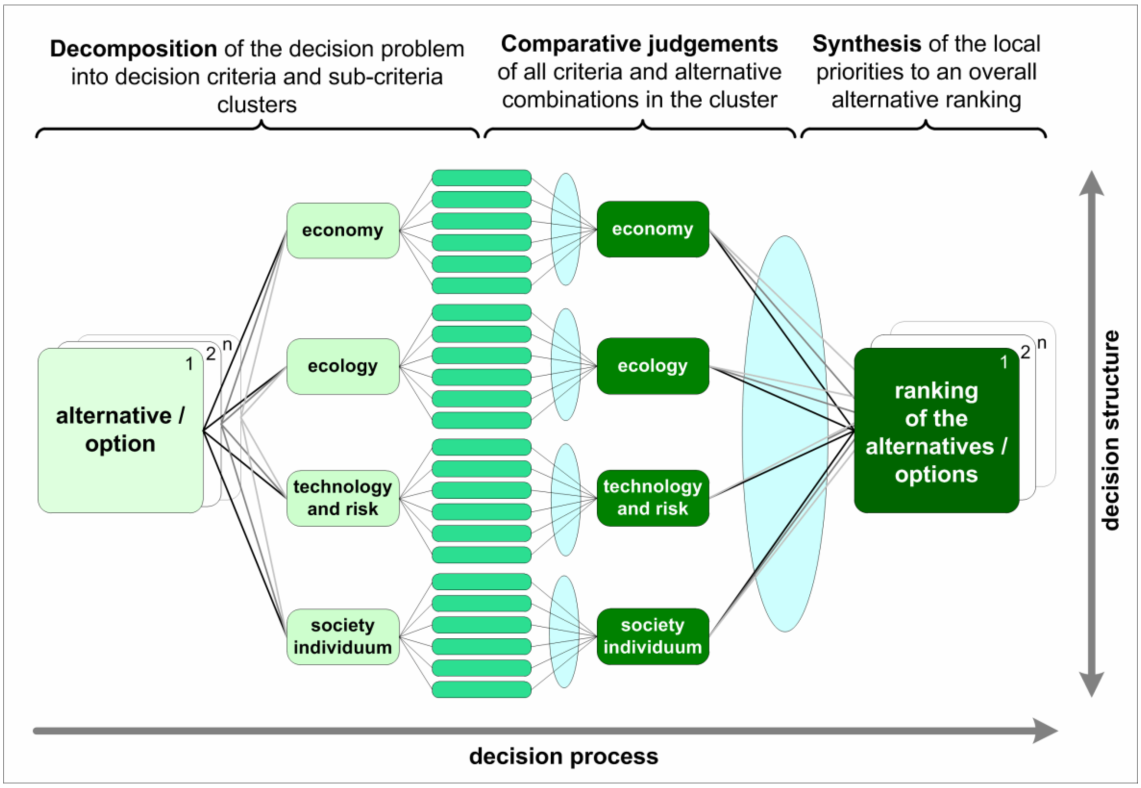


Figure 2.4. Phases of the analytical hierarchy process according to Saaty (1980, 1994) illustrated with the Brunswikian lens model adapted from Scholz and Tietje (2002).

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).

2.4.2.3. The value/utility function methods

The method is based on multiattribute utility theory (Keeney and Raiffa, 1976). The value function approach is applicable in the decision situation under certainty (deterministic approach) which assumes that the attributes are known with certainty whereas the utility function approach is convenient for the uncertainty conditions (probabilistic in nature).

The GIS based value/utility function involves the following steps:

1. Determination of the set of attributes (attribute map layers) and the set of feasible alternatives.

2. Estimation of the value (utility) function for each attribute and use the function to convert the row data to the value (utility) score map layer

3. Derivation of the scaling constants or weights for the attributes

4. Construction of the weighted value (utility) map layers; that is, multiply the weights of importance by the value (utility) map layers

5. Combination of the weighted value (utility) maps by summing the weighted value (utility) map layers

6. Ranking of the alternatives according to the aggregate value (utility): the alternative with the highest value (utility) is the best alternative.

The value/utility function involves two elements: (1) the single attribute utility/value function to transform attribute levels into an interval utility/value scale, (2) the trade off analysis for defining the weights (Keeney, 1980). By multiplying the utilities by the weights, the trade-offs among the attribute utilities are taken into account in the multi attribute utility function. The overall utility or value for any alternative is a weighted average of the single attribute utilities. This method is similar to SAW method except the score xij is replaced by a value or utility derived from the value/utility function.

There are two assumptions of preferential independence, which refers that the relative preferences of attributes are not altered by changes in other attributes, and utility independence which means that the utility function over single attribute does not depend on the other attribute (Malczewski, 1999).

One of the most important advantages of this method is the above assumptions which enables decision maker to focus initially on deriving utility function for one attribute at a time. The method provides a better theoretical foundation for describing the utilities. However, the method is impractical and it is difficult to obtain a mathematical representation of decision maker's preferences, because assessing utility functions with even a moderate number of criteria is very time consuming and tedious. In addition, the method neglects the existence of spatial relationships among spatial alternatives (Malczewski, 1997).

2.4.2.4. The ideal point methods

In the ideal point method the alternatives are ranked according to their separation from an ideal point. The ideal point is defined as the most desirable, weighted, hypothetical alternative (decision outcome). The alternative, closest to the ideal point is the best alternative. The separation is measured in terms of metric distance (Janssen, 1992; Malczewski, 1997).

One of the most popular ideal point methods is the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) developed by (Hwang and Yoon, 1981).

The GIS based ideal point method involves the following steps:

1. Determine the set of feasible alternatives.
2. Standardize each attribute map layer.
3. Define the weights assigned to each attribute ($0 \leq w \leq 1$, $\Sigma w = 1$),
4. Construct the weighted standardized map layer by multiplying each value of the standardized layer by the corresponding weight.
5. Determine the max value for each of the weighted standardized map layers (the values determine the ideal point).

6. Determine the mean value for each weighted standardized map layer (the values determine negative ideal point).

7. Using a separation measure, calculate the distance between the ideal point and each alternative.

8. Using the same separation measure, determine the distance between the negative ideal point and each alternative.

9. Calculate the relative closeness to the ideal point.

10. Rank the alternatives according to the descending order of ideal point.

Although the ideal point methods can be implemented both in raster and vector GIS, the technique is especially suitable for the raster GIS (Carver, 1991; Janskowski and Ewart, 1996; Malczewski, 1996). The method provides complete ranking and information on the relative distance of each alternative to the ideal point. In this method, an alternative is treated as an inseparable bundle of attributes which makes the method an attractive approach when the dependency among attributes is difficult to test or verify (Malczewski, 1997).

2.4.2.5. Outranking methods

These methods, which are also known as concordance methods, are based on a pairwise comparison of alternatives. They provide an ordinal ranking and sometimes only a partial ordering of the alternatives which means that it can only express which alternative is preferred but cannot indicate how much.

The best known outranking method is the Elimination and Choice Translating Reality (ELECTRE I) and several modifications of this method have been suggested (ELECTRE II, III, IV, PROMETHEE I and II) (Goicoechea et al., 1982; Vincke, 1989). The basic elements of this method is concordance measures which are the set of all criteria for which alternative i is not worse than the competing alternative i' and disconcordance measures which are the set of all criteria for which alternative i is worse than the competing alternative i' (Nijkamp and van Delft, 1977). These indicators are calculated for all pairs of alternatives and then the alternatives with the highest concordance value and with the lowest disconcordance value are found. There are formulas suggesting to determine overall score for each alternative based on these indicators (Massam, 1988).

The GIS based outranking method involves several steps:

1. Determination of the set of feasible alternatives

2. Standardization of each attribute

3. Definition of the weights assigned to each attribute ($0 \leq w \leq 1$, $\Sigma w=1$)

4. Generation of the concordance matrix by calculating the concordance indices for each pair of alternatives

5. Summation of the rows of the concordance matrix to obtain the overall score for each alternative

6. Ranking the alternatives according to the descending order of the sum of the concordance indices (Ci), the alternative with the highest value of Ci is the best alternative (Malczewski, 1999).

The advantages of this method include that least amount of information from decision maker is required and it can consider both objective and subjective criteria. However, complete ranking of the alternatives may not be achieved and since the method requires comparison across alternatives, it can not be implemented directly by using cartographic modeling techniques in a GIS (especially for raster GIS). The method provides an ordinal ranking (Malczewski, 1999).

2.4.2.6. Ordered weighted average (OWA)

The OWA method has been developed in the context of fuzzy set theory (Yager, 1988). There are three basic types of aggregation operators on fuzzy sets (1) operators for the intersection of fuzzy sets (the MIN operations), (2) operators for the union of fuzzy sets (the MAX operations), and (3) averaging operators (Eastman, 1993). (Yager, 1988) introduced an aggregation technique based on the ordered weighted averaging (OWA) operator, which is a generalization of the three basic aggregation functions. OWA is a weighted sum with ordered evaluation criteria. Thus, in addition to the criterion weights which are assigned to evaluation criteria to indicate their relative importance, order weights are used. The order weights are associated with the criterion values on the location by location basis. They are assigned to a given location's attribute values in decreasing order without considering from which attribute map the value comes (Malczewski, 1997).

2.4.2.7. Compromise programming

It is a MODM method based on the displaced ideal concept which assumes that the choice among alternatives depends on the point that is used as a reference (Zeleny, 1982). This point is the ideal point which defines the optimal value for each objective considered separately. Compromise programming attempts to minimize the distance from the ideal solution.

The advantage of this method is its simple conceptual structure. The set of preferred compromise solutions can be ordered between the extreme criterion outcomes and consequently, an implicit trade off between criteria can be performed. However, there is no clear interpretation of the various values of the parameter p which gives the importance of the maximal deviation from the ideal point. Therefore, the selection of the best alternative within the reduced set of compromise alternatives must be made based on intuition (Malczewski, 1997).

2.4.3. 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. A justified and jointly accepted model (Lahdelma et al., 2000) replaces intuitive or adaptive choices.

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 has been use 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 ofMCDA 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 onsite 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 sitting (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; 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.

3. MATERIALS AND METHODS

To evaluate study area for selection of a suitable landfill site, the analytical hierarchy process (AHP) together with GIS with its special analysis tools, were used to prepare maps layered according to sixteen criteria. Analytical hierarchy process (AHP) is a widely used approach for obtaining preferences or weights of importance regarding to the criteria and alternatives for a variety of research fields. The main advantages of this method are the possibility to use qualitative and quantitative criteria. The AHP is simple and fast understandable methods for people who are not familiar with the multi-criteria decision support methods. The main steps of landfill site selection, based on current criteria, can be divided into the following (Figure 3.1):

- Expected future quantities of municipality solid waste generated and the landfill required area.
- Creating decision-making tree for selection of landfill site.
- Selecting suitable criteria for the current study.
- Creating appropriate special constraints around important areas to suit each criterion map.
- Preparing the database for the all digital maps with in GIS for the study area.
- Determination of the sub-criteria weights based on opinion of experts, literature, environmental and scientific requirements.
- Determination of the criteria weights using AHP analytical hierarchy process model.
- Produce the map of candidate sites for landfill through using determination of a suitability index.
- Determination of the location and area of the candidate site which required being accommodate the cumulative quantity of municipality solid waste generated from 2020 to 2032 in Sulaymaniyah area.

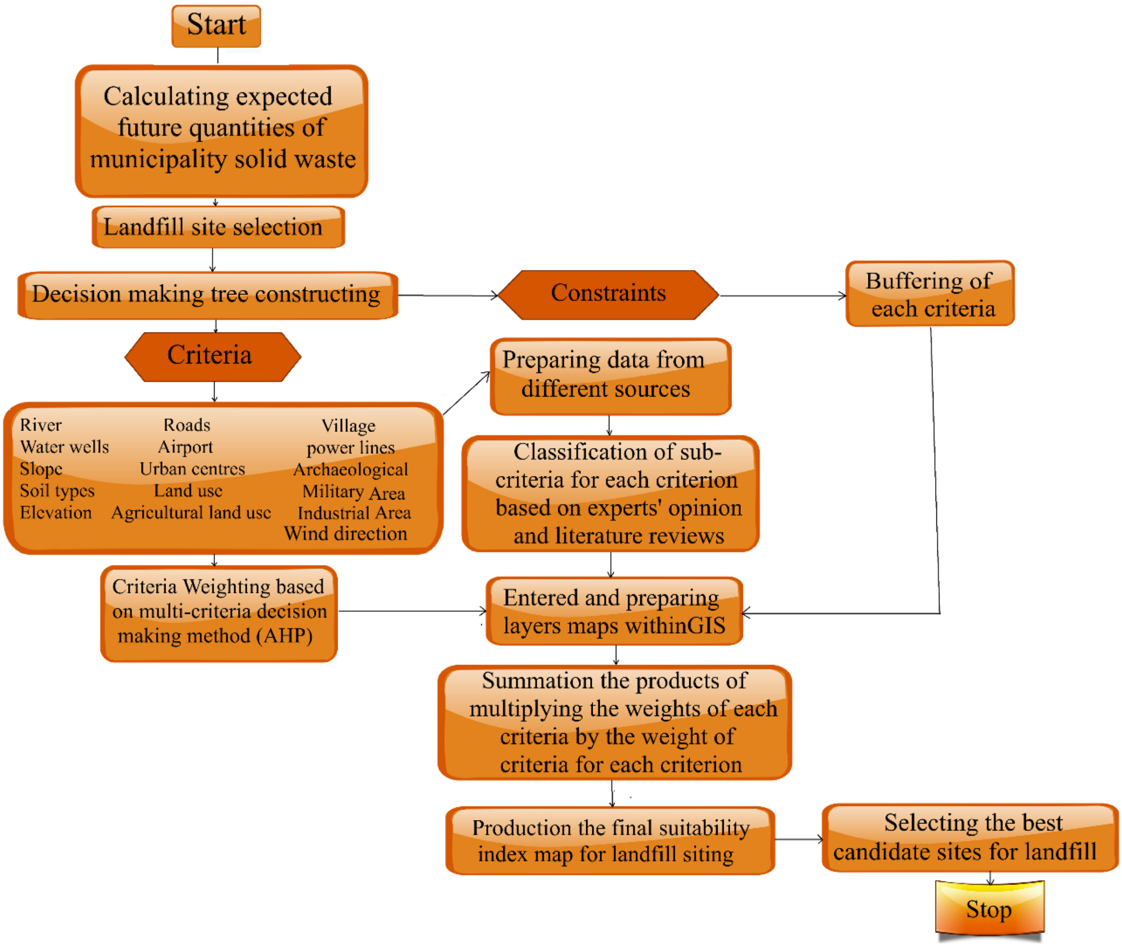


Figure 3.1. Flowchart of model for landfill sitting.

3.1. Expected Future Quantities of Municipality Solid Waste Generated

The production Rates of solid waste are subject to certain variables, such as population density, types and levels of economic activity, and the income level of the population (Al-Ansari, 2013). In 2010 (United Nation, 2010) established that the generated rate of solid waste in low income countries was (0.9 - 0.4) kg/(capita. day), whilst the generated rates for middle and high-income countries were (0.5 - 1.1) and (1.1 - 5.07) kg/(capita. day) correspondingly (Al-Ansari, 2013).

The generated rate of solid waste in Sulaymaniyah Governorate in 2009 was 0.69 kg/(capita· day) (Sulaymaniyah Directory of Municipality). This value is considered very low and is unsatisfactory, compared with the generation rates of waste for both Iraq as a whole and for Baghdad (the capital of Iraq), which were (1.01 and 1.47) kg/(capita· day) respectively. This rate is also low in comparison with the international standard rate of 1.5 kg/(capita· day) (Iraqi Ministry of Municipalities and Public Works, 2009). The figures for the generation of municipality solid waste per capita for Sulaymaniyah city would place it as middle income in relation to the data of the Department of Economic and Social Affairs of the UN in 2010 (Al-Ansari, 2013; Iraqi Ministry of Municipalities and Public Works, 2009). The whole population of Sulaymaniyah Governorate in 2016 was 2084492 inhabitants (Kurdistan Region statistics office) based on the population growth rate of 2.99%. According to (World Bank, 2015), the annual population growth of Iraq is 2.5% for years 2010-2014. The quantity of municipality solid waste generated in Sulaymaniyah Governorate in 2016 was 604107 tonnes (Sulaymaniyah directory of municipality). Generation rate of municipality solid waste in 2016 was 0.794 kg/(capita· day) in the Sulaymaniyah city depending on calculation methods which are illustrated below. The rate for Sulaymaniyah city as a function of population density. Depended on the information cited in the records of the Sulaymaniyah statistics office, an attempt was made to determine the future expected of municipality solid waste in Sulaymaniyah city for the year 2032. This was achieved through using series of Equations using two methods as follow:

3.1.1. Method one

This method was built depended on multiplying the expected population number for the specific year by the average of municipality solid waste generation rate for the last eight years (GRWA) from 2009 to 2016 as a fixed value. The average municipality solid waste generated was determined through dividing the average quantity of municipality solid waste (Qs) for years 2009-2016 by the average population (P) for years (2009-2016) of Sulaymaniyah city using Eq. (3.1):

$$\text{GRWA}=(\text{Q}_{\text{S(av.)}} \text{ x } 1000)/(\text{P}_{(\text{av.})} \text{ x } 365) \qquad (3.1)$$

Where:

GRWA: Average generation rate of municipality solid waste kg / (capita. day).

Qs(av.): Average quantity of municipality solid waste for years (2009-2016) (kg).

P(av.): Average Population of Sulaymaniyah city for years (2009-2016).

Eq. (3.2) (Jarabi, 2015; United Nations, 1952) was used to determine the population for each year from 2016 until 2032.

$$P_t = P_0(1 + r)^t \tag{3.2}$$

Where:

Pt: Future population at the end of period.

Po: Present population for year 2016.

r: The annual population growth rate (2.99 %)

t: Number of years

Eq. (3.3) was used to find the produced solid waste quantity for year 2032. Using the average of solid waste generation rate for the years 2009-2016 then:

$$Q_s(\text{for specific year}) = \frac{(\text{GRWA X } P_{2032} \text{ X } 365)}{1000} \tag{3.3}$$

Qs: Quantity of municipality solid waste produced each year (tonnes).

The cumulative of municipality solid waste quantity generated in 2032 can be determined, as shown in Eq. (3.4):

$$Q_{S(C)} = Q_{s(ct)} + Q_{s(ct-1)} \tag{3.4}$$

Where:

Qs (c): Cumulative quantity of municipality solid waste for the specific year (tonnes).

Qs (ct): Quantity of municipality solid waste for the specific year (tonnes).

Qs (ct-1): Cumulative quantity of municipality solid waste for the last year before specific year (tonnes). In order to calculate the cumulative municipality solid waste generated by year 2032

For illustration the cumulative municipality solid waste quantity in 2032 Qs(c) is equal to the municipality solid waste quantity of produced in 2032 Qs (ct) using Eq. (3.3) plus the cumulative municipality solid waste quantity in 2031 Qs(nt-1) form the year 2016.

$$Q_{S(C)(2032)} = Q_{s(ct)(2032)} + Q_{s(ct-1)(2031)} \tag{3.5}$$

3.1.2. Method two

Another attempt was prepared to calculate the future expected of municipality solid waste in Sulaymaniyah city for the year 2032. This method was made through calculating the expected population for each specific year as well as the increment rate of solid waste generation rate in Sulaymaniyah city, which was 0.013 (kg / capita. day). Generation rate of municipality solid waste for each year was used in the equation (3.11) of this method in order to fulfill several factors such as improving standards of living in study area and increasing levels of industrial and commercial activities in urban areas. This attempt was based on the fact that waste generation rates in 2009 and 2016 (Sulaymaniyah directory of municipality) to calculate the increment of generation rate of solid waste as follows:

$$\mathrm{GRW} = (\mathrm{Q_s})/(\mathrm{P}) \qquad (3.6)$$

Where:

GRW: Generation rate of municipality solid waste kg / (capita. day).

Qs: Quantity of municipality solid waste for one year (kg).

P: Population of city for one year.

The rate of increment for municipality solid waste generation rate of Sulaymaniyah city was 0.013 (kg /capita / day) (RGI) based on values of waste generation rate in 2009 and 2016 is:

$$\mathrm{RGI} = \frac{(\mathrm{GRW}_{2016} - \mathrm{GRW}_{2009})}{(\mathrm{n})} \qquad (3.7)$$

Where:

RGI: Rate of increment for solid waste generation rate.

GRW 2016: Solid waste generation rate was 0.794 (kg / capita / day) of year 2016 (Sulaymaniyah directory of municipality).

GRW 2009: Solid waste generation rate was 0.69 (kg / capita / day) of year 2009 (Sulaymaniyah directory of municipality).

n: Period (years).

The population for each year from 2016 until 2032 was calculated as follows:

$$\mathrm{P_t} = \mathrm{P_0}(1 + \mathrm{r})^{\mathrm{t}} \qquad (3.8)$$

Eq. (3.9) is used to determine the municipality solid waste generation rate for year 2032 or specific year (GRSW) depended on present generation rate of solid waste for year 2016 from Eq. (3.6) and rate of increment for solid waste generation rate of each year from Eq. (3.7), this equation similar to equation that used by (Al-Rawi and Al-Tayyar, 2012).

$$\mathrm{GRSW} = \mathrm{GRW}_{(\mathrm{year})}(1 + \mathrm{RGI})^{\mathrm{n}} \quad (3.9)$$

Where:

GRSW: Generation rate of municipality solid waste for each year.

GRW: Present solid waste generation rate for year 2016 from Eq. (3.6).

RGI: Rate of increment in solid waste generation per year from Eq. (3.8).

n: Number of year.

$$\mathrm{GRSW}_{(2032)} = \mathrm{GRW}_{(2016)}(1 + 0.01)^{16} \quad (3.10)$$

The quantity of solid waste (Qs) produced each year till year 2032 was depended on generation rate of municipality solid waste for specific year (GRSW) from Eq. (3.9) and future population for specific year (Pt) from Eq. (3.7) was calculated as:

$$\mathrm{Q_s}(\text{for specific year}) = \mathrm{P_t} \text{ X GRSW X } \left(\frac{365}{1000}\right) \text{ or}$$

$$\mathrm{Q_s}(\text{for specific year}) = \mathrm{P}_{2013}(1 + 0.299)^{\mathrm{t}} \text{ X } \mathrm{GRW}_{(2013)} (1 + 0.01)^{\mathrm{t}} \text{X } \left(\frac{365}{1000}\right) \quad (3.11)$$

Qs: Quantity of solid waste produced each year (tonnes).

The cumulative quantity of municipality solid waste generated by 2032 can be calculated as:

$$\mathrm{Q}_{\mathrm{S(C)}} = \mathrm{Q}_{\mathrm{s(ct)}} + \mathrm{Q}_{\mathrm{s(ct-1)}} \quad (3.12)$$

Where:

Qs (c): Cumulative quantity of municipality solid waste for the specific year (tonnes).

Qs (ct): Quantity of municipality solid waste for the specific year (tonnes).

Qs (ct-1): Cumulative quantity of solid waste for the last year before specific year (tonnes).

For illustration the cumulative municipality solid waste quantity in 2032 Qs(c) is equal to the solid waste quantity produced in 2016 Qs(ct) from Eq. (3.11) by adding the cumulative quantity of solid waste in 2031 Qs(nt-1) to quantity of municipality solid waste in 2032, accumulatively from year 2016 until 2032, the increment is done through adding the value of current year to past year until year 2032 as:

$Q_{S(C)(2032)} = Q_{s(ct)(2032)} + Q_{s(ct-1)(2031)}$

3.2. Decision-Making Tree for Landfill Siting

The primary object of the decision hierarchy is the selection of a appropriate location fo r a landfill site. (Figure 3.2) shows the hierarchical structure of the decision problem, which contains three levels. At the first level the evaluation criteria have been classified into two broad classes – natural environmental factors and artificial factors. At the second level, there are six categories, including hydrological, land, topographical, infrastructure, accessibility and social-cultural criteria. The third level comprises the sub-criteria used in this study, which consist of the sixteen layers of raster Maps

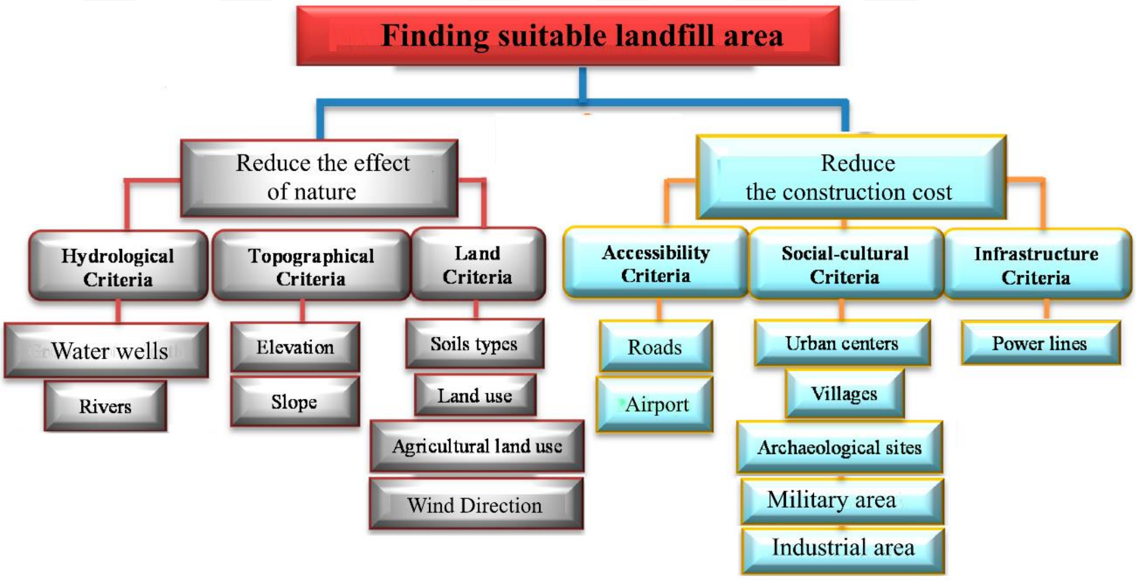


Figure 3.2. Tree diagram of the decision process developed for selection of suitable landfill site.

3.3. Sources of Data

Collecting reliable and accurate data is the most determinant factor for any research as it determines the quality of the research. Accordingly, the required data which were collected from the respective primary and secondary data sources. Borehole data like ground water wells which were collected from (Sulaymaniyah directory of Water Resources) and converted as an input data in GIS environment.

River were prepared from converting dwg file to shape files according to (sulaymaniyah directory municipality), the Digital Elevation Model (DEM) was used to derive the elevation and slope of the study area obtained from (Sulaymaniyah directory of statistics). The soil map was digitized from exploratory soil map of Iraq 1960. The layer of agricultural land use as a shape file was mapped in polygon form from Sulaymaniyah Governorate satellite images from 2012 and Google earth, the roads layer were prepared from converting dwg file to shape files according to (sulaymaniyah directory municipality), the Airports shape file was mapped in polygon form from Sulaymaniyah Governorate satellite images from 2012. Settlements (including urban centres and villages) were prepared from converting dwg file to shape files according to (sulaymaniyah directory municipality). Archaeological sites map (scale 1:1500000) (The Archaeological Map of Iraq, 2013), military area industrial area were prepared from converting dwg file to shape files according to (sulaymaniyah directory municipality), power lines data was digitized from (sulaymaniyah districts map, 2007). All information was projected onto the World Geodetic System (WGS 1984) using a projected coordinate system system- universal transverse Mercator (UTM).

3.4. Restriction of Locations Using Buffer Zone

To find the most suitable site for landfill it needs a process of large-scale evaluation. Any selected site should satisfy the governmental regulations' requirements as well reducing environmental, social and economical costs (World Bank, 2015). Restricted sites mean areas, which do not allow for a landfill site to be situated within them due to potential risk to the environment, excessive cost or human health (United Nation, 2010). Spatial constraints, or buffer zones, were used around each important sites or specific geographic features in each criterion in the GIS environment through using "buffer" in the special extension tool. The buffer zones for wells, rivers, roads, airport, urban centers, villages, archaeological sites, military, power lines and industrial were created at distances of 500, 1000, 500, 5000, 1000, 1000, 750, 30 and 400 m respectively (Table 3.1).

Table 3.1. Description of values of buffer zones for criteria.

Criteria	**Buffer zones**	**Researchers' suggested buffers**
Land use	Should be excluded airport Industrial area, schools and university, Archaeological sites, Wells, Rivers, Urban footprints, Military, Villages and agricultural lands from landfill siting.	
Water wells	1 km from boundaries of wells to sites.	0.5 km (Hasan et al.,2009)
Rivers	1 km from boundaries of rivers to sites.	1 Km (Sharifi et al., 2009; Yildirim, 2012; Eskandari et al., 2012).
Airport	0.5 km from boundaries of roads to sites.	0.5 km (Şener et al., 2006; Şener et al., 2011; Effat and Hegazy, 2012).
Urban centers	3 km from boundaries of roads to sites.	Chalkias (1997)
Villages	5 km from borders of village to sites.	5 Km (Şener, 2004; Alavi et al., 2013; Isalou et al., 2013).
Archaeological sites	1 km from borders of village to sites.	1 Km (Charnpratheep et al., 1997; Şener, 2004; Şener et al., 2006).
Military area	1 km around archaeological sites to sites.	1 Km (Gupta et al., 2003; Ersoy and Bulut, 2009).
Power lines	2 km around Military sites to sites.	500 m (Al-Anbari et al. 2015)
Industrial area	30 m from power lines on both sides to sites.	30 m (Şener et al., 2006; Yildirim, 2012).
	0.400 km from boundaries of industrial zones to sites.	250 m (Al-Anbari et al. 2015)

3.5. Sub-Criteria Weights

In this research, based on the opinion of experts and reviews of literature in this field, as well as several available and required data about the study area, each criterion was classified into classes (sub-criteria), and each class was given a suitability rating value. This was carried out by decision makers who gave their opinions about the sub-criteria. In order to prepare each sub-criteria and criterion, a number of steps were done in GIS (e.g., buffer, extract, clip, overlay, proximity in vector format and then convert it to raster format to reclassify maps and use map algebra, in raster etc.) (Table 3.2).

Table 3.2. The summary of the input layers used in the analysis.

No.	**Criteria**	**Sulaymaniyah**	
		Sub-criteria values	Sub-criteria rating (0-10)
1	Water wells (m)	0-1000	0
		>1000	10
2	Rivers (m)	0-1000	0
		>1000	10
		<900	10
3	Elevation (a.m.s.l)	900-1180	8
		1180-1240	6
		1240-1340	2
		>1340	0
4	Slope (degree)	<9°	10
		9°-18°	8
		18°-25°	4
		>25°	0
		A33	7
		B36	3
5	Soil types	C37	10
		D38	5
		E39	1
		Archaeological sites	0
		Rivers	0
		Villages	0
		School university	0
		Airport	0
6	Land use	Urban centers	0
		Military	0
		Green area parks	0
		Industrial area	0
		wells	0

Table 3.2. The summary of the input layers used in the analysis (Continued).

No.	**Criteria**	Sub-criteria values	Sub-criteria rating (0-10)
		Unused lands	10
		Agricultural lands	0
7	Agricultural lands use	Orchards	5
		Unused lands	10
		0-500	0
		500-1000	7
8	Roads (m)	1000-2000	10
		2000-3000	5
		>3000	3
9	Airport (m)	0-3000	0
		>3000	10
		0-5000	0
10		5000-10000	10
	Urban centers (m)	>10000	7
11	Villages (m)	0-1000	0
		>1000	10
		0-1000	0
12	Archaeological sites (m)	1000-3000	5
		>3000	10
13	Military (m)	0-2000	0
		>2000	10
14	Industrial area (m)	0-400	0
		>400	10
15	Power lines (m)	0-30	0
		>30	10

3.5.1. Water wells

The groundwater circulation and the downward flow of pollutants through soils and rocks are based on the hydro geological condition of the materials more specifically hydraulic properties such as porosity, permeability, transivity etc (Tsegaye, 2006). The chemical constituent and flow of ground water are controlled by the lithological type, thickness, distribution and structure of hydro geological units through which it moves (UNESCO, 1992; Tsegaye, 2006).Moreover the stresses due to tectonics and weathering govern the hydro geochemical characteristics of earth materials (Tamiru et al., 2003; Tsegaye, 2006). Landfill Proximity to a water well is an important environmental criterion in the landfill siting so that wells may be protected from the leaching of the landfill and runoff. Hence, solid waste disposal should be placed away from water wells. Otherwise, it can have irretrievable human and environmental effects.

As a result, proximity from water well was considered as an important criterion for this research. Accordingly, 337 groundwater well points are currently functional, it was obtained from Sulaymaniyah directory of Water Resources, and Proximity Buffer tools were used to make buffer zones around each well. (Chang et al., 2007) described as landfill should not be sited within 50m buffer distance from water wells. However (Al-Anbari et al., 2015) used 400m and (Kabite et al., 2012) used 500 m (Hasan et al., 2009) used 500- 1000m and (Jamjan, 2009) used 700m as a minimum distance from which landfill can be safely sited in (Gizachew, 2011). In this study, a buffer zone of more than 1000 m around each and every well points was adopted in order to protect ground water from contamination. Any distance less than 1000 m was, thus, given a grading value of zero and any distance greater than 1000 m was given a score value of 10. (Figure 3.3).

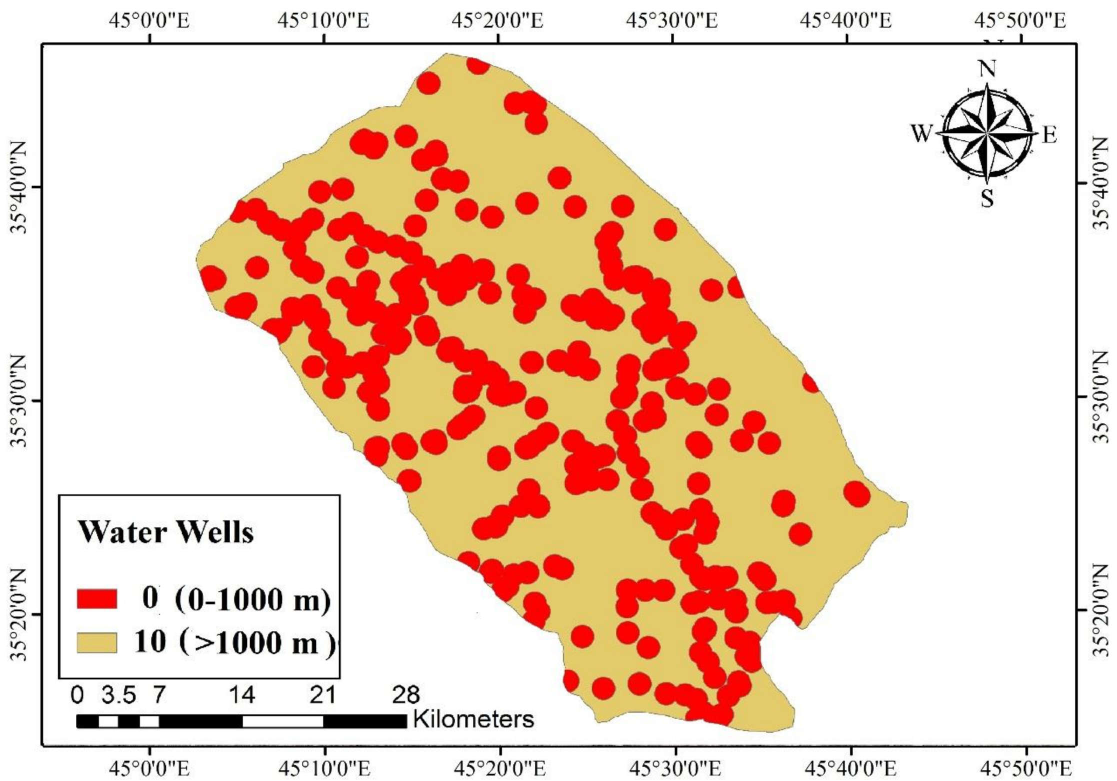


Figure 3.3. Water well sub criteria map.

3.5.2. Rivers

The landfill locate should not be placed within surface water or water resources protection areas to keep surface water from pollution by leachate. Safe distances from seasonal and permanent rivers should be preserved to prevent waste from eroding into major rivers and streams. For creating the river layer a suitable buffer distance 1000 m from a river boundary to a landfill site adopted to keep surface water from contamination (Yildirim, 2012; Eskandari et al., 2012). (Siddiqui et al., 1996) suggests that 800 m buffer distance of from the boundary of landfill to the river. (Demesouka et al., 2013) and (Sadek et al., 2006) advise that 500 m as an even smaller buffer distance from a river is suitable to reduce the potential for river contamination.

In this research, a buffer distance of more than 1000 m from any river boundary was adopted in order to keep surface water from contamination. Given a rating value of zero for any distance less than 1000 m, and any distance greater than 1000 m was given a score value of 10 (Figure 3.4).

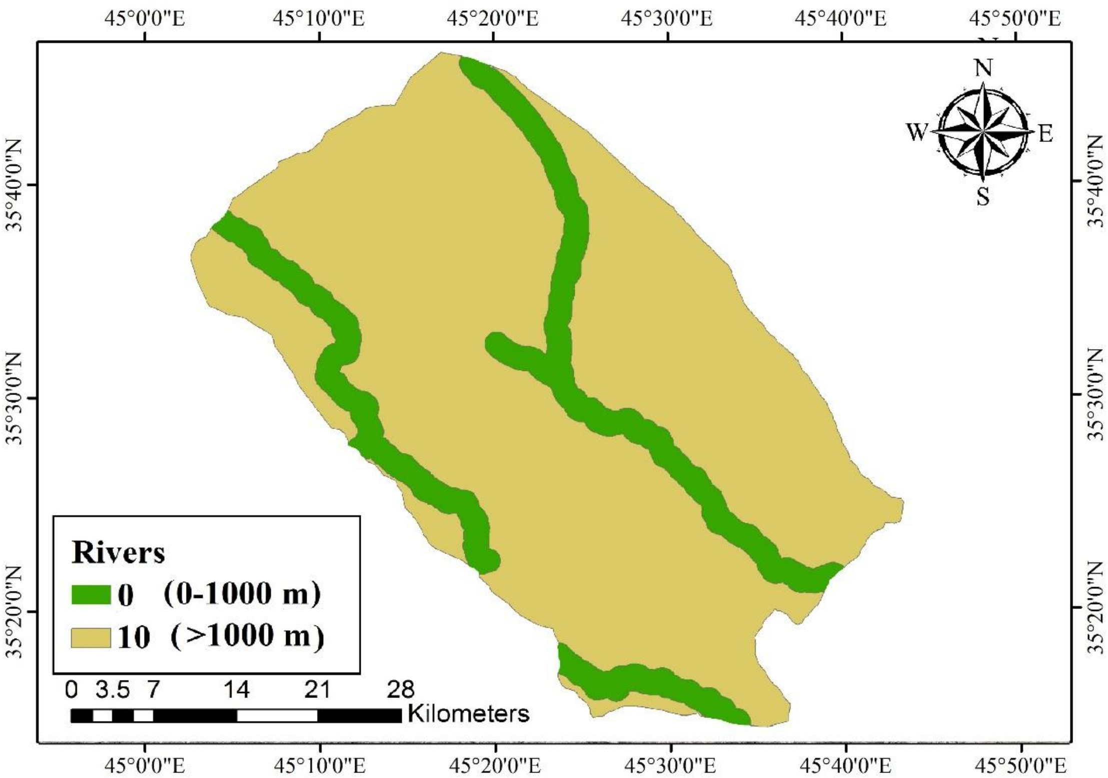


Figure 3.4. River sub criteria map.

3.5.3. Elevation

The (DEM) digital elevation model was adopted in this work (The Sulaymaniyah directory of statistics). The raster elevation map was divided into five categories according to study area (Figure 3.5).

In this study, the most suitable elevations were between 531-900 metres above mean sea level (a.m.s.l.) in Sulaymaniyah city respectively and assigned values of 10 to reduce the potential of leachate leaking from the landfill (Demesouka et al., 2014). also elevations between 900-1180, 1180-1240 and 1240-1340 (a.m.s.l.) were given a grading value of 8, 6, 2. And elevations greater than 1340 (a.m.s.l.) were scored as 0.

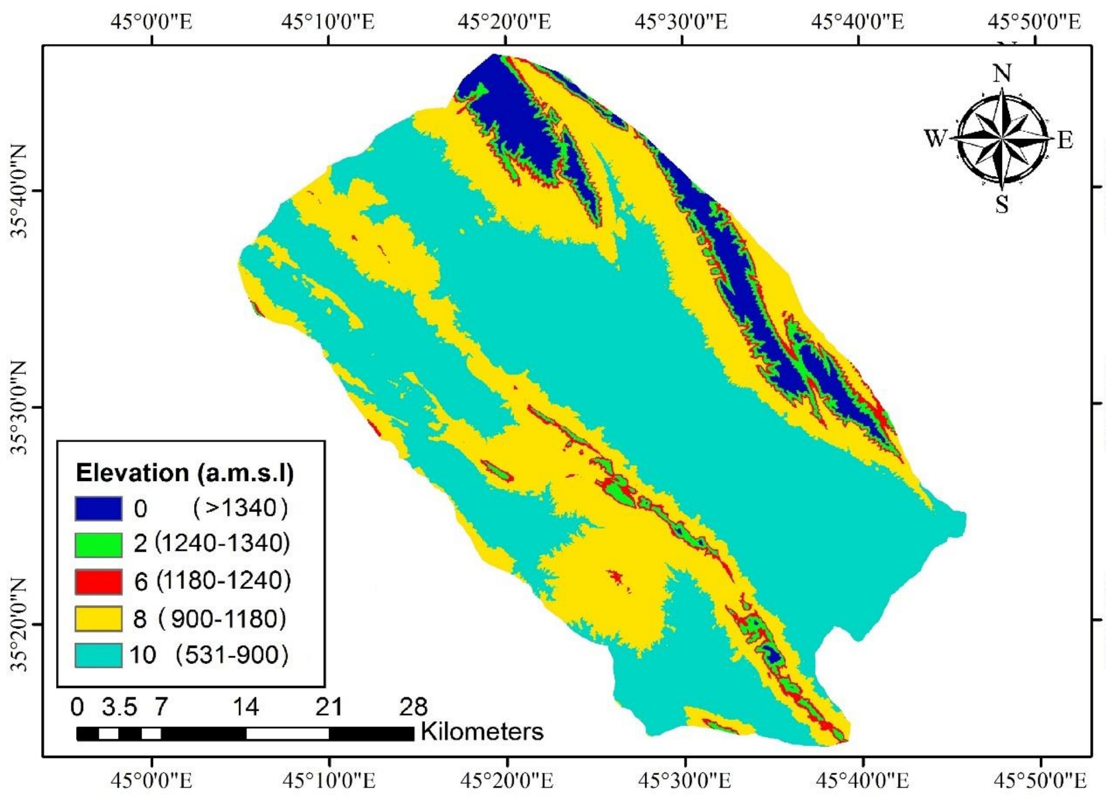


Figure 3.5. Elevation sub criteria map.

3.5.4. Slope

The slope facet is one of the most effective factors in landfill site selection. Because it manages the amount of surface, runoff produced the precipitation rate and movement velocity of water to the potential site in addition to the construction cost. Very steep slopes will cause to higher excavation costs, while flat site areas are more suitable for constructing of landfill. An area with a very steep slope will increase drainage of contaminants from the landfill site to surrounding areas (Lin and Kao, 1999) as well as flowing of leachate from high slopes to flat and low areas or bodies of water increasing the risk. This may lead to leachate pollution and contaminants moving long distances from their sources (Leao et al., 2004; Nas et al., 2010). (Hasan et al., 2009) set areas with slope <15-20% as the best site for landfill, while (Change et al., 2007) describe slope <12% as the best site and slope >12% unsuitable for selecting for landfill. Moreover, (Elahi and Samadyar, 2014) state that areas with slope <25% is optimum site for landfills.

The "slope" layer was created based on the (DEM) digital elevation model of the study area. Slopes were determined and reclassified in GIS environment. (Figure 3.6) shows that most of the land in the study area has a slope of 0-25° and the area with the slope less than 9 was assigned a rating value of 10. Areas with a slope between 9-18 were graded 8. Areas with the slope 18°-25° and more than 25° were given a score of 4 and 0.

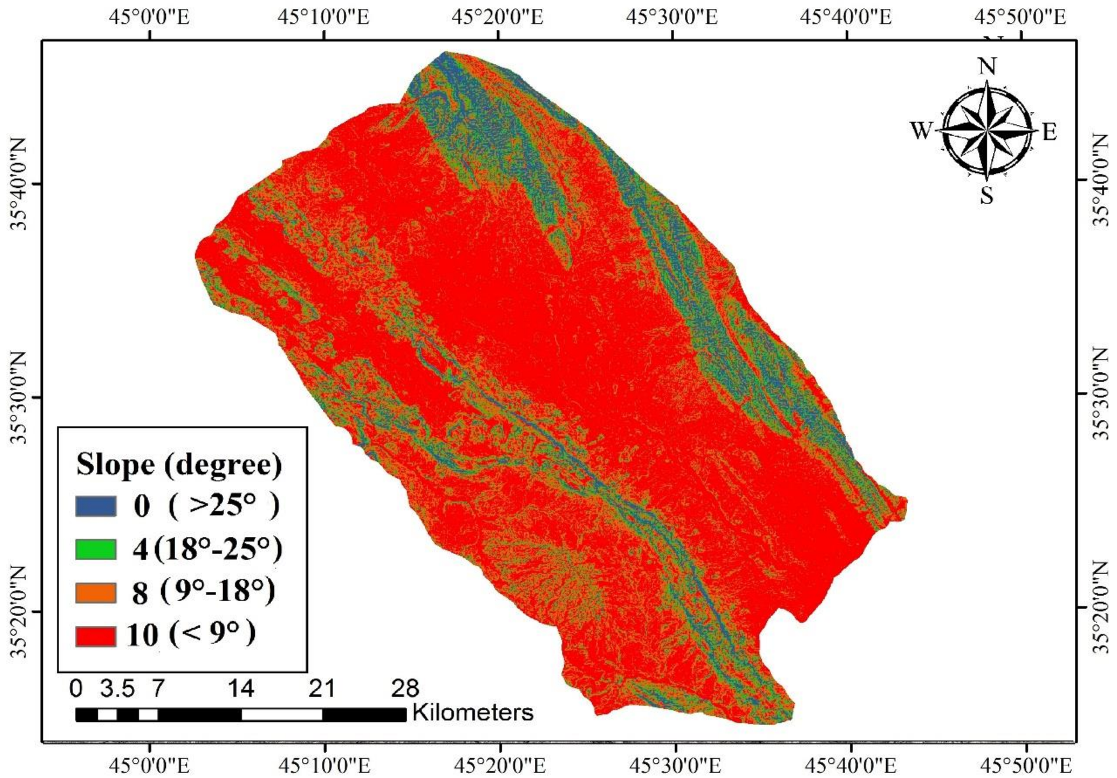


Figure 3.6. Slope sub criteria map.

3.5.5. Soil type

For preparing the layer for the soil types map of the exploratory soil of Iraq scale of (1:1,000,000) was digitized in polygon type. There were five types of soils in Sulaymaniyah area (Figure 3.7) (Buringh, 1960). A short description of the types of soil in the study area, according to (Buringh, 1960) can be summarized as follows:

1. Brown soils, medium and shallow phase over Bakhtiari gravel A (33).

These soils are predominantly Brown soils. with a small proportion of Lithosols. The parent material for this soil type is Limestone and Bakhtiari gravel. These soils haven't salinity. These soils are Shallow and moderately deep.

2. Chestnut soils, shallow, strong and sloping phases Chestnut soils B (36).

These soils consist of Chestnut soils, with a small proportion Reddish Chestnut, Rendzina soils and Lithosols. The Soil depth Shallow to moderately shallow. The parent materials of this soil is Limestone . In this soil type, haven't salinity and Locally some sheet and rill erosion.

3. Chestnut soils, deep phase C (37).

These types of soils consist of Chestnut soils, with a small proportion of Reddish Chestnut and Chernozem soils. The parent material for this soil type are Fluviatile and limestone. These soils are Moderately deep to deep and No saline.

4. Rough broken and stony land D (38)

These soils are consist of Lithosols and Rendzina soils, with a small proportion of Brown and Chestnut soils. The Soil depth are Shallow, minor areas deep. The parent materials of this soil is Limestone. In this soil type have not salinity and have some erosion (locally).

5. Rough mountainous land E (39)

These soils primarily consist of Lithosols, with a small proportion of Brown and Rendzina soils. These soils are Shallow and haven't salinity. The parent material for this soil type is Metamorphic rocks and limestone.

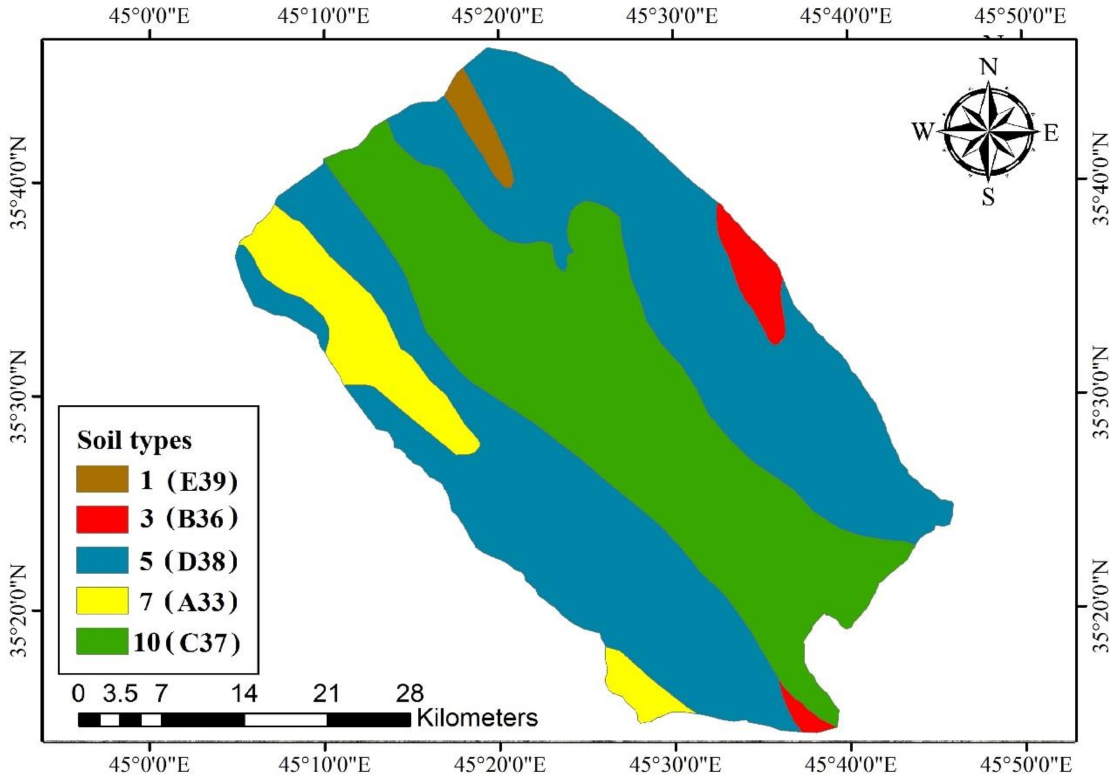


Figure 3.7. Soil type sub criteria map.

3.5.6. Land use

Maps were digital as a shape file (vector), whilst the remaining maps need to be converted into digital maps. Individual maps detailing topography, industrial, river, roads, military, settlements (including urban centres and villages) were prepared from converting dwg file to shape files according to (sulaymaniyah directory municipality).

The layer of agricultural Land Use shape file was mapped in polygon form from Sulaymaniyah Governorate satellite images from 2012 and Google earth. The layer of pwer lines data was digitized from (sulaymaniyah districts map, 2007). "archaeological sites" map (scale 1:1500000) (The Archaeological Map of Iraq, 2013), The layer of groundwater wells as a shape file obtained from (Sulaymaniyah directory of Water Resources). The Airports shape file was mapped in polygon form from Sulaymaniyah Governorate satellite images from 2012. The soil map was digitized from exploratory soil map of Iraq 1960. The Airports shape file was mapped in polygon form from Sulaymaniyah Governorate satellite images from 2012 All information was projected onto the World Geodetic System (WGS 1984) using a projected coordinate system

system- universal transverse Mercator (UTM). And Digital camera and GPS used to capture and exact location of the final landfill site.

In this study, twelve categories were used to prepare the "land use" layer; these are urban centers, villages, green area parks, industrial areas, archaeological sites, schools universities, rivers, airport, military site, agricultural land, orchards and unused land. All shape files were merged in a single layer called "land use". The categories of orchards and unused lands were given ratings of 5 and 10, respectively, whilst other categories were assigned a score of zero (Figure 3.8).

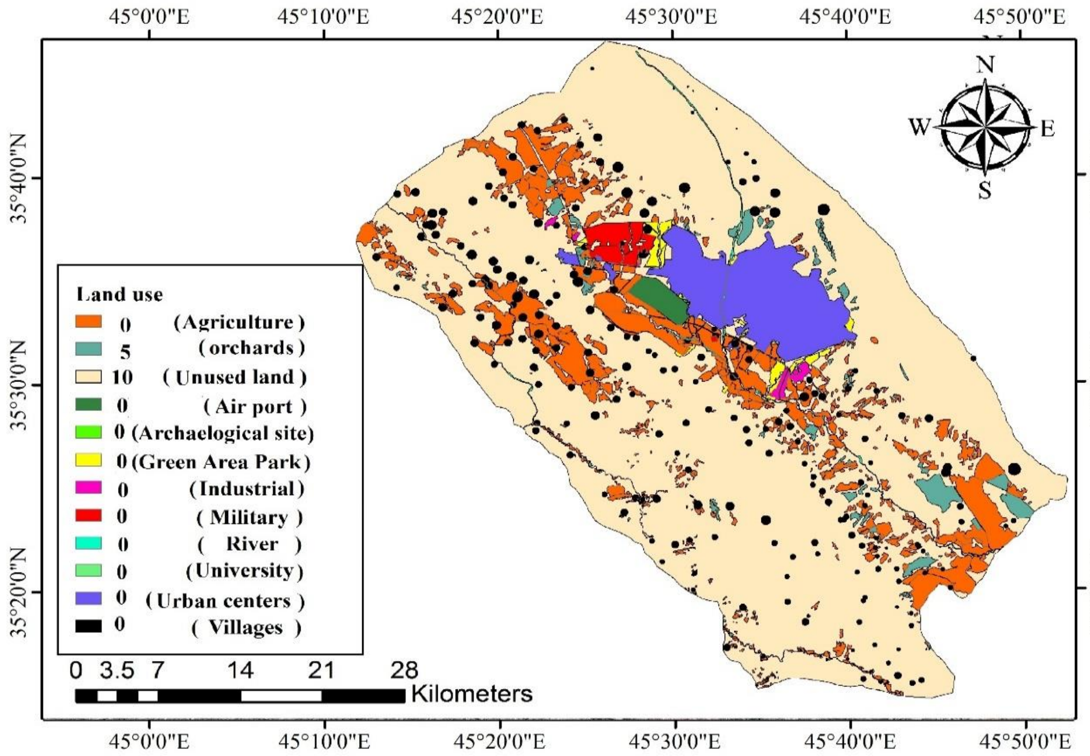


Figure 3.8. Land use sub criteria map.

3.5.7. Agricultural landuse

Each layer map of "agricultural land use" Sulaymaniyah area divided into four categories: agricultural land, green area parks, orchards and unused land. These categories were drawn in polygon form in separate shape files based on 2012 satellite images of Sulaymaniyah area (Sulaymaniyah directory of Municipalities) and Google earth pro. Then, they merged in a single layer, which is called ‘agricultural land use’. Logically, landfill sites should not be located on areas of the "agricultural land" and green area parks (Figure 3.9). This category was, therefore, assigned a grade of zero. The "orchards" category was given a grade of 5, and the "unused land" category was assigned the highest possible score of 10.

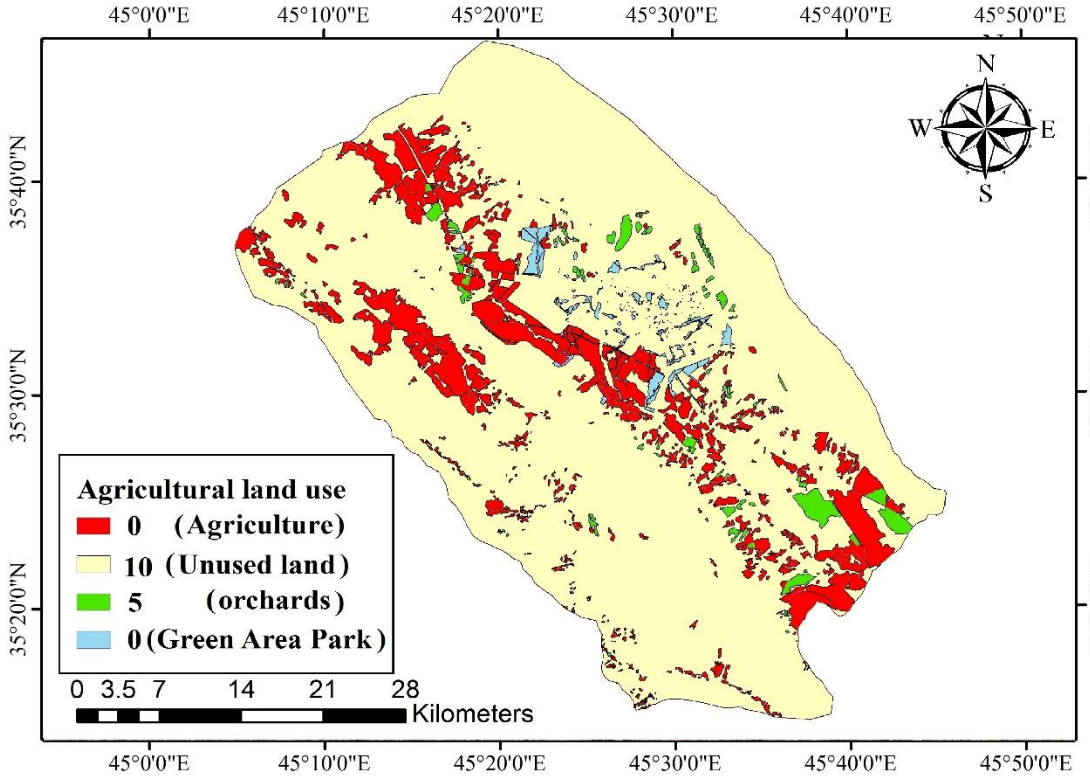


Figure 3.9. Agricultural land use sub criteria map.

3.5.8. Roads

A road is one of the criteria that should be considered from economic and social point of views during solid waste landfill site selection processes. This layer consists of main roads and highway roads. Distances from landfill site to a roads should be sufficient to ensure there are no negative aesthetic impacts. (Moeinaddini et al., 2010), as well as to ensure that drivers are protected from accidents that may occur due to the material which has been blown onto roads by strong winds (Baban and Flannagan, 1998; Demesouka et al., 2013). Moreover, economic factors must be taken into consideration, and landfill very close to roads may have public health problem as landfill can have hazardous effect to health. Moreover, landfill site very far from road network is also not recommended due to high transportation cost. Therefore, to minimize such problems a landfill site should be located within a reasonable distance of existing roads in order to reduce the cost of construction of roads leading to the site in future (Lin and Kao, 1999; Zeiss and Lefsrud, 1995; Nas et al., 2010).

In this study, buffer zones from landfill sites to roads of less than 500 m were given a grade value of zero in the rating of this layer. Buffer distance of 500–1000 m were given a grade value of 7, whilst the buffer distance of 1000–2000 m were given the highest score value of 10. Buffer distance of 2000–3000 m and those greater than 3000 m were given a grading value of 5 and 3, correspondingly (Figure 3.10).

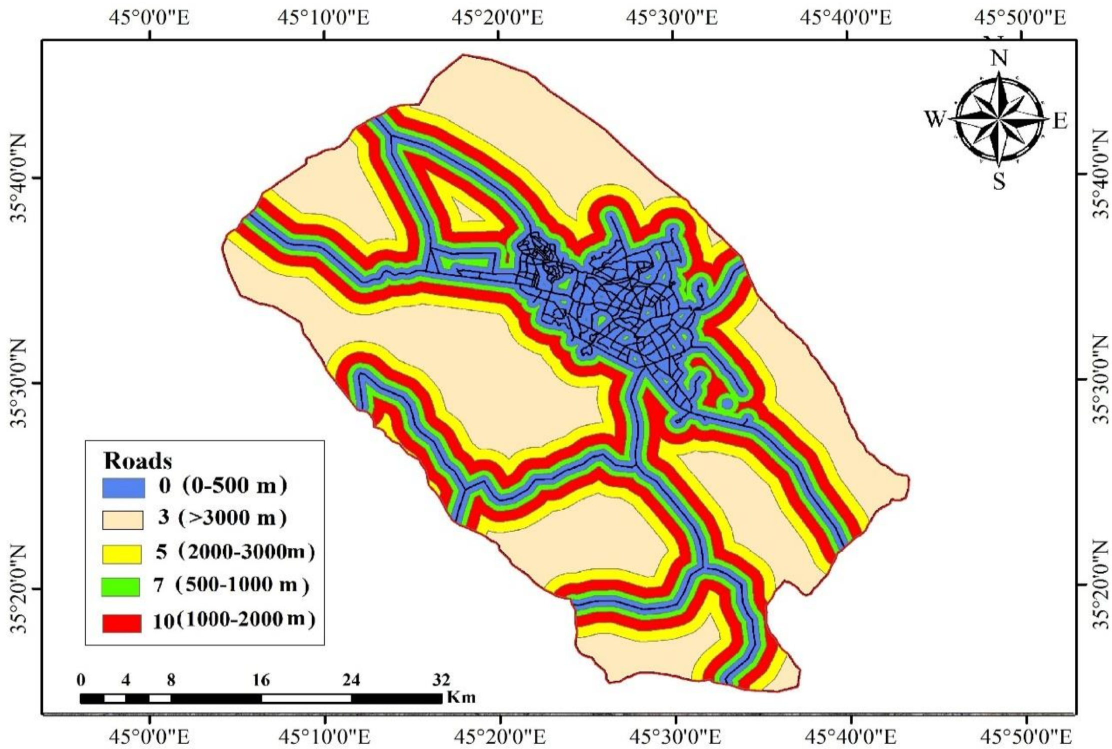


Figure 3.10. Roads sub criteria map.

3.5.9. Airport

The airport is one of the important factor should be considered in selection of landfill siting. Aim for locating a landfill far from the airport is to avoid birds that easily get attracted to landfill. landfill should be located at a suitable distance from airports. The distance between a landfill site and airport should be a minimum of 3 km for safety measures (Wang et al., 2009; Moeinaddini et al., 2010). (Bagchi, 2004) submit that a buffer distance of 3048 m from a airport boundary to the landfill. (Chalkias, 1997) suggest that buffer zone of 3000 m from a airport is adequate and 3000 m and 1500 m according to (EPA, 1991). In this study, a buffer distance of more than 3000 m from airport boundary was adopted, considering the effect of landfill on aircraft and passengers as a farther landfill from the airport. Any distance less than 3000 m was, thus, given a grade value of zero and any distance greater than 3000 m was given a score value of 10 (Figure 3.11).

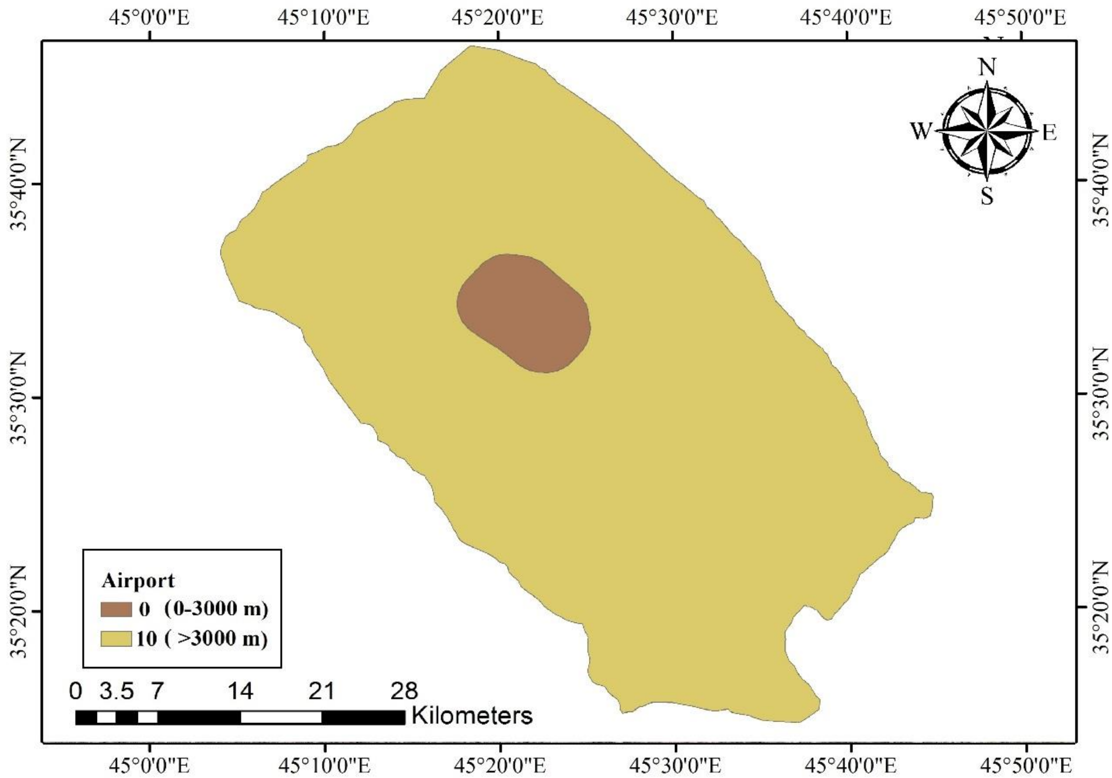


Figure 3.11. Airport sub criteria map.

3.5.10. Urban centers

For the "urban centres" layer, many researchers suggested that the suitable distance from the landfill site to borders of urban areas should be more than 5 km, taking into account economic factors and impact on the general public. The cost of this land as well as health and safety laws often prevent siting of a landfill within the boundaries of an urban area. Important factors to consider are noise, decreases in property value (Zeiss and Lefsrud, 1995), odour, aesthetics (Tagaris et al., 2003), as well as ensuring that the urban area retains the potential to expand in the future (Effat and Hegazy, 2012). (Effat and Hegazy, 2012; Isalou et al., 2013) recommend distance of 5 km as a suitable buffer zone from city borders to a landfill site, while (Chang et al., 2007) suggested 3 km as a sufficient buffer.

In this research, buffer zones of less than 5 km were given a grading of 0. Buffer zones between 5–10 km were given the highest score which was 10. Buffer zones of 10–15 km and more than 15 km were given a score of 4, respectively (Figure 3.12).

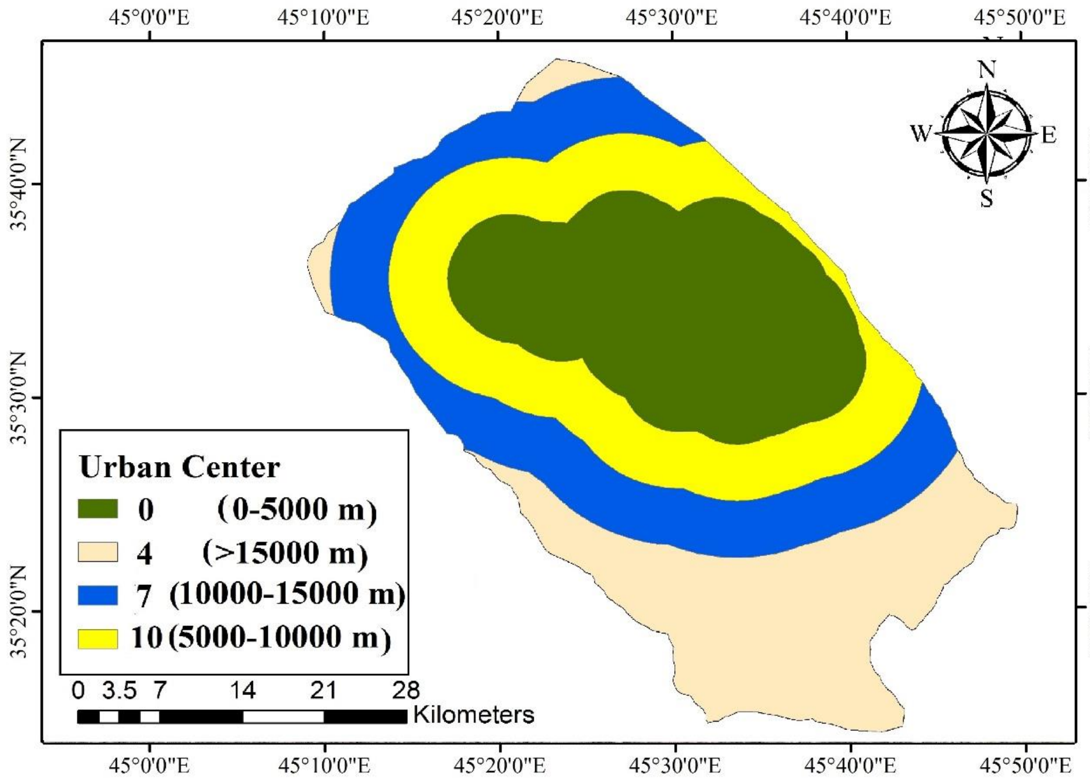


Figure 3.12. Urban center sub criteria map.

3.5.11. Villages

For the layer of villages map the literature suggests a minimum of 400–1000 m (Siddiqui et al., 1996) stated that the distance from landfill to all built-up area consisting of ten houses or more should be at least more than 400 m (0.25 mi). whilst (Charnpratheep et al., 1997) and (Sener, 2004) recommend a minimum distance from a villages to landfill area of 1000 m. In the current study, buffer distance less than 1000 m were given a grade value of 0, while those with buffer distance greater than 1000 m were given a grade value of 10 (Figure 3.13).

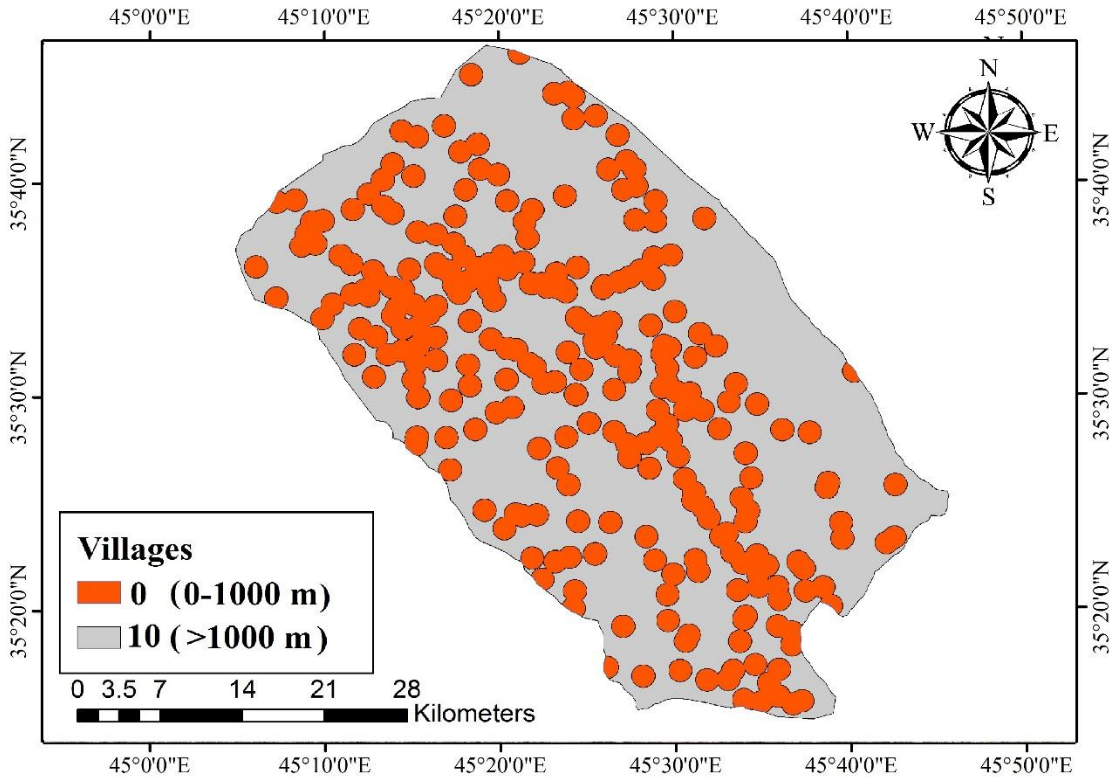


Figure 3.13. Villages sub criteria map.

3.5.12. Archaeological sites

Sulaymaniyah has a rich history and are home to a number of significant archaeological and religious sites. These areas are considered absolutely inappropriate to be within or near a landfill site because of their high historical value and importance for tourism (and the development of tourism) in this area.

In this study, for the "archaeological sites" layer, buffer zones of more than 3000 m around these areas were scored 10. Buffer zones of 1000-3000 m were scored 5. Buffer zones of less than 1000 m around these areas were excluded and scored zero, as shown in (Figure 3.14). In the literature, (Ersoy and Bulut, 2009) and (Gupta et al., 2003) suggested that the distance of 0-1000 m from archaeological and religious locations is not suitable and distances between 1000-3000 m are suitable, while the distance of more than 3000 m is the most suitable and got the highest grade. (Demesouka et al., 2013; Eskandari et al., 2012; Nas et al., 2010) used a 500 m as a buffer zone from archaeological and religious sites; 71 Km distance from temples and archaeological sites according to (Charnpratheep et al., 1997).

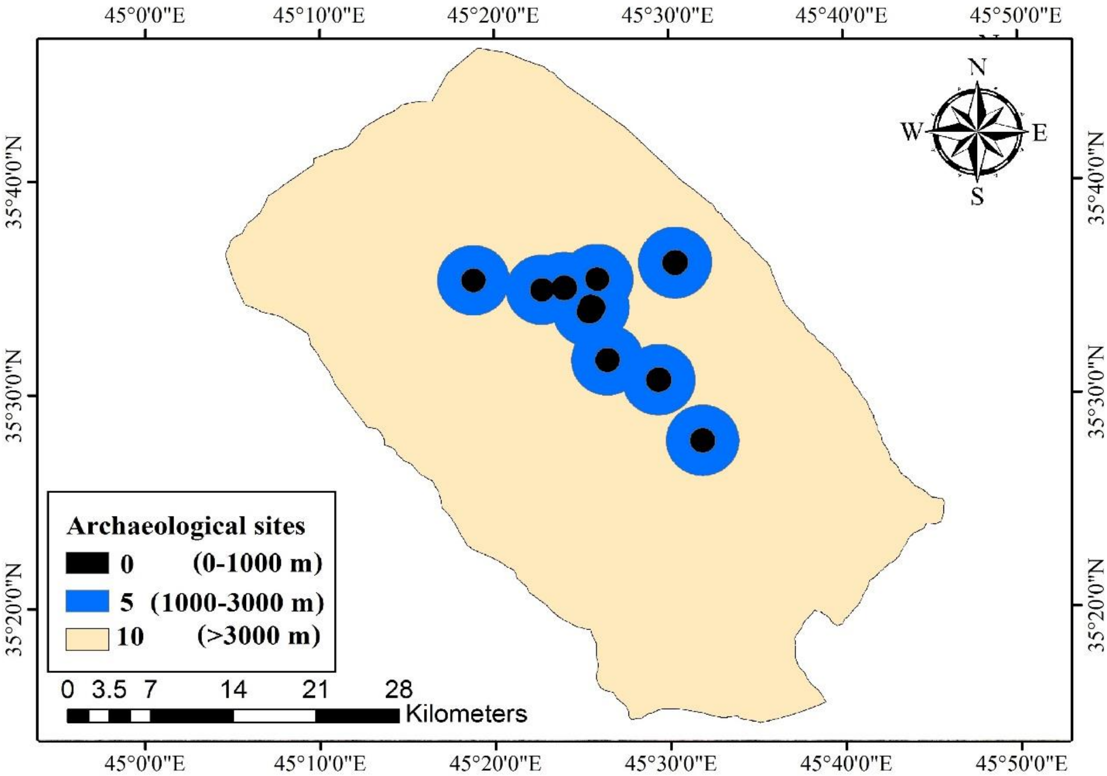


Figure 3.14. Archaeological sites sub criteria map.

3.5.13. Military area

For the layer map of military a buffer distance of more than 500 m is a suitable distance from landfill site to the boundary military area. because military areas used for training of military personnel or for the testing of military equipment that are not open for public usage. (Al-Anbari and Thameer, 2015) suggests that a suitable distance of 500 m from a military site boundary is sufficient.

In this research, a buffer distance of more than 2000 m from boundary of military area was adopted in order to protect military area from contamination. Any distance less than 2000 m was, thus, given a grade value of zero and any distance greater than 2000 m was given a grade value of 10 (Figure 3.15).

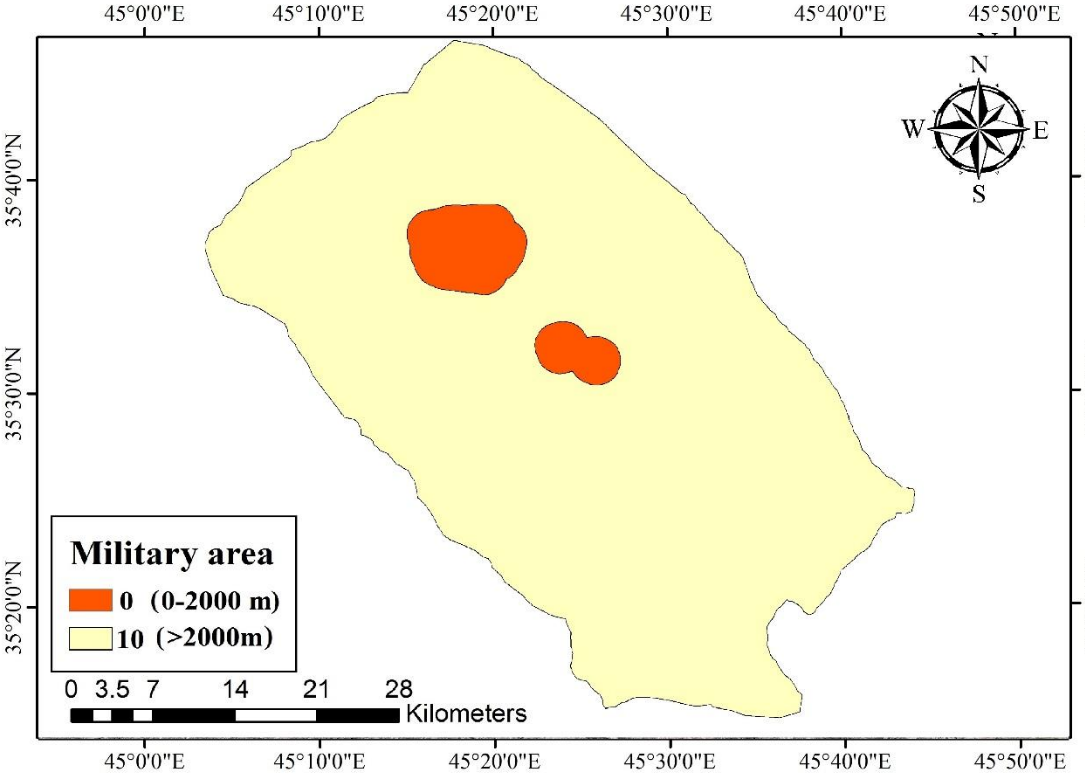


Figure 3.15. Military area sub criteria map.

3.5.14. Industrial area

For the layer of industrial area map the literature suggests at least 200 meters from landfill site to industrial area the (Yaw et al., 2006). (Al-Anbari and Thameer, 2015) suggests a distance from landfill site to any industrial area should be at least more than 250 m. (Akbari et al., 2008) submits a distance from landfill site to any industrial area should be at least more than 300 m. In the current research, buffer distance less than 400 m were given a grade value of 0, whilst those with buffer distance greater than 400 m were given a grade value of 10 (Figure 3.16).

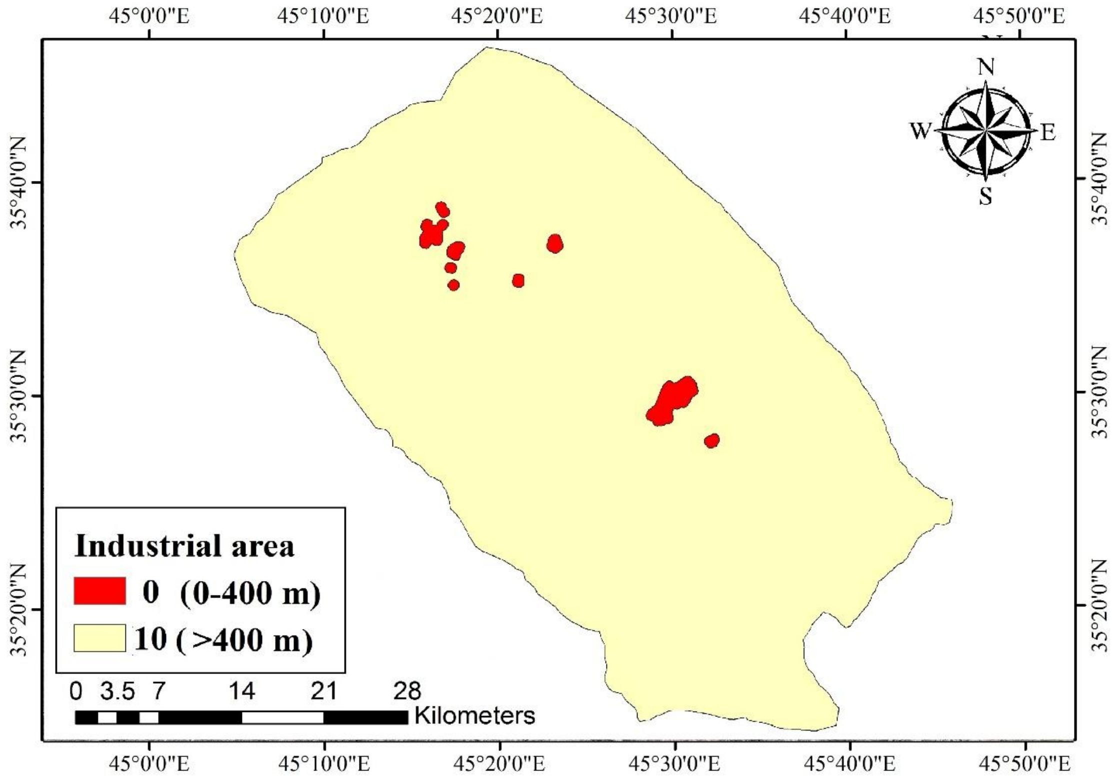


Figure 3.16. Industrial area sub criteria map.

3.5.15. Power lines

In relevant literature, (Sener, 2004; Yildirim, 2012; Al-Anbari and Thameer, 2015) suggest that a suitable buffer distance from a landfill site to power line should be more than 30 m on both sides to avoid risks related with high voltage whilst taking into account the required to provide electricity to the infrastructure of the landfill site. (Sadek et al., 2006; Demesouka et al., 2013) suggests distances 40 m and 50 m correspondingly in their study to be a suitable buffer distance on both sides from landfill area. In this research, buffer distance for power lines which were smaller than 30 m on both sides were given a grade value of zero, while distance greater than 30 m were given a grade value of 10 (Figure 3.17).

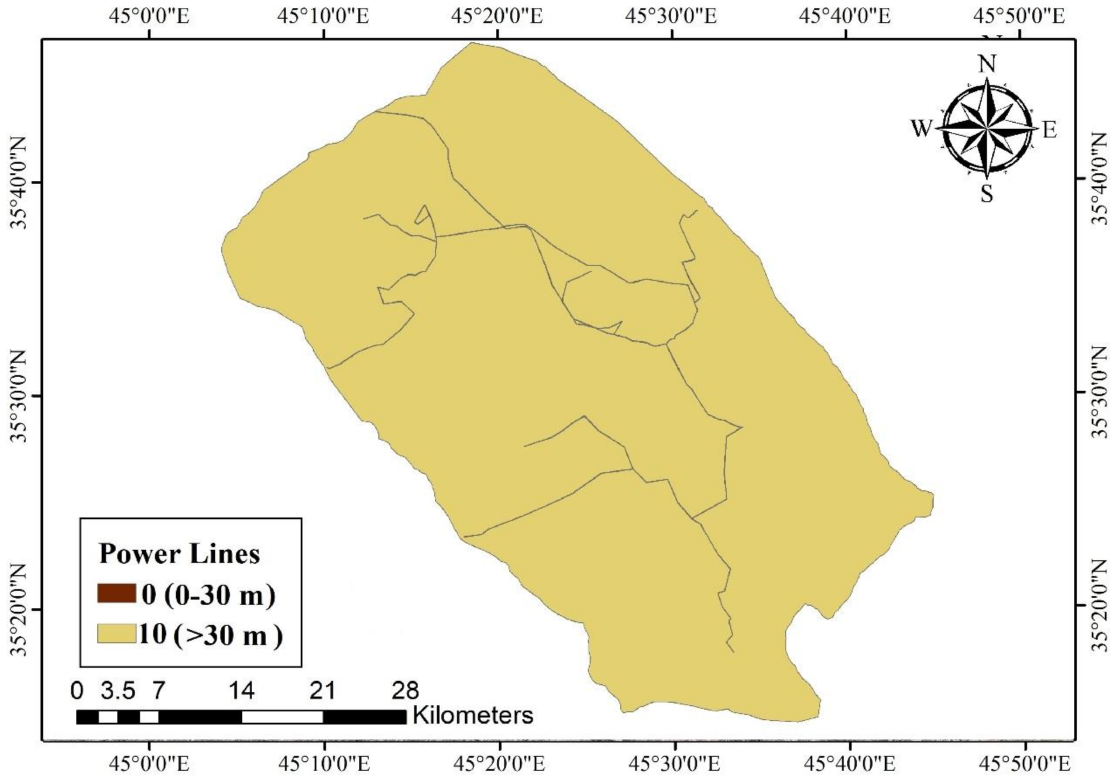


Figure 3.17. Power line sub criteria map.

3.5.16. Wind direction

One of the most important criteria in landfill site selection is the wind direction and wind speed to protect the human health from landfill odor, because strong wind and storm are spreading dust and odor from the landfill site to the sulaymaniyah city. Therefore the landfill site shouldn't be placed in the direction of wind towards to the sulaymaniyah city to protect the city from bad odor and human health. In this study we selected the wind direction and wind speed by using wind rose pro3, the direction of wind in Sulaymaniyah were illustrated in figure 3.18.

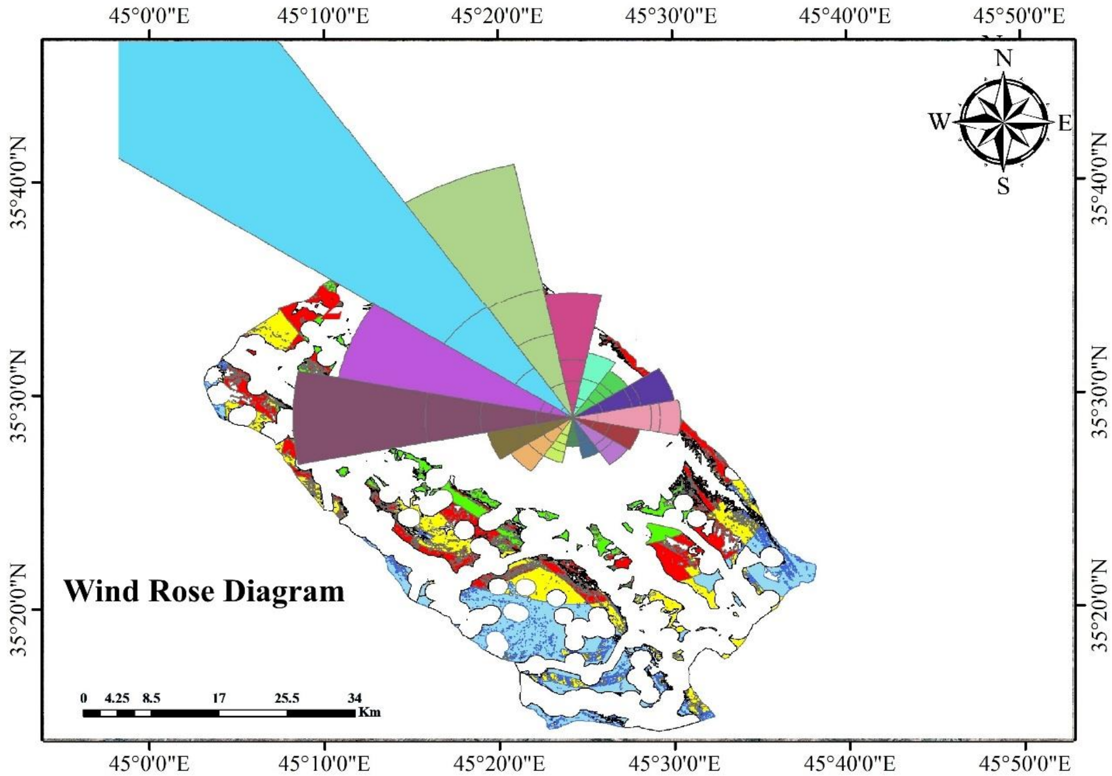


Figure 3.18. Wind direction sub criteria map.

3.6. Determination of Relative Importance Weights of All Criteria Using the AHP Method

In the AHP method, selection criteria can be identified and weighted, and the collected data can also be analyzed, accelerating the process of decision-making. The hierarchy is deconstructed into a pair comparison matrix. This pair-wise comparison is used to determine the relative importance of each alternative in terms of each criterion. In typical analytical hierarchy process a nine-point scale is used, where each point equates to an expression of the relative importance of two factors, e.g. "A is of the same importance as B" or "A is more important than B", etc. These studies use a scale with values ranging from 1 (equal importance or no difference) to 9 (absolute importance or extreme preference) (Table 3.3). This will enable the decision maker to assess the contribution of each factor to reach the objective independently through pair-wise comparison, thus simplifying the decision-making process (Rezaei-Moghaddam and Karami, 2008).

Table 3.3. Scale of relative importance for pairwise comparison (Saaty, 1980).

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

In this reseach, the typical structure of the decision problem is formed and consists of numbers, which were represented by symbol m, whilst alternatives were given numbers represented by symbol n. Each alternative can be evaluated in terms of the decision criteria as well as each criterion can be estimated by its weight (or its relative importance).

The values of aij (i = 1, 2, 3…..m) and (j = 1, 2, 3…..n) are used to signify the performance values in terms of the i-th and j-th in a matrix (Hussain, 2004; Teknomo, 2006; Uyan, 2014). The upper triangular of the matrix is filled with the values of comparison criteria above the diagonal of the matrix. In order to fill the lower triangular of the matrix, the reciprocal values of the upper diagonal are used. This is done by using Eq. (3.1):

$$(a_{ij} = 1/a_{ij}) \qquad (3.13)$$

Where, a_{ij} is the element of row i and column j of the matrix. The typical comparison matrix for any problem and the relative importance of the criteria can be represented in a decision matrix as follows:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \ldots\ldots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \ldots\ldots & a_{2n} \\ a_{31} & a_{32} & a_{33} \ldots & \ldots & a_{3n} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & a_{ij} & \ldots\ldots\ldots\ldots \\ a_{m1} & a_{m2} & a_{m3} & & a_{mn} \end{bmatrix} \begin{bmatrix} W1 \\ W2 \\ W3 \\ \ldots\ldots \\ \ldots\ldots \\ Wn \end{bmatrix}$$

The eigenvectors for each row were calculated using geometric principles (multiplying the value for each criterion in each column in the same row of the original pair-wise comparison matrix and then applying this to each row) as follows:

$$\text{Egi}=\sqrt[n]{a_{11}xa_{12}xa_{13}x \ldots\ldots x\ a_{1n}} \qquad (3.14)$$

Where, Egi = eigenvalue for the row i; n = number of elements in row i. The priority vector is determined by normalizing the eigenvalue to 1(divided by their sum) as follows:

$$Pr_i = Eg_i/(\sum_{k=1}^{n} Eg_k) \qquad (3.15)$$

The lambda max (λmax) was obtained from the summation of products between each element of priority vector and the sum of columns of the reciprocal matrix as shown in the following formula:

$$\lambda_{MAX} = \sum_{j=1}^{n}\left[W_j \sum_{i=1}^{m} a_{ij}\right] \qquad (3.16)$$

Where, aij = the sum of criteria in each column in the matrix; Wi = the value of weight for each criterion

which is corresponding to the priority vector in the matrix of decision, where the values (i=1, 2,…., m) and (j= 1, 2,…., n). So, the lambda max (λmax) in this study is equal to 16.852.

The CI (consistency index) was estimated using the following Eq. (3.5):

$$\text{CI} = (\lambda\text{max} - \text{n})/(\text{n} - 1 \qquad (3.17)$$

Where, CI represents the equivalent to the mean deviation of each comparison element and the standard deviation of the evaluation error from the true ones (Sólnes, 2003), and n is size or order of the matrix.

In this study, CI = 0.1323.

The consistency ratio (CR) was obtained according to (Saaty, 1980), by dividing the value of consistency index (CI) by the Random index value (RI = 1.59) for n=15 (Table 3.4), where this table displays mean Random index value RI for matrices with different sizes according to (Saaty, 1980).

$$CR = (CI/RI) \tag{3.18}$$

If CR less than 0.1, the ratio indicates a reasonable consistency level in the pairwise comparison. CR should, therefore, be less than 0.1.

In this study, CR = 0.0832< 0.1 and RI15= 1.59. For any matrix, the judgments are completely consistent if a CR is equal to zero (Coyle, 2004). The pairwise comparison matrices were prepared for fifteen criteria.

Table 3.4. Random inconsistency indices for different values of (n) (Saaty, 1980)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

In the process of selection the weight and importance of each criterion was compared with each criterion in this research. It was done through the adoption of the opinions of experts who have operated in this field. Each criterion was given a rate of weight that it deserves by implementing the method of (SAW) simple additive weighting, which is well considered the simplest method in the decision-making process (Afshari et al., 2010). Then these weights have been applied and used in preparing the matrix of AHP to get the accurate weight for each criterion (Table 3.5).

Table 3.5.Pair-wise comparisons matrix for selecting a suitable landfill site, eigenvector and relative weight of criteria

Criteria	Water wells	Slope	Elevation	Rivers	Roads	Airport	Urban centers	Land use	Agricultural	Villages (m)	Military (m)	Archaeological	Industrial area	Power line	soil type	Eigen vector	Relative weight of criteria
Water wells	1	5	4	2	5	4	2	6	5	3	4	6	7	7	5	3.94	0.189
Slope	1/5	1	1/2	1/4	1	3	1/5	1/2	1	1/3	1/4	2	1/2	4	1/2	0.64	0.033
Elevation	1/4	2	1	1/3	2	1	1/3	3	2	1/2	1/3	3	1	4	1	1.02	0.050
Rivers (m)	1/2	4	3	1	6	5	1/3	3	4	2	3	5	6	6	3	2.66	0.127
Roads (m)	1/5	1	1/2	1/6	1	1	1/7	1/3	1	1/3	1/2	2	1/3	2	1/5	0.50	0.026
Airport (m)	1/4	1/3	1	1/5	1	1	1/7	1/3	1/2	1/6	1	1/2	1/3	1	3	0.50	0.031
Urban centers	1/2	5	3	3	7	7	1	5	4	2	4	5	5	7	4	3.46	0.164
Land use	1/6	2	1/3	1/3	3	3	1/5	1	1/2	1/4	1/5	1	1	3	1/3	0.65	0.035
Agricultural	1/5	1	1/2	1/4	1	2	1/4	2	1	1/3	1/3	2	2	3	1/2	0.76	0.037
Villages	1/3	3	2	1/2	3	6	1/2	4	3	1	2	4	3	6	4	2.09	0.099
Military	1/4	4	3	1/3	2	1	1/4	5	3	1/2	1	3	2	5	2	1.43	0.074
Archaeological	1/6	1/2	1/3	1/5	1/2	2	1/5	1	1/2	1/4	1/3	1	1/2	3	1/4	0.48	0.025
Industrial area	1/7	2	1	1/6	3	3	1/5	1	1/2	1/3	1/2	2	1	3	1/2	0.77	0.039
Power lines	1/7	1/4	1/4	1/6	1/2	1	1/7	1/3	1/3	1/6	1/5	1/3	1/3	1	1/4	0.29	0.015
soil type	1/5	2	1	1/3	5	1/3	1/4	3	2	1/4	1/2	4	2	4	1	1.02	0.055

3.7. Evaluation of Landfill Suitability Site

In order to find the suitability index value of the potential areas, A total of sixteen layers map were entered in raster in to the GIS. Then, the weighted linear combination (WLC) method was used based on the following Eq. (3.19):

$$A_i = \sum_{j=1}^{n} W_j X C_{ij} \quad (3.19)$$

where, Ai is the of suitability index for site area i, Wj is the relative importance weight of criterion, Cij the grade value of site area i below criterion j and n is the total number of criteria (El-Alfy et al., 2010; Eskandari et al., 2012).

The equation (3.19), was applied on all criteria through using the GIS, map algebra tool in special analysis tool. The procedures for calculating the index of suitability was prepared using the summation of the products of multiplying the score values of the sub-criteria for all criterion depended on the opinion of experts in this field by the corresponding relative importance weight, which was determined by the AHP method.

4. RESULTS AND DISCUSSION

The AHP technique was applied in arranging of every criteria's weight, and the suggestions opinion of experts, the prior research on this topic and different essential and obtainable data that is connected to the current research were applied in the creation of the weighting for each sub-criteria of every criterion. In the current research 16 layer were inserted into the dispensation of an overlying analysis of possible location in GIS to handle the issue of landfill site selection in the city of Sulaymaniyah. In the GIS environment "Map Algebra" in the special analysis tool has been applied to create the final map of the landfill suitability site index. Divided the final map into five-group type depending on the suitability of the candidate landfill site selected. This group types include the excluded locations area, unsuitable location, relatively suitable location, suitable location and most suitable location. The section of "excluded locations area" involved the urban centers, villages, airport, rivers, historic sites, wind direction higher learning institutions, and the industrial areas located in the city of Sulaymaniyah. These locations were assigned to a zero value. The (Table4.1) illustrated group type area and study area proportion of each group type.

Table 4.1. Show the proportion and their areas for group types of landfill suitability index of Sulaymaniyah city.

		Sulaymaniyah city	
No.	**Group Type Area**	**Area in Km^2**	**Proportion (%)**
1	Excluded area	1553.5613	82.462
2	Unsuitable area	127.6491	6.775
3	Moderately suitable area	95.9670	5.093
4	Suitable area	72.3672	3.841
5	Most suitable area	34.4192	1.827

The cumulative of municipality solid waste quantities in Sulaymaniyah city for the specific year (2032) was determined through applying the two different methods of calculating the expected future of municipality solid waste quantities produced in Sulaymaniyah city as illustrated in (Table 4.2) and (Table 4.3).

The municipality solid waste cumulative quantity, which determined applying second method, was used to determine estimate the necessary area site for candidate landfill sites in Sulaymaniyah city.

The population in year (2032) was resulted through applied (Equation 3.2) ($P(2032) = P(2016)*(1+r)^t$), depended on the current population in 2016 with the growth rate of population 2.99%. Therefore, the Sulaymaniyah city population in (2032) will be 1,126,168 people.

Resulted from using the method one, the municipality solid waste average generation rate for the last eight years (2009 to 2016) in Sulaymaniyah city was (0.8065) kg / (capita* day) resulted through applied (Equation 3.1)

$$(GRWA)=(Q_{S(average)} \text{ x } 1000)/(P_{(average)} \text{ x } 365)$$

$$(GRWA)=\frac{187016.5 \text{ x } 1000}{635254 \text{ x } 365} = 0.8065 \text{ kg/(capita* Day) for last eight years.}$$

(Equation 3.2) was applied to determine the whole population for all years from 2016 till 2032.

$$P_{(t)} = P_0(1+r)^{(t)}$$

$$P_{2032} = P_{2016}(1+r)^{(t)}$$

$$P_{2032} = 702882(1+0.0299)^{16} = 1126168 \text{ capita.}$$

The produced municipality solid waste quantities (Qs.) for the year (2032) in Sulaymaniyah city was 331513 tons respectively using (Equation 3.3).

$$Q_s(2032) = \frac{(0.8065 \text{ X } 1126168 \text{ X } 365)}{1000} = 331513 \text{ tons (for year 2032).}$$

The Qs(c) municipality solid waste cumulative quantity from 2020 to 2032 in Sulaymaniyah city will be 3,633,366 tons correspondingly applying (Equation 3.4)

$$Q_{S.(2032)} = Q_{s.(2032)} + Q_{s.(2031)} = 331513 + 3301853 = 3633366 \text{ tonnes.}$$

Table 4.2. Show the method one for computing the municipality solid waste quantity in 2032 and the municipality solid waste cumulative quantity for year 2020-2032 in Sulaymaniyah city.

Average population 2009-2016	**Average quantity of municipality solid waste 2009-2016 (tonnes)**	**(GRWA) kg/ (capita* Day).**	**quantity of municipality solid waste $Q_{s(c)}$(tonnes) for 2032**	**Cumulative quantity of municipality solid waste Q_s(tonnes) for 2020-2032**
635,254	187,016	0.8065	331,513	3,633,366

GRWA: The municipality solid waste average generation rate for the last eight years 2009 to 2016.

As a resulted form method two, the (GRW) municipality solid waste generation rate for 2016 in Sulaymaniyah city was (0.86) kg/ (capita* day) Applying (Equation 3.6) as follows.

$$(\mathrm{GRW}) = (\mathrm{Q_s}.)/(\mathrm{P})$$

$$\mathrm{GRW}=\frac{220635 \times 1000}{702882 \times 365} = 0.86 \text{ (kg)/(capita* Day) for year 2016.}$$

(Equation 3.2) was applied to determine the population for all years 2016 until 2032.

$$\mathrm{P_{(t)}} = \mathrm{P_0}(1 + \mathrm{r})^{(\mathrm{t})}$$

$$\mathrm{P_{2032}} = \mathrm{P_{2016}}(1 + \mathrm{r})^{(\mathrm{t})}$$

$$\mathrm{P_{2032}} = 702882(1 + 0.0299)^{16} = 1126168 \text{ capita}.$$

The increment rate of generation rate of municipality solid waste for Sulaymaniyah Governorate (RGI) was (0.013) kg / (capita*day). Determined This value depended on the values of municipality of solid waste generation rate, which were 0.69 in the year of 2009 and (0.794) kg/ (capita* day) for the year of 2016 applying (Equation 3.7).

$$\mathrm{RGI} = \frac{(\mathrm{GRW_{2016}} - \mathrm{GRW_{2009}})}{(\mathrm{n})} = \frac{0.86 - 0.7538}{8} = 0.013 \text{ (kg) / (capita.* day).}$$

The municipality solid waste generation rate for all years from 2020 to 2032 was resulted depended on the (Equation 3.9).

$$(\mathrm{GRSW}) = \mathrm{GRW_{(year)}}(1 + \mathrm{RGI})^{\mathrm{n}}$$

$$\mathrm{GRSW_{2032}} = \mathrm{GRW_{(2016)}}(1 + \mathrm{RGI})^{16} = 0.86(1 + 0.013)^{16} = 1.057 \text{ (kg)/(capita * day)}$$

Municipality solid waste generation rate for year 2032.

The produced municipality solid waste quantity (Qs) for the year 2032 in Sulaymaniyah city will be 434656 tons respectively using (Equation 3.11).

$$Q_s(\text{for specific year}) = P_t \text{ X GRSW X } \left(\frac{365}{1000}\right)$$

$$Q_s(2032) = \left(\frac{1126168 \text{ x } 1.057 \text{ x } 365}{1000}\right) = 434656$$

The municipality solid waste cumulative quantity Qs(c) for the years 2020 to 2032 in Sulaymaniyah city will be 4437189 tons using (Equation 3.12)

$$Q_{(S)C} = Q_{(s)ct} + Q_{(s)ct-1}$$

$$Q_{S(2032)} = Q_{s(2032)} + Q_{s(2031)} = 434656 + 4002533 = 4437189 \text{ tonnes}$$

Table 4.3. Show the method two for computing municipality solid waste quantity in 2032 and the municipality solid waste cumulative quantity for year 2020-2032 for the Sulaymaniyah city.

Present population P_o(2016)	**Future population P_o(2032)**	**Quantity of municipality solid waste(ton) in 2016**	**Municipality solid waste Generation rate (GRW) kg/(capita*day) in 2016**	**Quantity of solid waste Q_S (ton) in 2032**	**Municipality solid waste Cumulative Quantity $Q_{(S)c}$ (ton) for 2020-2032**
702,882	1126168	220635	0.86	434656	4437189

The average projections generations of municipality solid waste in the year 2025 will be: 0.6 - 1 kg/(capita· day) in low income countries, 0.8 - 1.5 in medium-income countries and 1.1 - 4.5 kg/(capita* day) in the country which are in high-income countries Hoornweg and Bhada-Tata (2012). These data are expected depended on several sources (United Nations World Urbanization Prospects, 2007; Annual Energy Outlook IEA, 2005; World Development Indicators, 2005). In the current research, the expected generation of municipality solid waste in 2025 in Sulaymaniyah is 0.966 kg/(capita*day) which will be in a medium-income municipality. (Table 4.4) illustration the municipality solid waste quantity, the municipality solid waste cumulative quantity and population in Sulaymaniyah city using method one, whilst (Tables 4.5) illustration the same information but using method two.

Table 4.4. Show population and municipality solid waste quantity and the municipality solid waste cumulative quantity in Sulaymaniyah city using method one.

year	population	Total solid waste (tonnes)	Cumulative solid waste (tonnes)	Municipality solid waste generation rate kg/(captia*day
p(2020)	790793	232788	232788	0.807
p(2021)	814437	239748	472536	0.807
p(2022)	838789	*246916	**719452	0.807
p(2023)	863869	254299	973751	0.807
p(2024)	889699	261903	1235654	0.807
p(2025)	916301	269734	1505388	0.807
p(2026)	943698	277799	1783186	0.807
p(2027)	971914	286105	2069291	0.807
p(2028)	1000975	294659	2363951	0.807
p(2029)	1030904	303470	2667421	0.807
p(2030)	1061728	312544	2979964	0.807
p(2031)	1093474	321889	3301853	0.807
p(2032)	1126168	331513	3633366	0.807

*(838789X0.807X365)/1000=246916 tonnes
** (246916+472536)= 719452 tonnes

As illustrated in this method, the average municipality solid waste of generation rate was deli berated as a stable value. It was determined using (equation 3.1) depended on the average population (P) during (2009-2016) and municipality solid waste average of quantity (Qs) during 2009-2016. Thus, the municipality solid waste generation rate were fixed during (2020-2032), the municipality solid waste generation rate in Sulaymaniyah city was (0.807) kg / (capita*day) correspondingly.

Table 4.5. Show quantity of municipality solid waste and municipality solid waste cumulative quantity of in Sulaymaniyah city and its population by using method two.

years	people	Total municipality solid waste (tonnes)	Cumulative municipality solid waste (tonnes)	Municipality Solid waste generation rate kg/(captia*day)
p(2020)	790793	261392	261392	0.906
p(2021)	814437	272707	534099	0.917
p(2022)	838789	*284512	**818611	***0.929
p(2023)	863869	296828	1115439	0.941
p(2024)	889699	309678	1425117	0.954
p(2025)	916301	323083	1748200	0.966
p(2026)	943698	337069	2085269	0.979
p(2027)	971914	351660	2436929	0.991
p(2028)	1000975	366883	2803812	1.004
p(2029)	1030904	382765	3186577	1.017
p(2030)	1061728	399334	3585912	1.030
p(2031)	1093474	416621	4002533	1.044
p(2032)	1126168	434656	4437189	1.057

$*\left(\frac{838789X(0.86)X(1.013)^{6}X(365)}{1000}\right) = 284{,}512\text{tonnes}$

**(284512+534099)= 818611tonnes

$***\left(\frac{(284512X1000)}{(838789X365)}\right) = 0.929\ (\text{kg})/(\text{capita} * \text{day})$

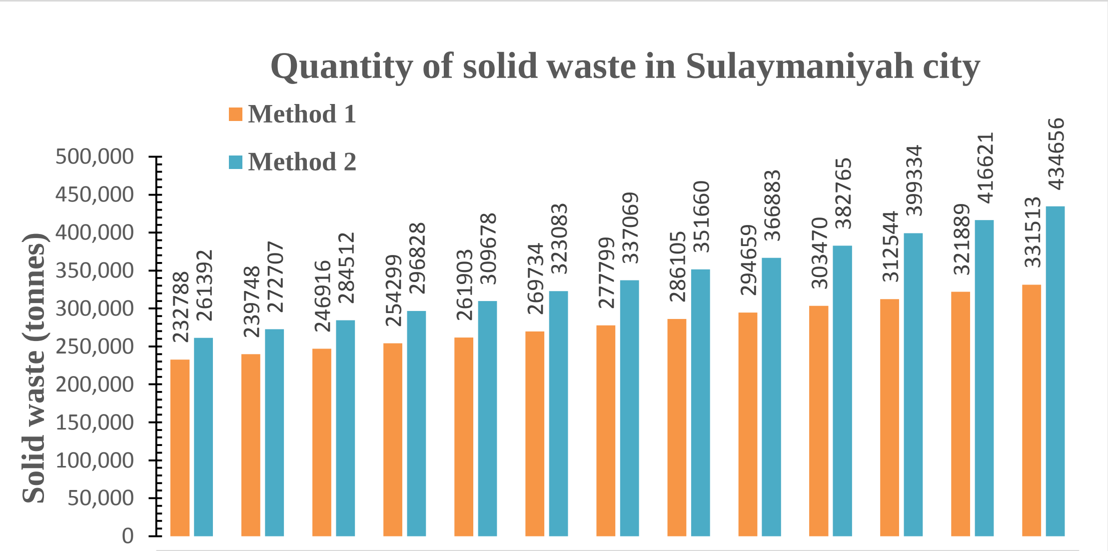
The rate of generation of municipality solid waste for specific year was determined depended on current municipality solid waste generation rate for year 2016 obtained from Equation (3.6), growth rate of municipality solid waste generation rate of each year 0.013 kg / (capita* day) obtained from Equation (3.7). The municipality solid waste volume for the year 2032 and the cumulative municipality solid waste volume during 2020 to 2032 in Sulaymaniyah city was determined depending on the following information:

The information data which was summarized and mentioned in (Tables 4.2 and Table 4.3). The density of municipality solid waste is 455 kg m^3 in Sulaymaniyah city according to information of (Sulaymaniyah Directory of Municipality). These values are obtained through divided quantity municipality solid waste by the municipality solid waste density as illustrated in Table 4.6.

Table 4.6. Show the volume municipality solid waste in 2032 and the cumulative of municipality solid waste volume during 2020 to 2032 in Sulaymaniyah city.

Volume of waste in 2032 (m^3)	**Cumulative waste volume from 2020to2032 (m^3)**
Method1	Method1
728600	7985419
Method2	Method2
955288	9752063

Figures (4.1) Show the expected of municipality solid waste quantities in Sulaymaniyah city from 2020 to 2032, while Figures (4.2) show the municipality solid waste cumulative in Sulaymaniyah city starting from 2020 until 2032.



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Method 1	232788	239748	246916	254299	261903	269734	277799	286105	294659	303470	312544	321889	331513
Method 2	261392	272707	284512	296828	309678	323083	337069	351660	366883	382765	399334	416621	434656

Figure 4.1. Show municipality solid waste quantities (tonnes) during 2020-2032 in Sulaymaniyah city.

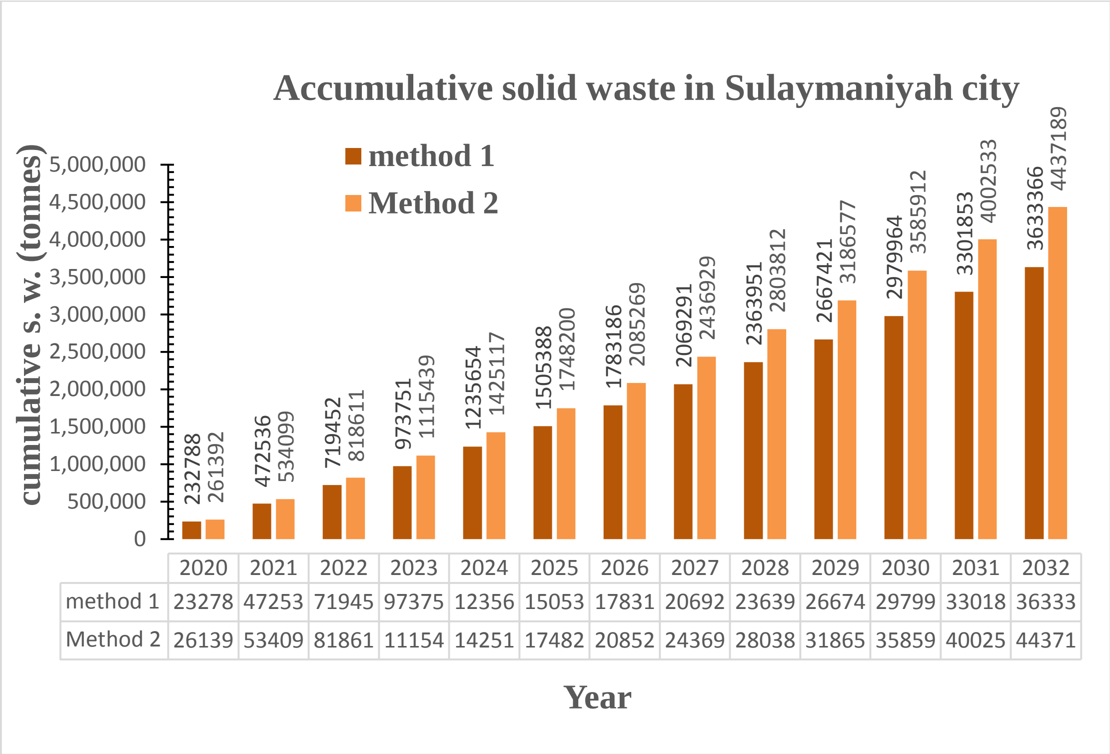


Figure 4.2. Show cumulative quantities of municipality solid waste between the years 2020-2032 in Sulaymaniyah city.

Possible Landfill Height = 4m. The necessary area of candidate landfill site to collect the cumulative generated of municipality solid waste quantity during 2020 - 2032 is 1.996 km^2 Sulaymaniyah city based on the calculated using method one. Based on the method two, the area of candidate landfill site in Sulaymaniyah city is 2.438 km^2 correspondingly.

In the research, were selected two candidate landfill sites between the several sites placed within the most suitable category, each sites were given a site number one and site number two. In the research, The Site one has an area of 4.4829 km2, whilst the Site two has an area of 5.4943 km2. The location of Site one is at Latitude 35° 27' 10" N, and Longitude 45° 31' 35" E, whilst location of Site two is at Latitude 35° 28' 48" N, and Longitude 45° 18' 56" E. (Figure 4.3). The summary of required landfill areas and candidate landfill sites areas, and the locations as illustrated in (Table 4.7.)

Table 4.7. Show required landfill area, location and areas of candidate landfill sites in Sulaymaniyah city.

City	Required area(Km^2)	Area of candidate sites Site	Area (Km^2)	Location
Sulaymaniyah	Method 1 1.996	No.1	4.4829	Latitude 35° 27' 10" N Longitude 45° 31' 35" E
	Method 2 2.438	No.2	5.4943	Latitude 35° 28' 48" N Longitude 45° 18' 56" E

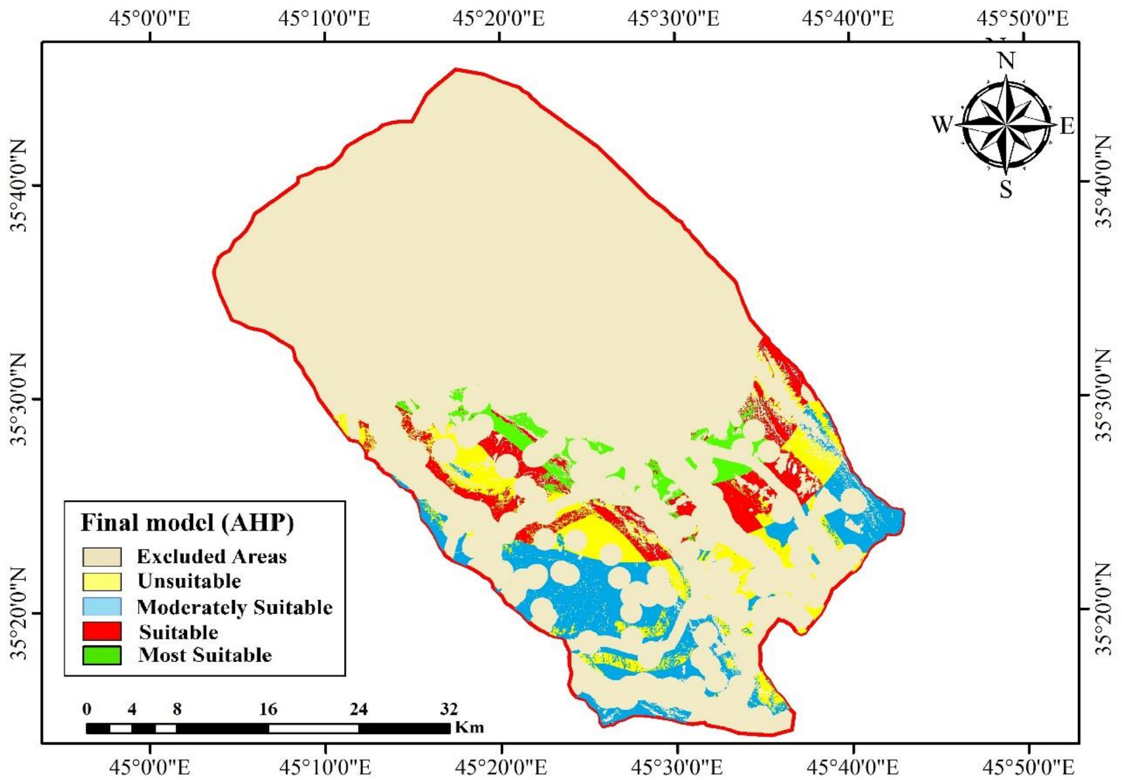


Figure 4.3. Landfill suitability map of Sulaymaniyah city.

These sites were been checked through using the Bing map and Google earth to know that these landfill sites selected were suitable for Sulaymaniyah city (Figure 4.4)

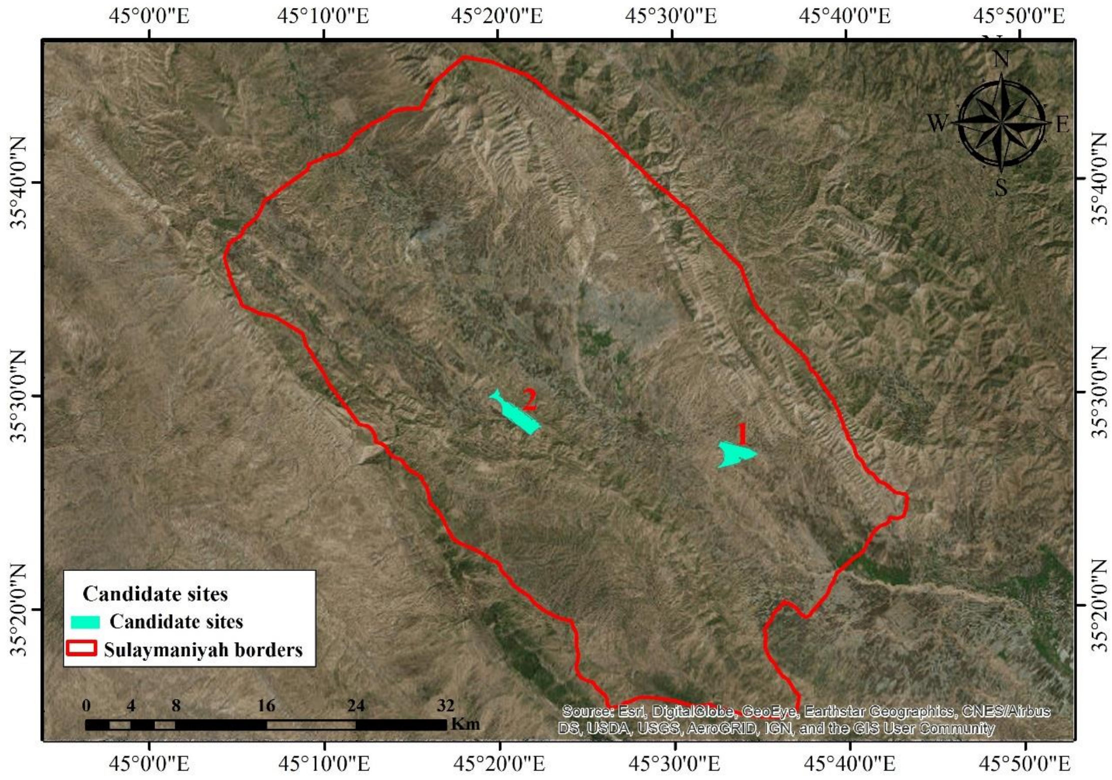


Figure 4.4. The candidate landfill sites for Sulaymaniyah city.

5. CONCLUSION

Solid waste dumping system in the Sulaymaniyah city is an open dumping system. As a result there are environmental and social problems resulted from the dumping site. Several of the sources of solid wastes are from household, market, agriculture and commercial area and putted in an open dumping site, which may contain the components of leachable toxic that are hazardous to the human health and to the environment, at the dumping site without any separation and treatment. Moreover, the dumping site is very close to the main road, and it has a low distance to Tnjaro river and surrounded by residential houses hence resulted in Societal problems like health danger and environmental problems.

This research looks to embrace the best methodology for the landfill site selection within the research area, and in addition taking into considering the artificial, natural and environmental factors. The GIS is considered as a powerful tool in helping a municipality waste disposal site selection over its capability to deal with a large volume of data from a various of sources. The analytical hierarchical process AHP method can be useful to solve each complex problem in a various fields of various practical conditions. The analytical hierarchical process AHP method uses the pairwise comparison to the making comparison matrix to derive weights of each criteria. Therefore, the combination between the AHP and the GIS may assistance decision makers in the express assessment consequently solving several problem, such as suitable landfill site selection. Utilizing the results of past and exhibit work, the conclusions can stated as following:

1. Open dumping of solid waste prompts numerous environmental issues, containing ground water and surface water pollution, rat, creepy crawly and ailment invasion and others. Municipality solid waste is discarded on the consistent schedule in Sulaymaniyah city by burning. This prompts numerous populace medical issue in the city and towns close them.

2. The value of solid waste generation rate 0.794 kg/ (capita· day) in 2016 based on information of Sulaymaniyah Directory of Municipality with the expected growth rate of generation rate (0.013) kg/ (capita· day) /year.

3. In Sulaymaniyah city, the generation rate values in 2016 were (0.8065 and 0.86) kg/ (capita· day) depended on the results from the method one and method two correspondingly.

4. Municipality solid waste Generation rate Comparison with other researches puts Sulaymaniyah city as a middle-income city.

5. Depended on expected rate of increment in the rate of generation 1.3 kg/ (capita*day) / year, the rate of generation in Sulaymaniyah city will be (1.057) kg/ (capita* day) in 2032 correspondingly.

6. The municipality solid waste generated quantities in Sulaymaniyah city was 230186 tons respectively when inhabitants of Sulaymaniyah city was 723898 inhabitants in 2017 correspondingly. With the growth rate of population (2.99%) the whole population in Sulaymaniyah city will be 1126168 citizens in 2032. Table 5.1 displays the expected municipality solid waste to be produced in 2032 and the cumulative of municipality solid waste quantity for the years between 2020- 2032 in the method one and method two correspondingly.

Table 5.1. Show generated municipality solid waste in 2032 and the generated cumulative quantity of municipality solid waste during 2020-2032 in the method one and method two

City	$P_{(2017)}$	$P_{(2032)}$	Waste generation rate (kg/(capita. day))	Quantity of waste generated in 2032 (tonnes)	Cumulative quantity of solid waste 2020-2032 (tonnes)
Sulaymaniyah	723898	1126168	Method 1	Method 1	Method 1
			0.8065	331513	3633366
			Method 2	Method 2	Method 2
			0.86	434656	4437189

7. The amount produced of municipality solid waste in 2032 and the accumulative amount of municipality solid waste 2020-2032 through method two were implemented to compute the landfill required area, where the rate was derived from the method two has resulted higher than the rate obtained from method one . Depended on these result, the landfill required area for Sulaymaniyah city is 2.438 Km^2.

8. In this research, sixteen map layers used in the overlaying process within GIS and analysis in instruction to find the most suitable landfill site in Sulaymaniyah city. These map layers are water wells, slope, rivers, elevation, type of soil, land use, agricultural land use, military site, roads, power lines, industrial area, airport, urban centers, archaeological sites, wind direction and villages. The used criteria in this study are not stable factors since they can be different from site to site and these criteria can be diverse appropriately the analysis process.

9. The weights of each criteria were determined utilizing AHP technique, and after that the sub-criteria weights of all criterion were calculated depended on the opinions of experts and produced supporting literature previously. To make the landfill map of suitability index, in map algebra in GIS in special analysis tool applied the WLC method for all criteria. After the analysis process, in the most suitable category on the latest map in Sulaymaniyah city, two suitable sites for landfill were selected between many sites. checked the appropriate for landfill selected sites on the Google earth.

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APPENDIX

APPENDIX-EXTENDED TURKISH SUMMARY
(GENİŞLETİLMİŞ TURKÇE ÖZET)

GELECEK KATI ATIK ÜRETİM MİKTARININ HESAPLANMASI VE CBS VE ÇOK ÖLÇÜTLÜ KARAR VERME ANALİZİ İLE ÇÖP DEPOLAMA ALANI YER SEÇİMİ SÜLAYMANİYE / IRAK ÖRNEĞİ

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Tez Danışmanı: Doç. Dr. Serkan KEMEÇ
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1. ÖZET

Irak'ın kuzey kesiminde yer alan Süleymaniye şehri yaklaşık 1893 km2'lik bir alanı kapsamaktadır ve 2016 yılında yapılan nüfus sayımına göre nüfusu 70.2883 kişidir. Uygun bir çöp depolama alanı seçimi, çeşitli faktörlere ve düzenlemelere bağlı olan karmaşık bir süreçtir. alışmanın amacı, kent için depolama sahasının seçilmesiydi. Uygun yer seçimi için çalışmada on altı kriter kullanılmıştır. Bu kriterler; şehir merkezleri, toprak tipi, yükseklik, arkeolojik alanlar, yollar, eğim, askeri üs, su kuyuları ve nehirler gibi su toplama alanları, köyler gibi yerleşim alanları, tarım arazisi kullanımı, ulaşım araçları yollar, elektrik hattı, sanayi siteleri ve havaalanı sahalarıdır. Çalışmada gerekli coğrafi işlemler, mekansal verileri yönetme ve analiz etme konusunda yüksek bir potansiyele sahip olan Coğrafi Bilgi Sistemi (CBS) ortamında uygulanmıştır. Ayrıca, Çok Ölçütlü Karar Verme Analizi (ÇÖKVA) metotlarından Analitik Hiyerarşi Prosesi (AHP) yöntemi, ikili karşılaştırma matrisi kullanılmıştır (ölçütlerin ağırlıklarını belirlemede). Aday depolama alanları arasından uygun yer seçimi için Ağırlıklı Doğrusal Kombinasyon (ADK) yöntemi kullanılmıştır. Çalışma sonucunda, aday alanların tamamının benimsenen bilimsel ve çevresel kriterleri depolama sahası için yerine getirme durumlarına göre yapılan değerlendirme sonucunda Süleymaniye kenti için iki uygun aday alan seçilmiştir. Seçilen noktaların alansal büyüklükleri Süleymaniye şehrinde 2020 yılından 2032 yılına kadar katı atıkların depolaması için yeterlidir.

2. GİRİŞ

Katı atıklar, insan faaliyetlerinin gaz ve sıvı formda olmayan ürünleri olarak tanımlanabilir. Bu atıkların kaynağı esas olarak hane halkı, inşaat ve belediyelerden gelmektedir. Belediye katı atıklarının üretimi ve yönetimi, hem gelişmekte olan hem de gelişmiş ülkelerin karşılaştığı sorunlardır. Belediye katı atıklarının üretilmesi artan bir halk sağlığı ve çevre sorunudur.

Depolama sahası, belediye katı atık yönetim sistemleri ile ilgili karmaşık bir süreçtir çünkü belediye ve merkezi yönetim fonlarına, artan çevresel farkındalığa, halk sağlığı kaygılarına ve nüfus yoğunluğuna bağlıdır.

2016 yılında 702882 kişi ile Süleymaniye şehrinde belediye katı atık üretimi günlük kişi başı ortalama 0,86 kg‘den 220635 ton katı atık üretmiştir.

Bu araştırma, depolama sahası yer seçiminde CBS ve bir ÇÖKVA yöntemi olan AHP kullanılmıştır, çünkü bu yöntemler düzenli depolama sahası seçimi sorununun çözümü için güçlü, entegre araçlar sunmaktadır.

3. KAYNAK BİLDİRİŞLERİ

Uygun depolama sahası seçimi, sağlam atık bertarafı ve çevrenin korunması, halk sağlığı ve yaşam kalitesinin temel adımıdır. Doğru bir şekilde uygulandığı takdirde, depolama sürecindeki ve sonraki adımların çoğunu belirler. Rahatsızlıklara ve olumsuz uzun vadeli etkilere karşı önlem almalıdır. Örneğin, iyi seçilmiş bir depolama sahası, genellikle karmaşık olmayan, tasarımı kolaylaştıracak ve geniş bir kaplama malzemesi sağlayacaktır. çevresel ve kamuya açık bir işlemi makul bir maliyetle kolaylaştıracak.

Depolama sahasında çok sayıda kriter dikkate alınmalı ve her birine ayrı ağırlık verilmelidir. Bu kriterler, doğal fiziksel özelliklerin yanı sıra sosyoekonomik, ekolojik, çevresel, sosyo-politik ve arazi kullanım faktörlerini içerir.

Bu çalışmanın ayrıntılı hedefleri şunlardır:

1. Süleymaniye şehrinde katı atık yönetiminin durumu ve şehrinde mevcut atık bertaraf tesislerinin kapsamlı bir değerlendirmesi.

2. Çalışma alanındaki miktarların ve katı atıkların kümülatif miktarlarının gelecekteki beklentilerinin tahmin edilmesi.

3. Beklenen gelecek katı atık miktarının hesaplanması (iki farklı yöntemle)

4. Süleymaniye şehrinde düzenli depolama sahası için gerekli alanın tahmini.

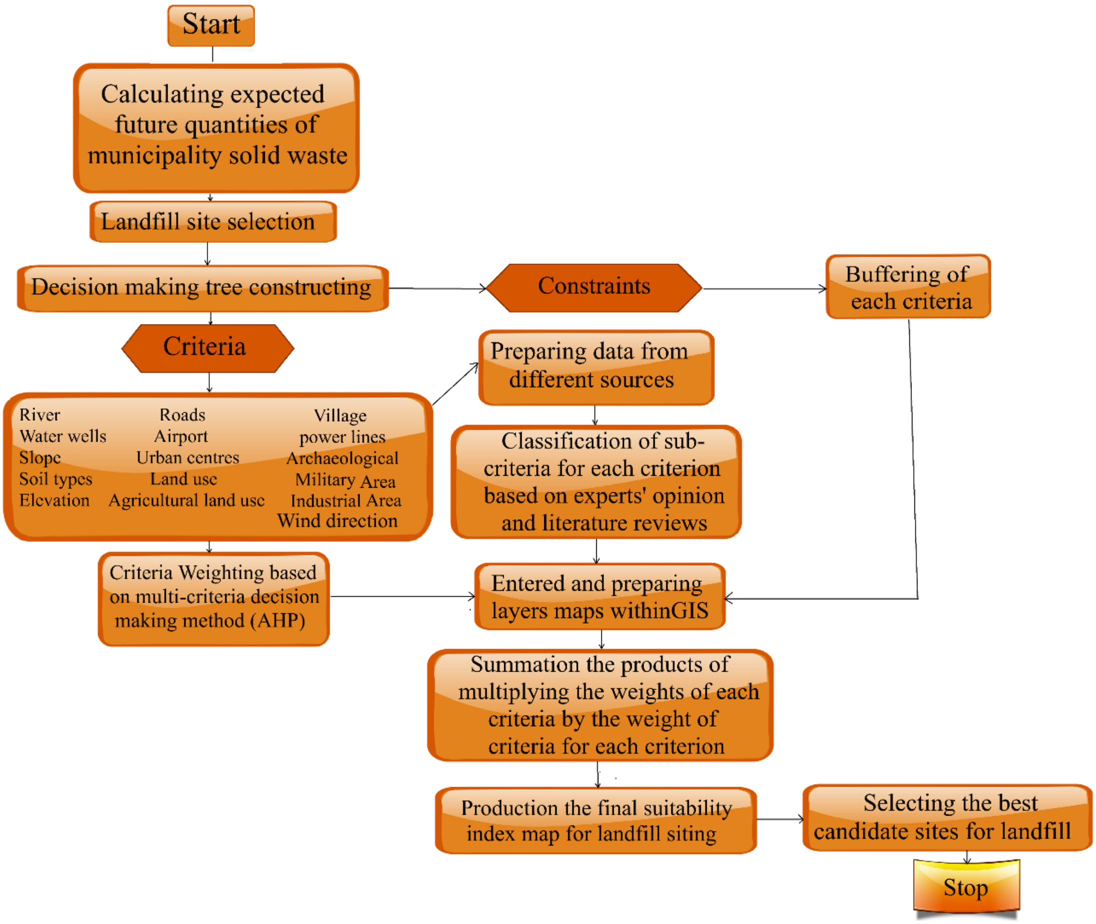
5. Süleymaniye şehrinde uluslararası kriterlere uygun depolama sahası yer seçini için değerlendirme kriterlerinin ve ağırlıklarının belirlenemesi. Gelecekte bu kriterler, planlamacıların ve karar vericilerin yeni bir çöplük alanı seçerken Irak'taki diğer benzer alanlarda uygulamalarını sağlamak için bir referans oluşturacaktır.

6. Seçilen kriterlere göre CBS ve AHP yöntemi ile Süleymaniye şehri örneğinde kullanılarak düzenli depolama alanı için uygun bir alanın belirlenmesi.

4. MATERYAL VE YÖNTEM

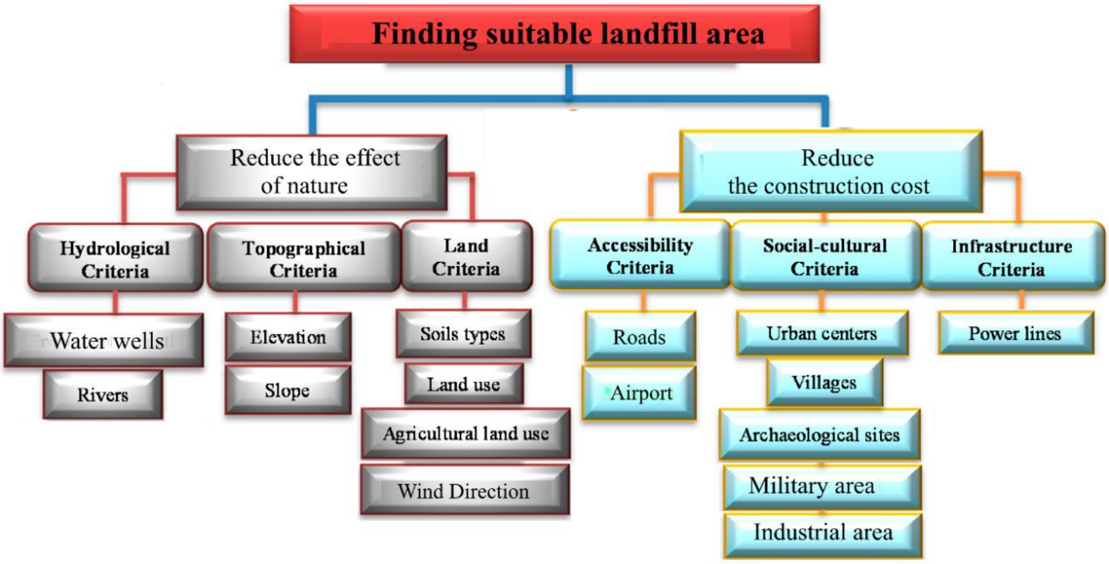
Uygun bir depolama sahası seçimi için, özel analiz araçları ile CBS ile birlikte AHP, onaltı kriterin haritalarının hazırlanması için kullanılmıştır. Bu yöntemin başlıca avantajları, niteliksel ve niceliksel kriterler kullanma olanağıdır. Mevcut kriterlere göre depolama sahası seçiminin temel adımları aşağıdaki adımlardan oluşmaktadır Şekil 3.1:

- Gelecekte beklenen katı atık miktarları ve depolama alanı gereksinimi.
- Depolama sahası seçiminde karar verme ağacının oluşturulması.
- Mevcut çalışma için uygun kriterlerin seçimi.
- Her bir kriter için uygun alanların belirlenmesi.
- CBS ile tüm kriterler için veri tabanının hazırlanması.
- Kriter ağırlıklarının, uzmanların, literatürün, çevresel ve bilimsel gereksinimlerin görüşlerine dayanarak belirlenmesi.
- AHP yöntemi kullanarak kriter ağırlıklarının belirlenmesi.
- Aday sahaların haritalanması.
- Süleymaniye bölgesinde 2020 yılından 2032 yılına kadar üretilen kümülatif katı atık miktarına yetecek aday alanın yeri ve büyüklüğünün belirlenmesi.



Şekil 3.1. Depolama sahası için model akış şeması.

Karar ağacının birincil amacı, bir depolama sahası için uygun bir yer seçimidir. Şekil 3.2. üç seviyeli karar probleminin hiyerarşik yapısını göstermektedir. İlk aşamada değerlendirme kriterleri iki hedef altında gruplanmıştır - doğal çevresel faktörler ve yapay faktörler. İkinci seviyede, hidrolojik, arazi, topografik, altyapı, erişilebilirlik ve sosyal-kültürel kriterler olmak üzere altı kategori vardır. Üçüncü seviye, bu çalışmada kullanılan onaltı katmanından oluşan alt kriterleri içermektedir.



Şekil 3.2. Uygun depolama sahasının seçimi için geliştirilen karar sürecinin ağaç diyagramı.

5. BULGULAR VE TARTIŞMA

Her bir kriterin ağırlıklarının belirlenmesinde AHP tekniği uygulanmış ve her bir alt grubun ağırlıklandırılmasının oluşturulmasında uzmanların önerileri, bu konuyla ilgili önceki araştırmalar ve mevcut araştırmaya bağlı farklı temel ve edinilebilir veriler kullanılmıştır. Her kriterler mevcut araştırmada Süleymaniye şehrinde çöp sahası seçimi konusu ile ele alınmak için CBS'deki muhtemel lokasyonlar analizi üzerine 16 katman yerleştirilmiştir. CBS ortamında, özel uygunluk aracında “Harita Cebiri”, depolama sahası uygunluk sitesi endeksinin nihai haritasını oluşturmak için uygulanmıştır. Aday depolama sahasının seçilen sahalarının uygunluğuna bağlı olarak nihai haritayı beş grupda tekrar sınıflanmıştır. Bu grup tipleri, “hariç tutulan yerler”, “uygun olmayan yerler”, “nispeten uygun yerler”, “uygun yerler” ve “en uygun yerler”’i içerir. "Hariç tutulan yerler" bölümü Süleymaniye şehrinde bulunan kent merkezlerini, köyleri, havalimanlarını, nehirleri, tarihi yerleri, rüzgar yönünü yüksek öğrenim kurumlarını ve sanayi bölgelerini kapsamaktadır. Bu yerler değerlendirfmede sıfır (0) değerine almıştır. Tablo 4.1, tekrar sınıflama sonrası her sınıf tipinin alanını ve çalışma alanına oranını göstermektedir.

Tablo 4.1. Süleymaniye şehrinin arazi dolgu uygunluk indeksi gruplarının oranlarını ve bölgelerini gösterir.

Nu.	Grup Türü Alanı	Süleymaniye şehri Alan Km^2	Alan Büyüklüğü (%)
1	hariç tutulan yerler	1553.5613	82.462
2	uygun olmayan yerler	127.6491	6.775
3	nispeten uygun yerler	95.9670	5.093
4	uygun yerler	72.3672	3.841
5	en uygun yerler	34.4192	1.827

Süleymaniye şehrinde, 2032 yılı için katı atık miktarlarının toplamı, Süleymaniye şehrinde üretilmesi beklenen katı atık miktarlarının hesaplanması için iki farklı yöntem kullanılmıştır (Tablo 4.2) ve (Tablo 4.3).

Tablo 4.2. Süleymaniye şehrinde 2020-2032 yıllarında katı atık miktarını ve katı atık kümülatif miktarını hesaplamak için kullanılacak birinci yöntem.

Ortalama nüfus 2009-2016	Ortalama belediye katı atık miktarı 2009-2016 (ton)	(GRWA) kg / (kişi * Gün)	belediye katı atık miktarı $Q_{s(c)}$(tons) 2032	Kümülatif belediye katı atık miktarı Q_s(tons) for 2020-2032
635,254	187,016	0.8065	331,513	3,633,366

Tablo 4.2. Süleymaniye şehrinde 2020-2032 yıllarında katı atık miktarını ve katı atık kümülatif miktarını hesaplamak için kullanılacak ikinci yöntem.

Mevcut nüfus P_o (2016)	Gelecek nüfus P_o(2032)	2016'de belediye katı atık miktarı (ton)	Belediyeden katı atık oluşumu Generation oranı (GRW) kg / (kişi başı * gün) 2016	2032'de katı atık miktarı Q_S (ton)	Belediye katı atığı Kümülatif Miktar$Q_{(S)c}$ (ton) 2020-2032
702,882	1126168	220635	0.86	434656	4437189

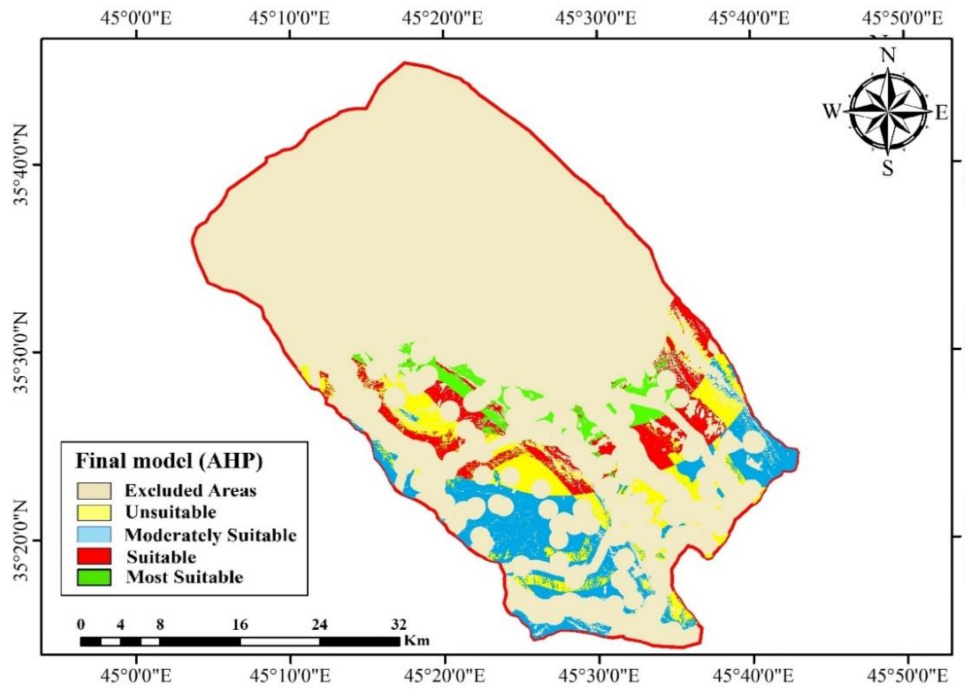
Süleymaniye şehrinde belediye katı atık yoğunluğu 455 kg m3'tür. Bu değerler, Tablo 4.6'da gösterildiği gibi katı atık yoğunluğu ile bölünerek elde edilmektedir.

Tablo 4.6. Süleymaniye şehrinde 2032 yılında katı atık miktarını ve 2020 ile 2032 yılları arasında katı atık hacmini göstermektedir.

Atık hacmi 2032'de (m^3)	**2020 - 2032 arası kümülatif atık hacmi (m^3)**
Yöntem 1	Yöntem 1
728600	7985419
Yöntem 2	Yöntem 2
955288	9752063

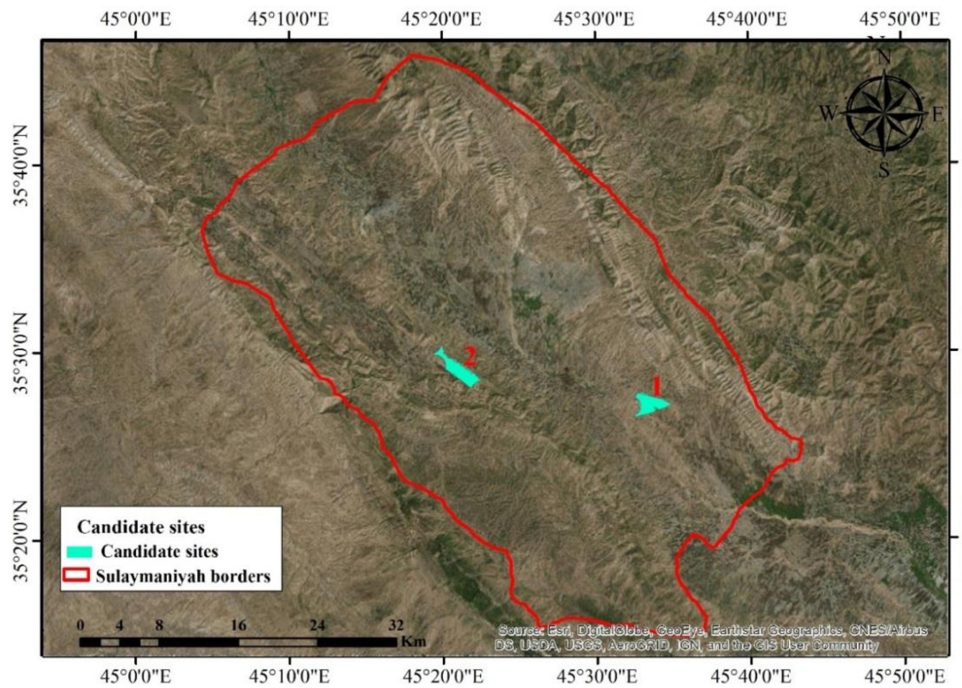
Mümkün olan Depolama Yüksekliği = 4m. 2020 - 2032 yılları arasında katı atık miktarının kümülatif olarak toplanması için gerekli olan aday depolama sahası alanı birinci yönteme göre 1.996 km2'dir. İkinci yönteme göre ise aday çöp sahası alanı 2.438 km2 olarak hesaplanmaktadır.

Aday depolama alanları arasından uygun yer seçimi için Ağırlıklı Doğrusal Kombinasyon (ADK) yöntemi kullanılmıştır. Çalışma sonucunda, aday alanların tamamının benimsenen bilimsel ve çevresel kriterleri depolama sahası için yerine getirme durumlarına göre yapılan değerlendirme sonucunda Süleymaniye kenti için iki uygun aday alan tespit edilmiştir. Seçilen alanların ikiside Süleymaniye şehrinin güneyinde yer almakta ve bu alanlardan bir tanesi 4.4829 km2 diğeri ise 5.4943 km2 alansal büyüklüğe sahiptir. 1.yerin konumu Enlem 35 ° 27 '10 ''N, Boylam 45 ° 31' 35'' E, 2.yerin konumu Enlem 35 ° 28 '48 ''N ve Boylam 45 ° 18' 56'' E dır. Şekil 4.3 seçilen noktaların her ikisinin de alansal büyüklükleri Süleymaniye şehrinde 2020 yılından 2032 yılına kadar katı atıkların depolaması için yeterlidir.



Şekil 4.3. Süleymaniye şehrinin çöp uygunluğu haritası.

Seçilen bu çöplük sahalarının Süleymaniye şehri için uygunluğu Bing ve Google Earth görüntüleri kullanılarak görsel olarak kontrol edilmiştir (Şekil 4.4).



Şekil 4.4. Süleymaniye şehri için aday depolama sahaları.

6. SONUÇ

Çalışmada tespit edilen sonuçlar aşağıdaki gibidir;

1. 2016 yılındaki kümülatif atık üretim oranı 0.86 kg / (kişi / gün) değeri, Sülaymaniye şehrinin tahmini üretim oranı (1.3) kg / (kişi / yıl) / yıl büyüme oranına dayanarak verilmiştir.
2. Süleymaniye şehrinde 2016 yılında üretim oranı değerleri, yöntem 1 ve yöntem 2'den elde edilen sonuçlara bağlı olarak (0.8065 ve 0.86) kg / (kişi / gün) olmuştur.
3. Süleymaniye şehrinde belediyeye ait katı atık miktarı sırasıyla 230186 ton iken, Süleymaniye şehrinde 2017 yılında 723898 nüfuslu iken, buna karşılık 2017 yılında 721898 kişi yaşamaktadır. Nüfus artış hızı (% 2,99) ile Süleymaniye ilindeki nüfusun tamamı 2032 yılında 1126168 vatandaş olacaktır. 2020- 2032 yılları arasında belediyeye ait katı atık miktarı kümülatif yöntem 1 ve 2. yöntem (3633366 ve 4437189) tondur.
4. 2032 yılında belediye katı atıklarının ve 2. yöntemle 2020-2032 belediye katı atık miktarının belediye katı atıklarından elde edilen miktar, dolgu yöntemini hesaplamak için uygulanmış olup, bu yöntemden iki yöntemden elde edilen oran, yöntemden elde edilen orandan daha yüksek olmuştur. Bu sonuca bağlı olarak Süleymaniye şehri için gerekli depolama alanı 2.438 km2'dir.
5. Bu araştırmada, Süleymaniye şehrinde en uygun depolama sahasını bulmak için CBS içerisindeki kaplama işleminde on altı harita katmanı kullanılmıştır. Bu harita katmanları; su kuyuları, eğim, nehirler, yükseklik, toprak tipi, arazi kullanımı, tarımsal arazi kullanımı, askeri alan, yollar, elektrik hatları, sanayi bölgesi, havaalanı, kentsel merkezler, arkeolojik alanlar, rüzgar yönü ve köylerdir. Bu çalışmada kullanılan kriterler, sahadan sahaya farklı olabileceğinden ve bu kriterler uygun bir şekilde analiz sürecinden farklı olabileceğinden, kararlı faktörler değildir.
6. Her kriterin ağırlıkları AHP tekniği kullanılarak belirlendi ve bundan sonra tüm kriterlerin alt kriterleri ağırlıkları uzman görüşlerine göre hesaplandı ve daha önce destekleyici literatür oluşturdu. Uygunluk indeksinin düzenli harita haritasını yapmak için, GIS'deki harita cebirinde özel analiz aracında tüm kriterler için WLC yöntemi uygulanmıştır After the analysis process, in the most suitable category on the latest map in Sulaymaniyah city, Birçok saha arasında düzenli depolama için iki uygun alan seçilmiştir. Google dünyasında seçilen depolama alanları için uygunluğu işaretliyedi.

Yürütülen Yüksek Lisans Tezi kapsamında belirlenen amaç doğrultusunda elde edilen sonuçlar ve çıktılar öncelikle uygulama alanı olan Süleymaniye City / IRAQ için doğrudan katkıya sahiptir. Kentte yaşanan güncel bir sorunun bilimsel yöntemler ışığında değerlendirilmesi ve bu değerlendirme sonrası geliştirilen çözüm alanları kentin gelecekte çöp depolama konusunda önemli çözüm önerileri getirmektedir. Konu ve uygulama aynı zamanda benzer büyüklüklerdeki bölge şehirleri içinde örnek teşkil edebilecek, önerilen yöntem çöp depolama alanı yanı sıra benzer mekansal yer seçim problemlerinin çözümünde alternatif araç niteliğinde olacaktır.

CURRICULUM VITAE

Luqman Hamad ABDALLA, was from sub-district of Hajiawa, Sulaymaniyah province of Iraq. He was born on December 17, 1985 in Bastasten. He was completed elementary, and High Schools in Hajiawa, after that I went to Koya city to begin the undergraduate admission process at the University of Koya in the College of Engineering during the years (2006-2010), and He was awarded a Bachelor’s degree in Geotechnical Engineering. He got admission in Van Yuzuncu Yil University in Turkey at February of 2016 and began postgraduate studies at Institute of Applied Science in Faculty of Engineering in the Department of Civil Engineering during the years (2016-2018).

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