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EVALUATION OF SOLID WATE LANDFILL POTENTIAL SITE USING GIS BASED MULTI CRITERIA EVALUATION METHOD:

A CASE STUDY OF ADDIS ABABA.

BY

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ADDIS ABABA, ETHIOPIA

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Acronyms

AACMA	Addis Ababa Cleansing Management Agency
AAWSA	Addis Ababa Water and Sewerage Authority.
AHP	Analytical Hierarchy Processes.
AU	Africa Union.
CR	Consistency Ratio.
CSA	Central Statistical Authority.
DEM	Digital Elevation Model.
ECA	Economic Commission for Africa.
EGSA	Ethiopia Geologic Survey Agency.
EMA	Ethiopia Mapping Authority.
EPA	Environmental Protection Authority.
ERCA	Ethiopia Road construction Authority
FAO	Food Agricultural Organization
GCPs	Ground Control Points.
GDM	Green Development Mechanism.
GIS	Geographic Information System.
GPS	Global Positioning System.
HHW	House-Hold Waste.
MSW	Municipal Solid Waste.
MCDM	Multi-Criteria Decision Making.
MCE	Multi-Criteria Evaluation.
MUDCI	Ministry of Urban Development and Construction Institute.
SMCDA	Spatial Multi-Criteria Decision Analysis.
UN	United Nation.
UNICEF	United Nation International Children Education Fund
UNDP	United Nation Development Program.
UNEP	United Nation Environment Program.
UNFCCC	United Nation Framework Convention on Climate Change.
UNHCR	United Nation Higher Commission Rehabilitation.
WLC	Weighted Linear Combination.

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ABSTRACT

Solid waste management system is the most difficult task that many countries, both developing and developed, are facing. In Addis Ababa, the last two decades of development activities, such as construction of roads and other buildings are established. As a result of development activities together with fast population growth, larger amounts of household, street, institutional and industrial solid wastes are generated and the city is facing problem in their improper disposal. Landfill is a common solution for the final disposal of Municipal Solid Waste (MSW) in Addis Ababa, but it is an extremely difficult task to accomplish because the site selection process depends on different factors and regulations. Appropriate landfill site is a systematic manner for solid waste management. Since unsuccessful landfill siting brought negative effect in both public health and the environment it raises strong public opposition. In this study, selected sites for an appropriate landfill area in Addis Ababa City are determined by using the integration of Geographic Information Systems (GIS) with Multi-Criteria Evaluation (MCE) and Remote sensing (RS) technology. Arc GIS software was used as a tool since it is able to perform suitability analysis using MCE analysis. To identify appropriate landfill areas in Addis Ababa region, 11 input map layers including ground water depth, borehole , surface water, airport, fault, road network (to set this criteria the new rail way lines were taken under consideration), distance from residential areas, land use/land cover, permeability of soil and land slope were used. A final map was generated which identifies regions showing suitability for the location of the landfill site. The finding of this study shows that 8.1% of the study area is most suitable, 0.9% is suitable, 13.7% is moderately suitable, 66.4% is poorly suitable and 10.9% is Unsuitable. At the end of the analyses, thirteen (13) selected sites are determined. Among all ,the most preferable solid waste landfill site located in the eastern part at Bole sub-city woreda10 its local place is called" Bole Arabssa".

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Solid wastes could be defined as non-liquid products which produced from human activities, regarded as being useless (Babayemi and Dauda, 2009). Poor solid waste management are the problems facing both developing and developed countries. The management of solid waste in Africa is often weak mainly due to lack of appropriate planning and poor technology.

One of the most important causes of environmental pollution is certainly an inadequate waste management. Factors that have primarily influenced this problem area are: ever increasing amount of municipal solid waste remaining at large space, increasing amount and types of hazardous waste, as well as lack of awareness on the importance of acting promptly in this field. Particular problems in waste management occur in developing countries, where the awareness of the importance of environmental protection has yet achieved an optimum level and where economic or political reasons, professional guidelines associated with waste management are not observed. Problems emerge either due to lack of trained personnel, inadequate waste management infrastructure, financial constraints in the establishment of a modern waste management system, lack of awareness about solid waste management among people, no selection of appropriate space for landfill developments (UNEP, 2005). Great problems of waste management in Addis Ababa are caused by increasing amount of waste has not sanitary landfills which full filled the international standards. Waste management is a complex activity which helps to control the entire inadequate waste management system under the umbrella of legislation and appropriate institutional organization such as Addis Ababa City Cleansing Management Agency (AACCMA), "Denbmaskeber "Office (which regulates all illegal activities in the city, including illegal dumping of solid waste), Environmental protection Authority etc. The present paper is placed on spatial planning as an inevitable instrument for strategic waste management, and points out the importance of spatial aspect of landfill site selection as importance components in the waste management planning process.

1.2. Statement of the problem

The population of Addis Ababa is growing at an alarming rate. Moreover, in the last two decades, development activities, such as construction of roads, residential houses, offices, industries, commercial etc. are established. As a result of fast population growth and development activities, larger amounts of household, street, institutional and industrial solid wastes are generated and the city is facing problem in their improper disposal. It has direct effect in polluting environments. Consequently, public health is also highly affected by the uncontrolled solid waste generation and insufficient disposal.

All the waste collected from households, streets and different institutes hauled and dumped in the exiting landfill site, which is located in the South Western part of the city, particularly in Kolfe-Keranyo sub-city, Woreda 6. This dumping site is located about 13 kilometer away from the city center (Piassa). Its coordinates is 8° 58′57″N and38°41′18″E. The landfill called 'Rappi' has been in use for the last forty years. The total area is 30.5 hectare, of which 26 hectare are occupied by the waste.

It is known that Addis Ababa is a city which has not engineered land fill sites and other efficient means of waste disposal strategies. Even the existing land fill "koshe (Rappi)" is becoming out of its capacity.

Landfill activities started in Addis Ababa in 1960E.C and the volume of waste on the site was estimated very approximately to 3 million m^3, so it is insufficient to execute activities. In addition to this poor maintenance of it, results in difficult conditions of operation. Covering the waste with soil is not done, as a result, human and animal scavengers are roaming the site. Recent abnormalities (probably fire) have led to the evacuation of pupils to a nearby school after gas and smoke threatened to intoxicate them. This type of crisis is not unusual and is a patent sign of inefficient management (kassahun, Personal communication) . These include:

1. Access roads near to the site are full of waste, so it creates traffic congestion.
2. When access roads are totally blocked by waste a large operation is launched to landscape and the odor expands throughout the area.

Generally the main issue with the "Koshe (Rappi)"site lies in its urban location, which is dangerous for the city in general. The recent financial efforts of the municipality to extend its lifespan through spreading and compacting waste, the site remains and will remain an increasing risk for the neighboring population, for example the odor is nuisance for the nearby dwellers ,they may goes up to death, or it causes environmental pollution.

In this regard, researchers carried out a number of studies on the case of landfill site selection in Ethiopia and the World at large. For instance, a study like GIS and remote sensing based solid waste landfill site selection was conducted at Behar Dar, Ethiopia (Asrat, 2005), and landfill site selection based on GIS, at Middle East technical university (Basak, 2002). But these studies could not saw the future situation of the country and not gave much emphasis on the gas produced due to solid waste which is called methane that affects the environment, specially a study which were conducted in Ethiopia could not consider the present and future reconstruction situation of the country and the modern and huge compactor track which have used for transporting wastes from transfer station to landfill like in primate city of a country. Therefore, this study will fill the gap and seek to validate the suitable site selection and the solutions of proper waste management by considering the sustainable development of the city.

1.3. Objectives of the Study

1.3.1. General Objective

- The general objective of this study was to determine suitable site for solid waste landfill through integrating spatial multi- criteria decision making (SMCDM), GIS and Remote sensing that are environmentally sound, socially acceptable and economically feasible.

1.3.2. Specific Objectives

- To produce thematic maps showing potential sites that are environmentally sound, economically feasible and socially acceptable for solid waste landfill.
- To identify the environmental, social and economic factors that are necessary for selecting landfill and prepare their suitability maps by using in Arc GIS, Remote sensing in order to solve MCDM systems based on analytic hierarchy process (AHP).
- To prioritize and rank the identified suitable landfill sites according to their suitability analysis.

1.4. Research Questions

- What are the different environmental, social and economic factors that are necessary for selecting landfill and prepare their suitability maps?
- What is the appearance of land use/land cover of Addis Ababa city from solid waste landfill suitability point of views?
- Where the potential sites that are environmentally sound, economically feasible and socially acceptable for solid waste landfill are located and how they are ranked?

1.5. Scope of the Study

This study was carried out at Addis Ababa city on solid waste landfill site selection on the basis of GIS and Remote Sensing. In this research, the important site selection criteria were considered mainly based on the experience of Ministry of Urban Development and Construction Institute

(MUDCI). The research was limited in Addis Ababa, because the city suffers from inadequate infrastructure and deficient services to guarantee sanitation and waste management for the level of development expected by its status of diplomatic Capital of Africa. The level of coverage of refuse collection is estimated at around 65%, while the remainder of the waste ends up on streets, public places, water courses and open spaces around a city (Addis Ababa City Cleansing Management Agency annual report, 2013).

1.6. Significance of the Study

Addis Ababa is a city which hasn't well designed land fill sites and other efficient means of waste disposal strategies, even the current dumping site "koshe (Rappi)" has already out of its capacity. The noise of the existing dump site is a very serious problem not only for the nearby dwellers and users of the nearby road but also for all dwellers of the city administration directly or indirectly. The result of this study is expected to add practical information to the body of knowledge in the area of waste management, enlighten the policy makers, the local leaders and the local people about the problems existing on the open land disposal site, help in drafting appropriate policies. Moreover, the findings of this study may act as a base line and provide information for future scholars and researchers regarding the causes of poor waste management.

1.7. Organization of the Research Paper

This paper has been organized into five chapters. Chapter 1: the introduction part including background and justification, statements of the problem, objectives, research questions, scope, significance and conceptual frame works of the study, Chapter 2: Review of related literature, Chapter 3: Materials and methods and Chapter 4: result and relevant discussion. A brief summary followed by some feasible suggestions are forwarded in the concluding chapter.

The study utilized both descriptive and quantitative methods. The descriptive mode has been used for expressing criteria of landfill site selection with their respective value in the study area and the status of the situation, as it exists at the time of the study and to describe the present conditions, events or systems based on the result of the research. This study was concerned with the relationships between practices that exist and processes that are ongoing, effects that are being felt or trends that are developing about poor waste management and how to select landfill site in Addis Ababa.

CHAPTER TWO

2. LITERATURE REVIEW

Here, attempts were made to review some relevant literature to help the understanding of poor waste management and sanitary landfill site selection. The researcher acknowledged the fact that there are some literatures on sanitary landfill in Ethiopia and in other countries of the world. Most of the literatures were reviewed from different sources such as text books, websites, Newspapers and journals. In this section, the main purpose is to review issues related to waste management that has been investigated by other researchers, in order to gain more insights into the subject under the study and avoid duplications of efforts in this area**.**

2.1. Definition of Waste

Waste is a substance at a given times and places which, in its actual structure and state, is not useful to the owner. It is also commonly referred to as rubbish, trash, garbage, refuse, effluents and "unwanted or unusable materials" (Zake, 2007).

2.2. Waste Management

The term 'Waste Management' includes all issues and processes associated with the generation, processing, and disposal of all categories of wastes produced by human activities or related to human existence; it includes, therefore, the stages of production and minimization, collection, handling and transportation, reuse and recycling, and treatment and disposal of all such wastes (Zake, 2007).

Despite the fact that waste handling and transport varies from region to region, country to country, there are waste management concepts that are universally accepted and implemented. These are the waste hierarchy or the 3Rs (reduce, reuse and recycle). According to National Environmental Authority (NEPA, 2000), solid waste management encompasses generation, collection, transportation and disposal of wastes. Authorities have the responsibility to ensure safe, reliable and cost effective removal and disposal of solid waste.

Waste management is undertaken mainly to minimize the effect of wastes on resource loss and conservation, health, environment, costs, and aesthetics. It incurs financial and social and other costs. The term includes the issue of 'regulation' of the various aspects of management of wastes. Waste management is the process by which products and by-products, generated by business and industry, are collected, stored, transported, treated, disposed off, recycled or reused in an effort to reduce their effects on human health. Therefore, a properly managed waste; that is well collected, sorted, recycled, treated, disposed off hygienically, will promote a clean and safe environment to live in(EPA, 2008).

2.2.1. Solid Waste Management

Solid waste management is defined as the process of controlling of waste generation, storage, collection, transporting and disposal of solid wastes. Integrated solid waste management includes the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals (Tchobanoglous and Kreith, 2002). Current solid waste management technologies can be summarized as: source reduction, recycling, waste transformation and landfilling

2.2.2. Solid Waste Management System in Addis Ababa

2.2.2.1. Primary Collection

Municipal waste collection is handled in three ways. These are

- Door-to-door collection for households along accessible streets.
- Block collection for clients (large hotels, enterprises, and institutions) requesting the municipality to provide them with refuse containers.
- Container system, which expects residents to carry and dump their waste in 8 m^3 refuse containers, placed supposedly accessible sites. In practice 85% of the wastes are collected through the containers system.

Primary collection to container is done by micro and small enterprises, or associations (cooperatives). The associations have formal agreement with sub-city administrations to collect waste from households or business establishments and dump them in designated containers (Mitku, personnel communication).

Waste on street and public areas are collected by street Sweepers. According to “Overview of Addis Ababa City Solid Waste Management System (2013)”, number of operators of micro enterprises were 5673, but number of enterprise associations were 570. Actually, associations were organized to pre-collect waste from household. Holds Waste (HHW) is collected once or twice per week. According to a survey of 2007 of the International Labor Organization, client of primary collectors are household for 89 %. But this survey shows that they collect private clinics, restaurant, hotels, and shops.

Frequency

Waste collection frequencies are various. Some micro enterprises report collecting waste 6 times a week, but in most instances, HHW is collected twice a week.

Plate 1: Micro enterprise's waste collection equipment

Source: Field survey, Jan. 2015 photo taken by author

Most micro enterprises use wheel barrows or carts pushed by two collectors. The capacity of a cart is about 200 kg. Some micro-enterprises use pick-up trucks or even compactor trucks on larger avenues. Once the cart is full, it is emptied at the skip point. A skip point is a rudimentary "transfer station", where carts are emptied into $8m^3$ metal bins. Each skip point may consist of one or several bins. (Mitku, personal communication).

2.2.2.2. Secondary collection

Secondary collection is entirely devolved to sub-cities and under the responsibility of Weredas.

Secondary Waste Collection Equipment

There are 183 trucks for collecting solid waste from skip points to the dump site and 512 steel containers of $8\ m^3$ of which 100 are used by commercial, industrial and institutional clients (Yaregal , personal communication).

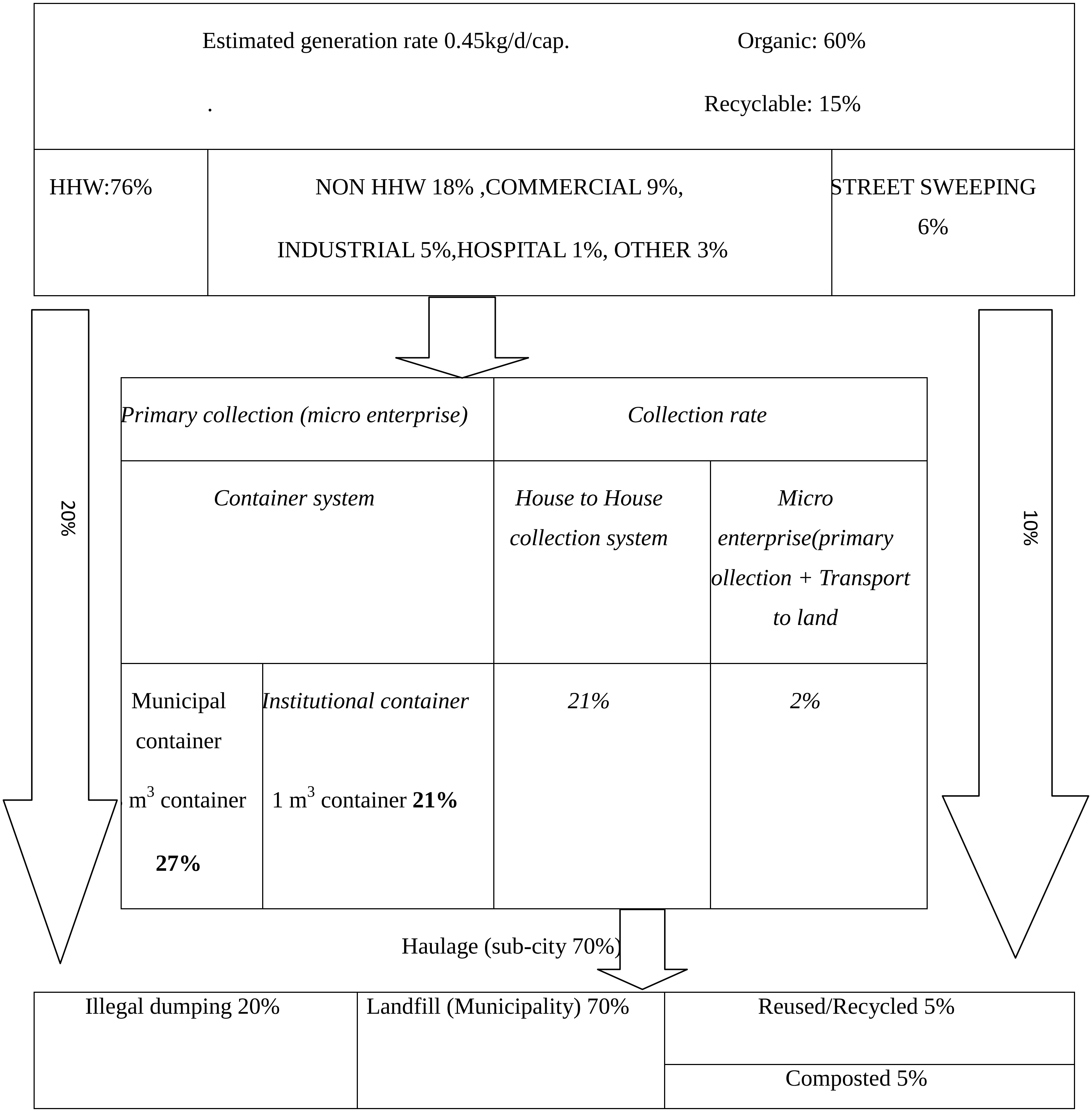
Plate 2 : Secondary waste collection equipment.

Source: Field survey, Jan. 2015 photo taken by author.

Maintenance is obviously an issue for sub-cities which have no facility for maintenance and depend on private companies for parts and labor.

Quantities

Since no weighbridge is installed, the quantity of HHW transported daily is drawn from the volume arriving at the landfill.



Graph 1: Waste Generation Rate, *Source :Addis Ababa City Cleansing Management Agency annual report, 2104.*

2.2.3. Causes of Poor Waste Management in Addis Ababa

There are a number of causes of poor waste management in Addis Ababa and these include lack of equipments used for waste collection and lack of enough awareness programs on Waste management (Addis Ababa City Municipality ,2010)

2.2.4. International and National Policy Context/Frameworks for Waste Management

There are various laws that regulate the generation and management of solid wastes in Uganda, and internationally, although some are out dated. They include:

Agenda 21 – program of action for sustainable development. This Agenda is a comprehensive blue print for global actions for sustainable development into the 21stcentury. Ethiopia being a member of the United Nations is a party and accountable to Agenda 21. It commits governments, United Nations organizations, development agencies, nongovernmental organizations and independent sector groups to implement programs and actions which would halt and reverse the negative impact of human behavior on the physical environment and promote environmentally sustainable economic development in all countries. In the context of waste management, Agenda 21 presents Section 21 on environmentally sound management of solid waste, particularly highlighting program areas and associated strategies to be implemented by all countries to ensure proper waste management (Agenda 21, 1994).

Biodegradable solid waste decomposition generates greenhouse gases such as Methane which contributes to depletion of the thin layer of Ozone that protects the earth from direct heat from the sun. Loss of this layer means that sun's rays will hit directly on the earth resulting in temperature raises which influence climate on the earth and these changes manifest as global warming, prolonged droughts, and unreliable rainfall. However, Ethiopia is signatory to the United Nations Framework Convention on Climate Change (UNFCCC) of the Kyoto Protocol. The UNFCCC provides an international framework for mitigating causes of climate change and its effects at both international and national level. For instance, the Green Development Mechanism (GDM) makes it possible for companies or countries that have to reduce emissions under the Kyoto Protocol to invest in emission reduction projects in developing countries (Agenda 21, 1994). There is a need for exploring opportunities in the Green development mechanism to utilize the accumulated solid waste managed under the land fill at Koshe (Repi) for energy production.

2.3. Landfilling

It is the process by which the solid wastes that cannot be recycled nor further used; the residual matter remaining after the recovery facility and after the recovery of conversion products and energy is placed in a landfill. Landfilling includes monitoring of the incoming waste stream, placement and the compaction of waste, and installation of landfill environmental monitoring and control facilities. There are some terms used in landfilling of solid waste which are defined in the following section (Tchobanoglous, 1993).

Landfills are the physical facilities used for the disposal of residual solid wastes in the surface soils of the earth. In the past, the term sanitary landfill is used to describe a landfill in which the waste placed in the landfill was covered at the end of each day. Today, sanitary landfill refers to an engineered facility for the municipal solid waste designed and operated to minimize public health and environmental impacts (Allen, 2001).

Leachate is known as the liquid collected at the bottom of the landfill. In general, leachate is a result of the percolation of precipitation, uncontrolled runoff, and irrigation water into the landfill, the water initially contained in the waste and also infiltrating groundwater. It contains a variety of chemical constituents derived from the solubilization of the materials deposited in the landfill and from the products of the chemical and biochemical reactions occurring within landfill (EPA, 1995).

Landfill gas is the mixture of gases within a landfill. It mainly consists of methane (CH_4) and carbon dioxide (CO_2). These are the principal products of the anaerobic decomposition of the biodegradable organic fraction of the municipal solid waste in the landfill. Other components of landfill gas include atmospheric nitrogen and oxygen, ammonia, and trace organic compounds (Sumathi *et al*., 2007).

Landfill liners are materials (both natural and manufactured) used to line the bottom area and below grade sides of a landfill. Liners usually consist of layers of compacted clay and geo-membrane material designed to prevent migration of landfill leachate and landfill gas (Tchobanoglous, 2002).

Landfill control facilities include liners, landfill leachate collection and extraction systems, landfill gas collection and extraction systems, and daily and final cover layers (EPA, 1995).

2.4. Landfill Site Selection

The major goal of the landfill site selection process is to ensure that the disposal facility is located at the best location possible with little negative impacts to the environment or to the population. For a sanitary landfill siting, a substantial evaluation process is needed to identify the best available disposal location which meets the requirements of government regulations and best minimizes economic, environmental, health, and social costs. Evaluation processes or methodologies are structured to make the best use of available information and to ensure that the results obtained are reproducible so that outcomes can be verified and defended (Siddiqui, 1996).

The use of maps containing various landfill selection criteria is a simple and common method to determine landfill suitability. Maps containing data such as geology, soils, water quality, and floodplains are superimposed on one another to determine a final map of landfill suitability. Low technology techniques consist of the use of manual overlays and hand drawn maps in order to determine landfill suitability. Simple overlays can be produced with tracing paper or acetate/made product. However, low technology cartographic procedures are time consuming and the accuracy of the final products depends on the cartographer (Schwartz, 2001).

Geographic Information Systems (GIS) are ideal for preliminary site selection studies because it can manage large volumes of spatially distributed data from a variety of sources and efficiently store, retrieve, analyze and display information (Siddiqui, 1996). Using GIS for site selection not only increases the objectivity and flexibility but also ensures that a large amount of spatial data can be processed in a short time. Relatively easy presentations of GIS siting results are also one of the advantages (Kao and Lin, 1996).

2.4.1. Criteria for Landfill Siting

There are a number of criteria for landfill site selection. These are environmental, political, financial and economic, hydrologic and hydro-geologic, topographical, geological, availability of construction materials, built up area, climatic, and difficult infrastructural provisions (Baban and Flannagan,1998).

Landfills may not be constructed on sites within a distance of less than 1000 m from settlements according to regulation on solid waste control in Turkey (Waste Disposal Directive of Turkey, 2004). Only if there are natural barriers like hills, trees or forests between the landfill site and the settlements, the construction of landfills in a distance less than 1000 m to settlements may be allowed after approval of the NEA and upon order of the highest local authority and the concerned municipality (Baban and Flannagan,1998).

The site selection process must consider climate characteristics such as prevailing winds, precipitation, temperature and evapotranspiration variations because they are related to odors, dust, leachate generation, blowing litter, cover soil and erosion (Wilson, 1977).

2.4.2. Landfill Siting and the Potential Application of GIS

Siting a sanitary landfill requires an extensive evaluation process in order to identify the optimum available disposal location. The evaluation of a new waste disposal site is a complicated process and it takes into considerations parameters such as distance to roads, habitation, key infrastructure elements and the propensity of soil to leachate contaminants. Therefore, it must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them (Sumathi *et al*., 2007). GIS has been found to play a significant role in the domain of siting of waste disposal sites. Many factors must be incorporated into landfill siting decisions and GIS is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. The integration of GIS and Analytical Hierarchy Process (AHP) is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and AHP supplies consistent ranking of the potential landfill areas based on a variety of criteria. AHP is a systematic decision making approach first developed by Saaty; 1980. This technique provides a means of subdividing the problem into a hierarchic of sub-sets that can be more easily comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values that are ranked on a numerical scale (Bhushan and Rai, 2004).

2.5. Spatial Multi-Criteria Decision Analysis (SMCDA)

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, 1997). In general, SMCDA 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 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 distinguish acceptable from unacceptable possibilities (Dodgson, 2000).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographic location

Addis Ababa was founded in1886, which is located in the Central part of Ethiopia covering an area extent of about 527km^2, with an average elevation of 2600m above sea level. Its geographic location is between 460000m and490000mEand, 975000m and 1005000mE.

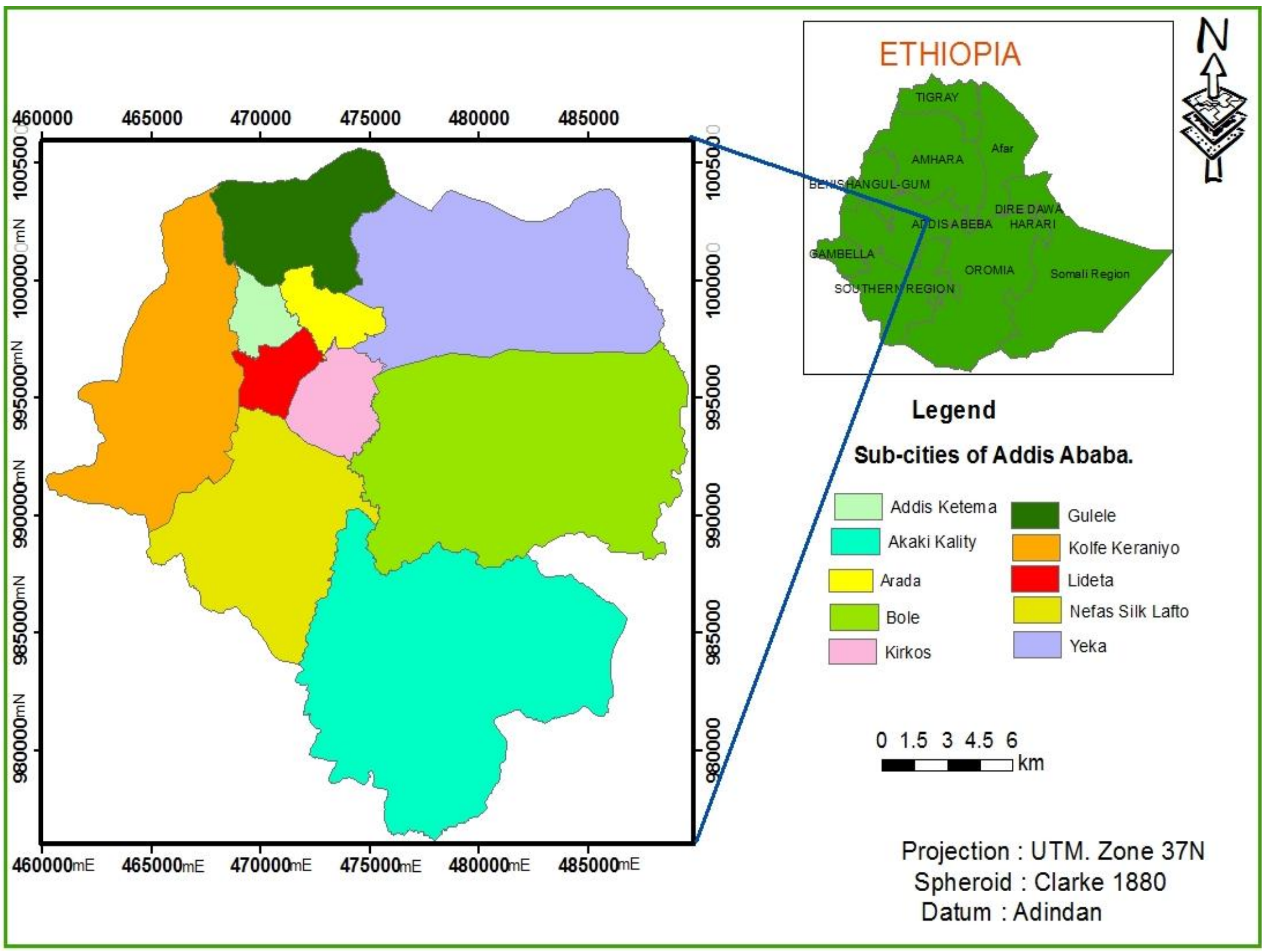


Figure 1 : Location map of the study area.

Source: Central Statistical Authority, 2014 Shapefile data.

3.1.2. Topography and Drainage

The altitude of Addis Ababa varies between 2000 m at Akaki to 3200 m at Intoto. The prominent landforms around and in Addis Ababa are the Intoto ridge in the northern side, the flat and undulating landform inside the city and young volcanic mountains of Wechacha (3350 m.a.s.l), Furi (2850m asl) and Yerer (3099 m.a.s.l) lying in the west, southwest, and southeast respectively. The two major rivers flowing in the city are Kebena (Big Akakaki) on the east and Small Akaki on the west. These two rivers drain to the south and join Lake Abasamueal which is out of Addis Ababa (Tsegaye, 1995).

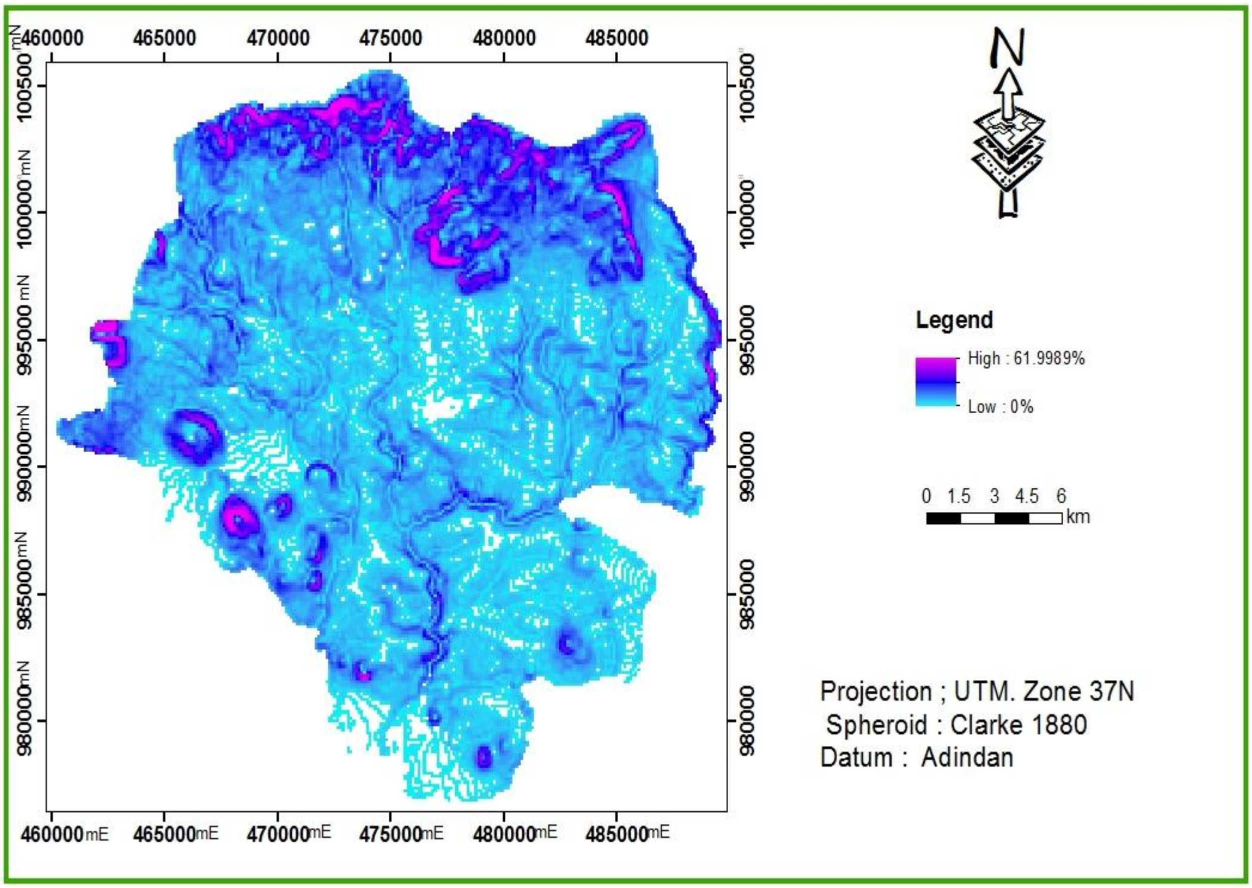


Figure 2 : Slope map of Addis Ababa.

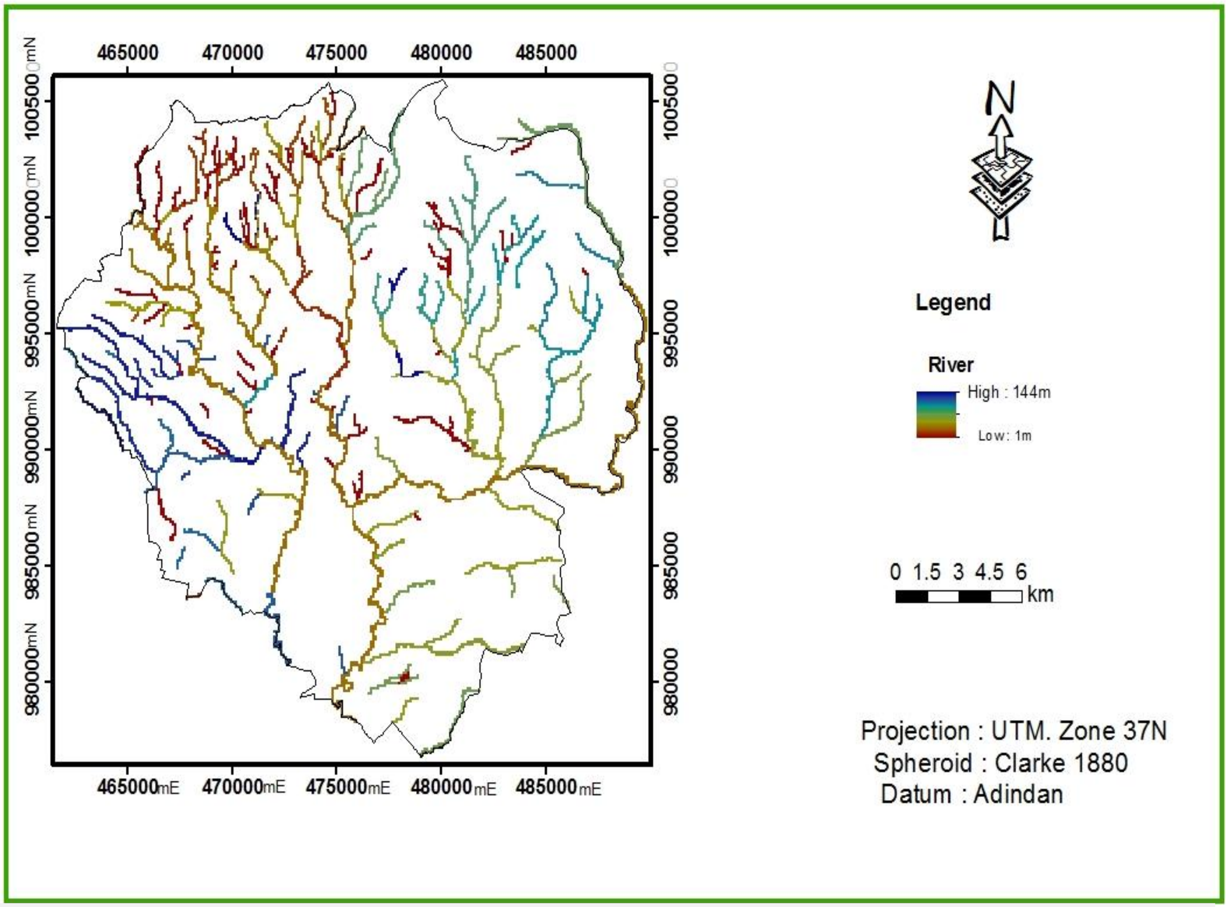


Figure 3 :Drainage map of Addis Ababa.

3.1.3. Population

The first census in Addis Ababa was made by the Central Statistics Authority (CSA) of Ethiopia in 1984. The population of the city was estimated to 1.4 million inhabitants (Central Statistical Authority, 1984). According to the last census of CSA 2007 the population of Addis Ababa was enumerated as 2.7 million inhabitants. The population nearly doubled in 23 years (Central Statistical Authority, 2007). Since Addis Ababa is a center of national and international organizations, the current estimated population is over 3 million inhabitants, with annual demographic growth rate of 2.6% (Central Statistical Authority, 2008).

Table1: Population of Addis Ababa sub-cities in 2007 and projection in 2013

Sub city	Population in 2007	Area (km^2)	Density/km^2	Population in 2013 (Projection)	Area (km^2)	Density 2013 (inhabitant /km^2)
Akakikality	162529	113.15	1436	184184	113.15	1628
Nifass Silk Lafto	316108	63.59	49710	358286	63.59	5634
KolfeKeraniyo	428654	65.1	6585	485854	65.1	7463
Gulele	267381	32.73	2169	303166	32.73	9263
Lideta	201613	12.4	16259	228501	12.4	18428
Cherkos	220991	16.26	13591	250615	16.26	15413
Arada	212009	11.56	18340.	239590	11.56	20726
Addis Ketema	255092	8.98	28407	289286	8.98	32215
Yeka	346484	82.3	4210	392702	82.3	4772
Bole	308714	120.93	2553	350029	120.93	2895
AACA	2719575	527	5160	3 103374	527	5889

Source: Central Statistical Authority, 2007.

Population Growth

According to different sources , demographic growth rate ranges between 2.1%, (Federal Democratic Republic of Ethiopia Population Census Commission, 2008), 3% (UN-Habitat 2007) and 3.8% (UN Data 2012),and 6% (understanding waste management in mega city- experiences in Addis Ababa, Ethiopia by Nicolas Escalante, Agata Rymkiewiez, Martin Kranert, 2010) to 9% (UN habitat 2006). The methodology of calculation for population projected in these studies is not detailed in the articles found. Only global projections for the city are mentioned. CSA of Ethiopia considers that the growth between 2007 and 2013 was of 2.1%.

Table 2: Distribution of population in each sub-city and growth rate

Sub-cities	2013	2025	2035	Annual growth rate
Akakikality	205345	390 404	666 866	5.5%
Nifass silk Lafto	358286	673467	1 139 523	5.4%
Kolfekeraniyo	485854	843073	1 334 543	4.7%
Gulele	303166	474293	688 685	3.8%
Lideta	228501	286405	345 718	1.9%
Cherkos	250615	310442	371 071	1.8%
Arada	239590	257421	273 290	0.6%
Addis Ketma	289286	296306	302 286	0.2%
Yeka	392702	643391	970 848	4.2%
Bole	350029	607386	961 461	4.7%
Total AACA	3103374	4 782588	7 054 291	3.7 to 4.1%

Source: Central Statistical Authority, 2007.

3.1.4. Climate

Addis Ababa is located in a tropical zone but it is influenced by the altitude, from 2000 to 3200 meters, which tempers the temperature. This climate is characterized by a wet season, from June to the end of September, dry season specially from December to the end of February and the rest of the month have little amount of rain. But temperature depending on the altitude, decrease from the south (Akaki) to the north (Gulele, Yeka) (Tamiru , 2003). The climatic elements are considering for landfill site selection to set the different criteria without affecting environmental feasibility, political and social acceptance.

3.1.4.1. Rainfall

The main rainfall season in the study area is from June to September, but there is relatively small rainfall during the month of March and April. The most beneficial rain is essentially of orographic type, produced from condensation of vapors driven by winds against marginal escarpment on the plateau. In summer, mainly Jun to September, the rain is very heavy with sporadic thunderstorm causing high runoff. whereas in Autumn, (late September, October and November) and Spring

(March, April and May) the rain has less intensity. During winter (from December to February), it is sunny and dry with a very little or no rain fall. The meteorological data shows the total rainfall of Addis Ababa is about 1076.6mm per year, with the high rainfall occurring in July to August , While in April , Jun and September moderate concentration of rainfall, In march and May small concentration and the remaining months (January, February, October , November And December) Are dry months (Tamiru, *et.al.*, 2003).

Table 3: Mean monthly rainfall of Addis Ababa

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
mount of F(mm)	*15.8*	*37.3*	*68*	*88.6*	*77.3*	*118.1*	*250.4*	*238.8*	*137.6*	*32.9*	*6.2*	*5.6*	*1076.6*

Source: Ethiopia Metrological Agency, 2014

Rain season

Dry season

3.1.4.2. Temperature

The minimum mean monthly temperature of the Addis Ababa ranges between 7.5^0c in December to 11.7^0C In May, while the maximum mean monthly temperature varies between 20.1^0C In August to 24.6^0C in March, throughout the year in the last ten years.

Table 4: Min and Max Monthly Temperature of Addis Ababa in(C°)

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
Max(Tc^o)	*24*	*24.1*	*24.6*	*23.9*	*24.6*	*22.9*	*20.3*	*20.1*	*21.1*	*22.4*	*22.6*	*22.8*	*22.8*
Min(Tc^o)	*10.3*	*9.5*	*10.9*	*11.5*	*11.7*	*10.8*	*10.8*	*10.8*	*10.5*	*9.2*	*7.9*	*7.5*	*10.1*

Source: Ethiopia Metrological Agency Annual Report, 2014.

3.1.4.3. Wind Speed and Direction

Average monthly wind speed data is available only at the Addis Ababa Observatory. The average monthly wind speed is generally low. The monthly maximum wind speed is 0.7 m/sec and the minimum is 0.3 m/sec. There is a seasonal variation in the wind speed data with the rainy season (June - September) has low values. Considering wind speed and direction during site selection are important to control the bad odor of the waste.

Table 5: Mean Monthly Wind Speed of Addis Ababa (m/sec)

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
Wind speed(m/sec	*0.6*	*0.7*	*0.7*	*0.6*	*0.6*	*0.4*	*0.3*	*0.3*	*0.4*	*0.6*	*0.6*	*0.6*	*0.5*

Source: Ethiopia Metrological Agency Annual report, 2014.

3.1.5. Soil

Soil is formed based on the five major factor namely climate (temperature and rainfall), topography, parent material, biological activities (flora and fauna) and time. These factors determine the types of soil that are formed in a particular area. As a result soil can vary from place to place. Accordingly, the soil of Addis Ababa is classified in to seven major types namely Calcic Xerosols, Chromic Luvisols, Chromic Vertisols, Eutric Nitisols, Leptosols, Ortic Solonchaks and PellicVertisols (Ministry of Agriculture, 2004). The dominant soil of the region is PellicVertisol (277.23 km^2) which is found in the southern and north east part of the city. Eutric Nitisol (111.55 km^2) is the second most dominant soil found in the central and north western part of the region. Calcic Xerosols (39.79km^2) is the third most dominant type of soil found in the northern part of the city. Chromic Vertisols are the forth dominant soil of the region covering an area of about 34 km^2 and found in the central part of the city center(Source: attribute table in Arcmap). The rest soil types are found in the northern part of a city and covering smaller areas (Fig. 5).

Topography (slope) is the major soil forming factors that determine the type and properties of soil mainly depth and texture via determining the degree of weathering and erosion. Generally, the steeper the slope, the less soil development and higher erosion rate and the shallower the depth and the courser the texture and vice versa (Hailesilasse *et.a'l.* ,1989).

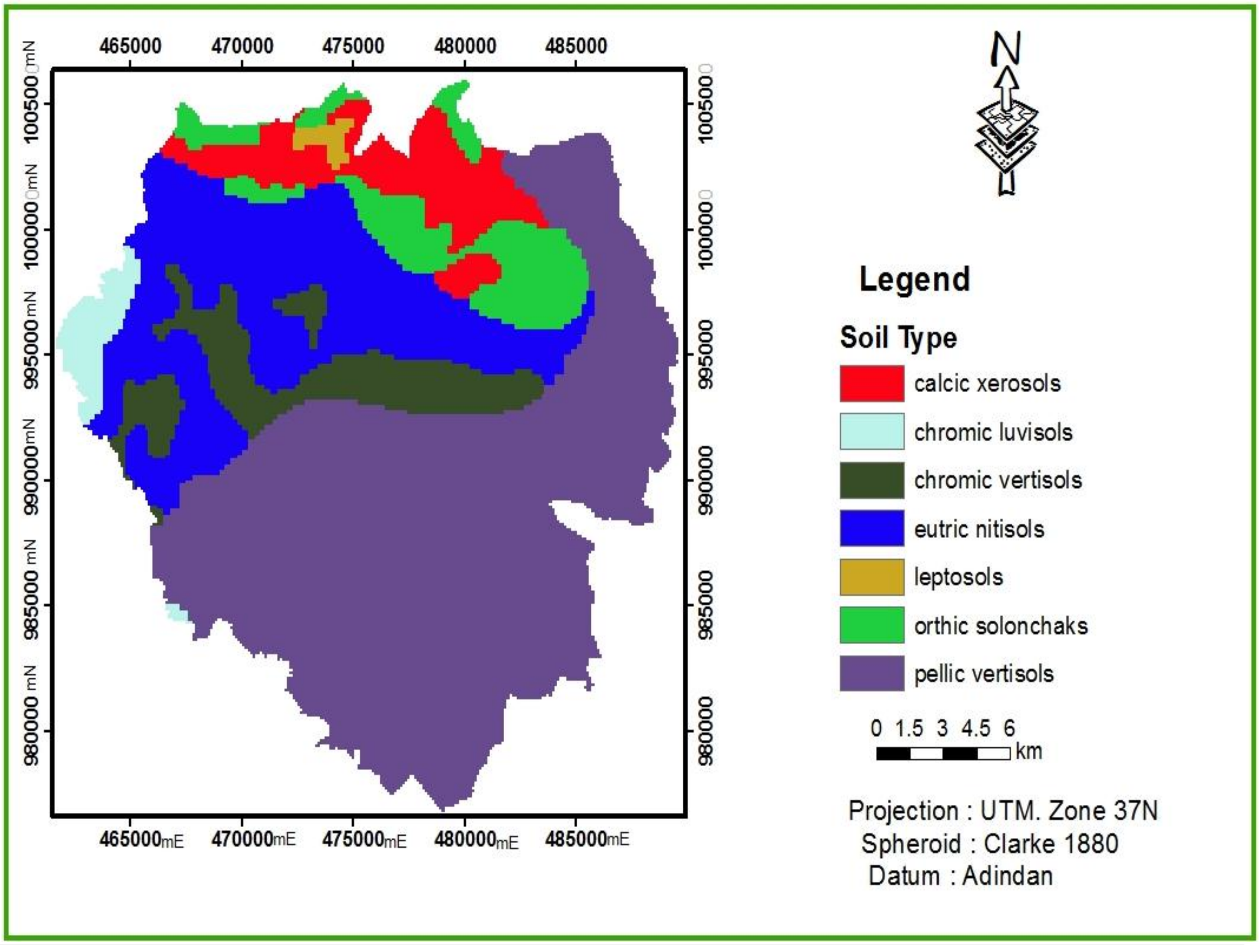


Figure 4 : Soil map of Addis Ababa.

3.1.6. Geology

The geology of NW, NE, SE, and SW areas of Addis Ababa comprise rocks ranging in age from Tertiary volcanic (Mulugeta et al., 2007). The Tertiary volcanic represent the area and comprises of aphanitic, pyroxene-phyric, plagioclase-phyric and olivine-phyric basalt, trachy basalt, trachyte, ash, ignimbrite and agglomerate and Tertiary sediments detail of each presented in figure 6, (Assiged, 2007).

3.1.6.1. Foota Basalt

This basalt is dark grey on fresh out crops. Up on weathering, it has been developed a laterite with maximum thickness of 2 m and locally it shows spheroidal weathering. It is characterized by sub-horizontal layering. Locally the rock is affected by 2 joint sets. It shows altering layers of vesicular basalt with either porphyritic basalt or aphanitic basalt. Thin section studies on a number of samples of aphanitic textured basalt shows about 99% ground mass and less than 1% plagioclase, where the ground mass made up of olivine, pyroxe and feldspars (Mulugeta *et al*., 2007)

3.1.6.2. Quaternary Olivine Basalt

It is exposed in the northern and south eastern part and covering 18.1% or 95.4 km^2 of the study area. This is grey color on fresh out crop and become reddish brown up on weathering. Most of the time, it out crops in boulder form. In hand specimen phenocrysts of olivine and pyroxene are clearly seen. Sometimes the rock is seen vesicular and the vesicles are filled by secondary zeolite and quartz. This rock is un conformably overlies the wechecha-Yeret-Furi-Ignimbrite and the wechecha-Yerer-Furi Trachyte and trachy basalt. Thinunit sample shows about 60% plagioclass, 20% pyroxene, and 5% opaque minerals and 15% ground mass. The ground mass is made up of feldspar, pyroxene, and other unidentified minerals. In some locality minor rock type composed of 15% plagioclass, 20% olivine mineral and with 60% ground mass is also observed. The groundmass is composed of microphenocrysts of pyroxene, plagioclass laths, and olivine and opaque minerals. This rock type exhibits pikiliotic texture (Tsegaye, 1995).

3.1.6.3. Tertiary Sediments

It is exposed in the southern part and covering 1.8% or 6.2 $km^2$of the study area .Out crops are mainly observed at the bank of the river and small creeks. It generally forms very gentle slope and lower topography. It is overlain by the young Quaternary basalt and overlay the Repi basalt. The maximum thickness is about 9m which is around Akaki area. This rock is yellow to yellowish pink. In this rock the dominant layers are conglomeratic sandstone to fine sandstone. It generally depicts coarsening upward sequence. In this sediment the pebbles and cobbles are basalt and scoracious basalt. Locally, this sediments are well stored. It shows bedding and lamination structure and the most interesting thing here is that the sediment contains bone fossil (Assiged, ,2007).

3.1.6.4. Wechecha- Furi- Yere Trachyte

It is located in the western part of the study area, and covering an area of 7.9% or 41.8 km^2. It mostly forms big mountains such as Furi, Wechecha and Yerer. This unit is found overlying the Repi basalt and the contact is marked by a thick paleo soil. But, in some localities it is covered by Quaternary olivine-phyric basalt .It is an aphanitic to medium grained in texture with vesicular varieties mostly at its lower part. This trachyte and trachy basalt is light grey to dark grey often to greenish grey. Weathered surface show various colors. It has aphanitic to vesicular texture. At its lower part it shows columnar jointing and is affected by two sets of joints. At some places it shows layering. Mostly the trachyte and the trachy basalt are found alternatively layered with the trachyte being dominant. The base of the unit is dominated by trachy basalt to basaltic rock type.

Thin unit sample shows a composition of 20-60% plagioclase, 5-12% olivine minerals and 15-70% groundmass is made up of olivine, pyroxene, plagioclase and opaque minerals. The plagioclase minerals lath like crystals. The pyroxene and olivine minerals are weathered to form secondary minerals of augite and iddingsite. The rock shows poikilitic texture. Moreover a porphyritic trachyte was locally observed and is composed of 30% feldspar (sanidine), 10% pyroxene minerals and 60% ground mass. Microphenocrysts of mainly feldspar and pyroxene form the groundmass (Mulugeta *etal*., 2007).

3.1.6.5. Quaternary Scoria

It is found in the south western part of the map area. It forms less than 0.1% of the total area. It covers an area of 0.7km^2. These scoria cones are found as either cones or simple domes. Mostly, they are layered and sometimes contain grey vesicular basalt bombs. This unit is mainly cut by basaltic dyke of different orientation (Assiged, 2007).

3.1.6.6. Repi Basalt

It is found generally in the central part of the study area. It covers an area of 81.2 km^2 which is 15.4% of the map area and forms mainly flat land except that at some places it forms ridges. In the central part it is overlain by Wechecha-Yerer-Furi ignimbrite where as in the central western part it is overlain by Yerer-Furi-Wechecha trachyte. It is mainly greenish grey to dark grey but rarely of pink color. This rock is porphyritic and aphantic with the top part mostly vesicular. Weathering of the rock forms different colors of mainly dark brown. Spheroidal weathering is more Conspicuous phenomenon. The Repi basalt is mainly affected by joints making it fissile. Mainly at the contact between the ignimbrite and this basalt it forms Paleosoil which is red in color (Tsegaye ,1995).

Thin section studies of samples from both porphyritic and aphanitic variety shows composition of 74% plagioclase laths and minor alkali feldspar, 10-12% opaque and magnetite minerals, with 8-10% epidote and 4% secondary serpentine. Generally, it shows poikilitic and flow texture (Kebede,1990).

3.1.6.7. Chelekleka Basalt

It is found in the eastern and southern parts of the study area where the north eastern part is more extensive. It makes up 6.3% of the total area and covers an area of 33.2km^2. It is formed by different layers which are aphanitic basalt agglomerate and pyroclastic rocks. In between each unit there is a baked soil horizon. The lower part is made up of aphanitic basalt and columunarly jointed, where as the top part is porphyritic in texture. Some of the layers of the basalt are more scoracious. This rock is highly fractured and dense below which there is a 40m thick crystalline and coarse grained trachyte. But at the north western part overlies the Wechecha-Yerer-Furi ignimbrite. At the top part it is covered by plagioclase-pyroxene-olivine-phyric basalt. The lower most part affected by joints 310^0 and 50^0 at some place parallel to 50^0, dyke is observed (Kebede, 1990).

3.1.6.8. Intoto Mixed Rocks

It is exposed in the northern part of the area. It makes up about 13% and covering an area of 68.7km^2. This unit consists of trachyte, ignimbrite, pyroclastic rocks and sediments. All the rocks are highly weathered and jointed with few layers of agglomerate at some places. It develops a thick red soil and it is covered by patches of quaternary basalt except in southern margins. The contact with the Chelekeleka basalt develops thick red baked soil. This rock is highly affected by joints trending E-W. The trachyte forms variegated color of weathering mainly pink, yellow, white and gray, whereas the pyroclastic rocks mainly from light green and reddish brown. At some places, the trachyte is porphyritic (Assiged, 2007). The pyroclastic rocks contain fragments of trachyte and rhyolite but because it is highly weathered it shows light grey to light yellow and also black color. The rhyolite is vesicular and amygdaloidal and the amygdales are secondary malachite (Tsegaye *et al.*, 1995).

3.1.6.9. Intoto Trachyte

This is exposed in the northern part of the area. It covers about 1.3% or 1.7 km^2 of the study area. This unit is generally coarse grained porphyritic and highly weathered. This makes it to have weathering color of light pink to white. The alkali feldspar phenocrysts are up to a centimeter in diameter. This unit is affected by EW and SE-NE joints. The joints are filled with dark brown clay and it is covered by patches of Quaternary olivine basalt (Tamiru, 2003).

3.1.6.10. Quaternary Elluvial Sediment

It is exposed in the SW corner of the study area. It makes up less than 1% of the map area. This unit forms small hills to plain land morphology. It is whitish pink to grey and consists of rock fragments with size ranging from boulders to pebbles size and sanidine crystals with the fine grained ground mass being dominant (Tsegaye, 1995).

3.1.6.11. Lower Ignimbrite

This unit is outcrops in the eastern and south western part of the study area with the eastern part being more extensive than the western part. It makes up about 8.6% of the total area and covers an area of $45km^2$. It is grey and black colored and shows columnar jointing. The rock is medium to fine grained and is composed of sanidine phenocrysts and fine grained ground mass. The top layer is very loose massive ash deposit which is whitish in color. It overlies the chelekleka basalt unit. In most of the case it is overlain by Repi basalt, but in the central eastern part it is overlain by Wechecha-Yerer-Furi ignimbrite and Wechecha-Yerer-Furitrachy basalt and trachyte. The top and lower contacts are marked by paleo soil. It consists of two layers. The top layer is coarse whereas the lower layer is fine grained. In between the two layers there is a backed soil horizon. At the center the lower part is very fine but to the periphery it becomes more coarse grained than the central. This ignimbrite shows inter layering of ignimbrite, ash and tuff. The boundary in between each rock type is marked by a paleosoil (Tamiru, 2003).

3.1.6.12. Wechecha-Yere-Furi Ignimbrite

It is found cropping out in the eastern and western part of the study area. It is grey, which contains fragments of ignimbrite, rhyolite and pumice with sanidinephenocrysts. It is fine to medium grained in texture. At the top part, it shows columnar jointing whereas at the base it shows layering. In the lower most part and top most part of this unit there are pyroclastic deposit which contains phenocrysts of sanidine. The pyroclastic layers are multiple with each layer separated by thin paleosoil. It is overlain by Wechecha-Yere-Furitrachybasalt and trachyte to the central and western part but to the north and Eastern part it overlies the lower ignimbrite, Intoto mixed rocks and Repi basalt.Elsewhere it is overlain by Quatrnary basalt (Assiged, 2007).

Thin section studies of this rock show a composition of 52% glass (ash), 18% sanidine crystals with accessory minerals of 4% magnetite and 5% hematite. The secondary minerals observed are3% augite, 5%rock fragments and 5% quartz.It has a flow texture abd also eutaxitic by major constituents which are glassor ash. But the ash flow/tuff which is found at the lower most and at the upper most part of the unit shows 69% quartz with 10% opaque and 5% hematite accessory minerals. Micro phenocrysts of 5% quartz, 3% sanidine, 3% plagioclase and 5% glass are also observed. This pyroclastic deposit shows layering of a millimeterthickness with major constituent showing radiating and fibrous texture (Tsegaye ,1995).

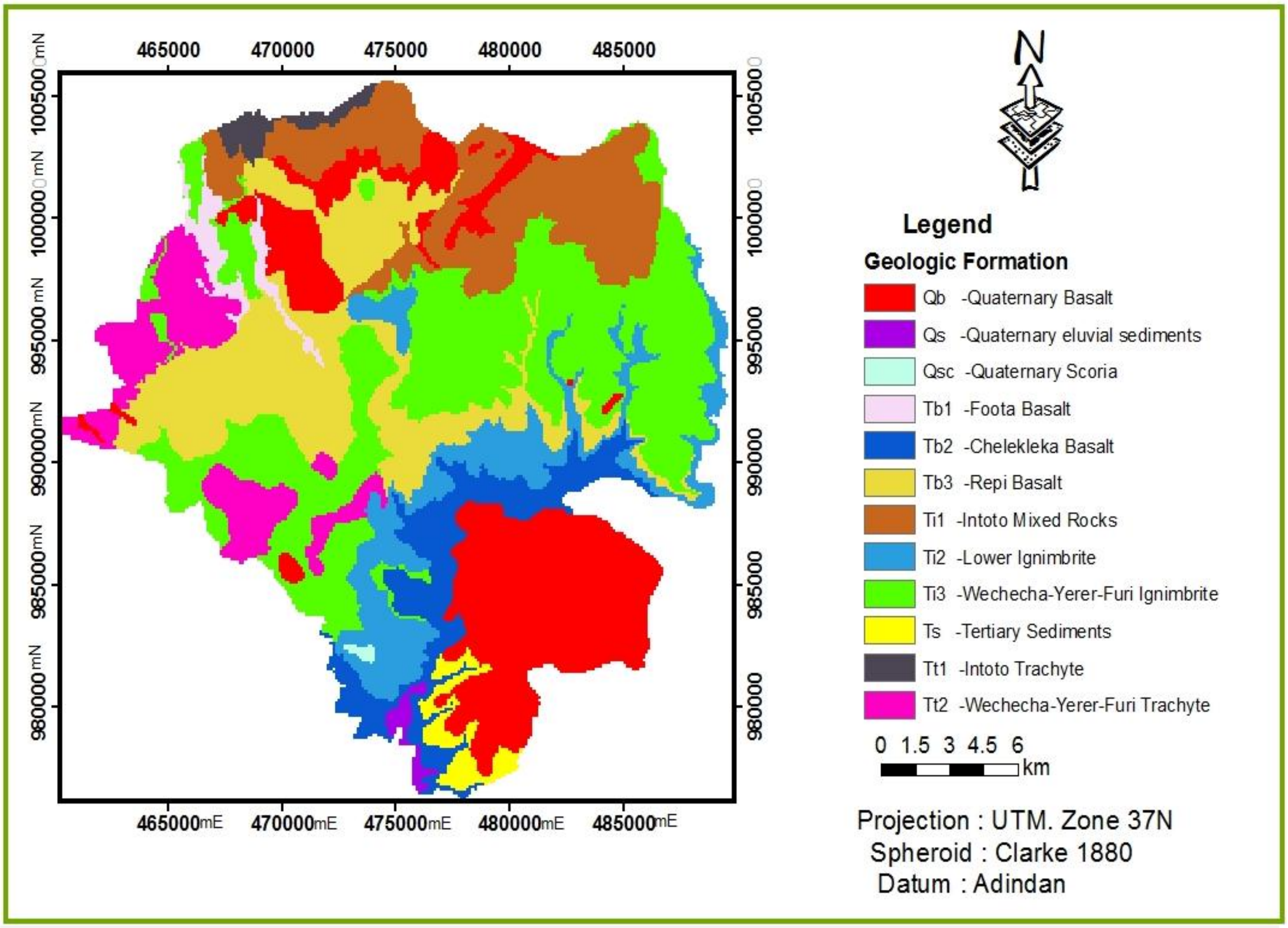


Figure 5 : Geology map of Addis Ababa

3.2. Assigning criteria for Landfill Siting

There are a number of criteria for landfill site selection. These are environmental criteria (ecological value of the flora and fauna, dust nuisance, other nuisance for neighboring areas, scientific or historical areas, risks for explosion or fire, tourist/recreation areas), political criteria (acceptance by the local people and municipalities, acceptance by the pressure groups involved, property of the landfill area), economic criteria (costs of land, costs for the access of the landfill, transport costs, cost for maintenance, costs for the after-care), hydrologic criteria (surface water, groundwater),topographical criteria, geological criteria, and social criteria (residential and urban areas, industrial areas, difficult infrastructural provisions, and climate).

3.3. Data Collection

3.3.1. Primary Data

Ground control points were collected by using GPS during field survey.

3.3.2. Secondary Data

Secondary data were collected from their respective sources(Table 6)

Table 6: Data input and source

Type of data	Description/ contents	Source
Maps	Geology map	Ethiopia Geologic Survey Agency (EGSA)
	Residential map	Clipping from LU/LC map of Addis Ababa
	LULC 2014 shapefile	Addis Ababa Municipality
	Digital Soil Map	Ministry of Agriculture
	Road network Map	Ethiopian Road Construction Authority(ERCA)
	Ground water (2015)	AAWSA
	Slope and Drainage	Generated from Digital Elevation Model
	Fault line	Digitized from geology map
	Airport ma	Ethiopian civil aviation

All these data were collected, manipulated and analyzed in GIS environment to be used for further analysis.

In addition to these input; Arc View GIS Version 10.1 software was used for developing the prototype database for the study area.

Methodologies were used normally based on a composite suitability analysis using map overlays (O'Leary *et al*., 1986) and their extension to include statistical analysis (Anderson and Greenberg, 1982). The utilization of GIS for a preliminary process was normally carried out by creating buffer zones around geographic features to be protected. With the aid of this functionality, GIS was be used to facilitate the process and decreases the cost of site selection for building sanitary landfills in the last few years (Siddiqui *et al*., 1996; Kao *et al*., 1997).

The slope of the land surface was calculated on the pixel basis using the Digital Elevation Model (DEM) of the study area, the land use types was grouped and ranked according to their suitability for a landfill site, the land use vector map was then converted to a raster map. For all criteria, standard criteria for pollution control on the landfill sites were used.

3.4. Method

3.4.1. GIS- Based-Multi Criteria Evaluation Methodology

GIS-based multi-criteria decision analysis involves the utilization of geographical data, the decision maker's preferences and the combination of the data and preferences according to specified decision rules (Malczewski, 2006). Multi-criteria approaches have the potential to reduce the costs and time involved in siting landfills by narrowing down the potential choices based on predefined criteria and weights (Carver, 1991). Weighted Linear Combination (WLC) and Analytic Hierarchy Processes (AHP) are the two most widely used Multi-Criteria Analysis methods that were used for this study.

3.4.2. Analytic Hierarchy Processes (AHP)

The Analytic Hierarchy Process is a decision making method for prioritizing alternatives when multiple criteria must be considered. It offers a methodology to rank alternative courses of actions based on the decision maker's judgments concerning the importance of the criteria and the extent to which they are met by each of the alternatives (Nydick and Hill, 1992). AHP is a powerful and flexible decision-making process to help people set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. It provides a hierarchical structure by reducing multiple variable decisions into a series of paired comparisons and develops subjective priorities based upon user judgment (Ersoy and Bulut, 2009). AHP was used in this study to derive weights for each criterion internally and externally. It was also used to breakdown decision problems and aggregates them in structured way so as to facilitate landfill siting processes.

3.4.3. Weighted Linear Combination (WLC)

Weighted Linear Combination is a type of Multi-Criteria Evaluation Method in GIS environment used to evaluate the suitability of a region for landfill. The WLC procedure is characterized by full tradeoff among all factors, average risk and offers more flexibility than the Boolean approaches in the decision making process. The approach allows the decision maker to assign weights according to the relative importance of each suitability map and combines the reclassified maps to obtain an overall suitability score (Malczewski, 2004).

In this particular research, GIS-based Multi-Criteria Evaluation Analysis was employed. This methodology is best suited for siting landfills accurately in time and cost effective manner and hence it is used by many researchers. Because the technique can effectively be used for suitability analysis in GIS environment via criteria establishment, standardization of factors, establishment of factor weights and finally WLC. Landfill site selection methodology is a two step process. The first step employs GIS to screen out unsuitable areas based on standards and criteria set by national and international environmental acts and rules and identify potential selected landfill sites. In the second step MCDM, is used for ranking the candidate sites and identify the best site based on the weights assigned to each criterion. AHP is a powerful MCDM tool to assign weights and rank the selected sites for selecting the best site among the competent. Generally, after finding out where the unacceptable areas are, the remaining areas should be classified into classes of high and low priority for being used as waste disposal areas (Ersoy and Bulut, 2009).

This is done through two steps of weighting process. In the first step, each layer was internally weighted based on the minimum and maximum distances and/or requirements. Finally, the layers were standardized and thematic map of each criterion/layer was produced. In the second step, each layer was externally weighted based on the fact that how critical and important the data layer is to the waste disposal problem. After external weight was assigned to each layer, WLC techniques were applied to combine all the factors and prepare landfill suitability map. After creating a final suitability map using GIS, the AHP process was applied again for comparing alternative landfill sites to each other against other criteria (size, distance from the center of the city and from nearby settlements) in order to choose the most suitable landfill site among candidate sites.

3.4.4. Analysis Method

Landfill site selection requires effective criteria assessment according to the governmental legislations to reduce social, economic, environmental and health costs (Siddiqui, 1996). In the present study, by taking into account of these criteria the overlaying method of information layers was used to achieve suitable landfill sites. In the multi criteria evaluation method, an integration of criteria was used for accessing a single combination in decision making.

3.4.4.1. Evaluated Criteria

Landfill site selection studies depend on the natural and legal condition of an area. In this regard the criteria and principles considered in this study were divided into three broad classes namely, physical, environmental and socio economic criteria. These criteria contained their own components and were selected according to the guide directions and legislations of EPA and municipality. Based on FAO classification, all the factors were internally classified in to five classes (most suitable, suitable, moderately suitable, poorly suitable and unsuitable) with values ranging from 5 to 1, where 5 denotes the most suitable and 1 denotes the unsuitable for all factors and constraints considered.

Table 7: Attributes and their suitability's/standards for landfill site.

Attributes	Standards for suitability	Reference
Characteristics of Soil type	Poor drainage soil(clay textured)	Jamjan (2009).
Characteristics of Geology	Consolidated lithology are	Ersoy and Bulut (2009).
Distance from Borehole	50m buffer	Chang *et al.*, (2007).
	500-1000m buffer	(Hasan *et al.*, 2009).
	700m buffer	Jamjan (2009).
Slope	8-12% suitable,	Chang *et al*., (2007).
	15-20% suitable	(Hasan *et al.*, 2009).
	>20% unsuitable	Ersoy and Bulut (2009).
Distance from settlement	500-2000m	(Hasan *et al*, 2009).
	3000m	Map Asia (2004), Yahaya(2010), Ersoy and Bulut(2009), EPA (1995) and UNEP (2005) and Chang *et al*., (2007).
Distance from road	75m buffer	Chang *et al*., (2007).
	50-100m buffer	(Hasan *et al.*, 2009).
	100m buffer	Map Asia (2004), Zain (2009), Yahaya (2010) and Ersoy and Bulut (2009) And EPA (1995).
Distance from faults	>60m buffer	Ersoy and Bulut (2009).
	100m buffer	Guam EPA (2004).
Distance from water bodies (lake, wetlands, rivers and streams)		Akbari *et al.*,(2009).
		Map Asia (2004), Ersoy and Bulut (2009),
	100m	Jamjan (2009).
	200m	Akbari *et al*., (2009).
	300m	(Hasan *et al*., 2009), UNEP (2005) and
	300-500m	EPA(1995).
Airport boundary	5km buffer	Jamjan (2009).
	3km buffer	UNEP (2005).
Land use	Low value lands	Jamjan (2009).
	Less economic importance of the site is more important	UNEP (2005).
Size of landfill	Enough to serve at least for 10 years	Zain (2009) and UNEP (2005). Jamjan (2009).
	Required at least for 20years	
Groundwater depth	Should be deep enough >50m	Jamjan (2009). Mahini and Gholamalifard (2006).

Physical criteria

Physical criteria consisted of slope, geology, surface water, groundwater, borehole, soil permeability and faults.

A. Slope

It is a fundamental factor in landfill establishment. Land morphology is evaluated by slope that is defined in percent or degrees (Kontos*et al*., 2005). Steep slopes are not suitable for landfill establishment where the construction costs of excavation increases in higher slopes (Gemitzi*et al*., 2007) it is difficult to maintaining. The suitable slope of land surface is important in preventing the leachate flowing (Khorasani and Nejadkorki, 2000). The slope layer map was obtained from the study area of DEM map on the basis of pixel size in percentage. According to Boolean rule the lands with the slope of more than 20 percent with 0 value were considered unsuitable. But according to Lin and Kao (1998, 2005) have suggested that the appropriate slope for constructing a landfill is about 8–12% because too steep of a slope would make it difficult to construct and maintain and too flat of a slope would affect the runoff drainage. Slopes above 12% created high runoff rates for precipitation. This subjects a larger environment to the dangerous chemicals produced within the leachate from the landfill, especially surface waters. In the study area, the slope is too flat and too steep are given less value (1)and if the slope is gentle have high value (5) (Allen et al. 2003).

By considering the suggestions in the literature, slope map is classified into five groups. The groups and related rankings are shown in table 8 and the final map ready for analysis is shown in Figure 7.

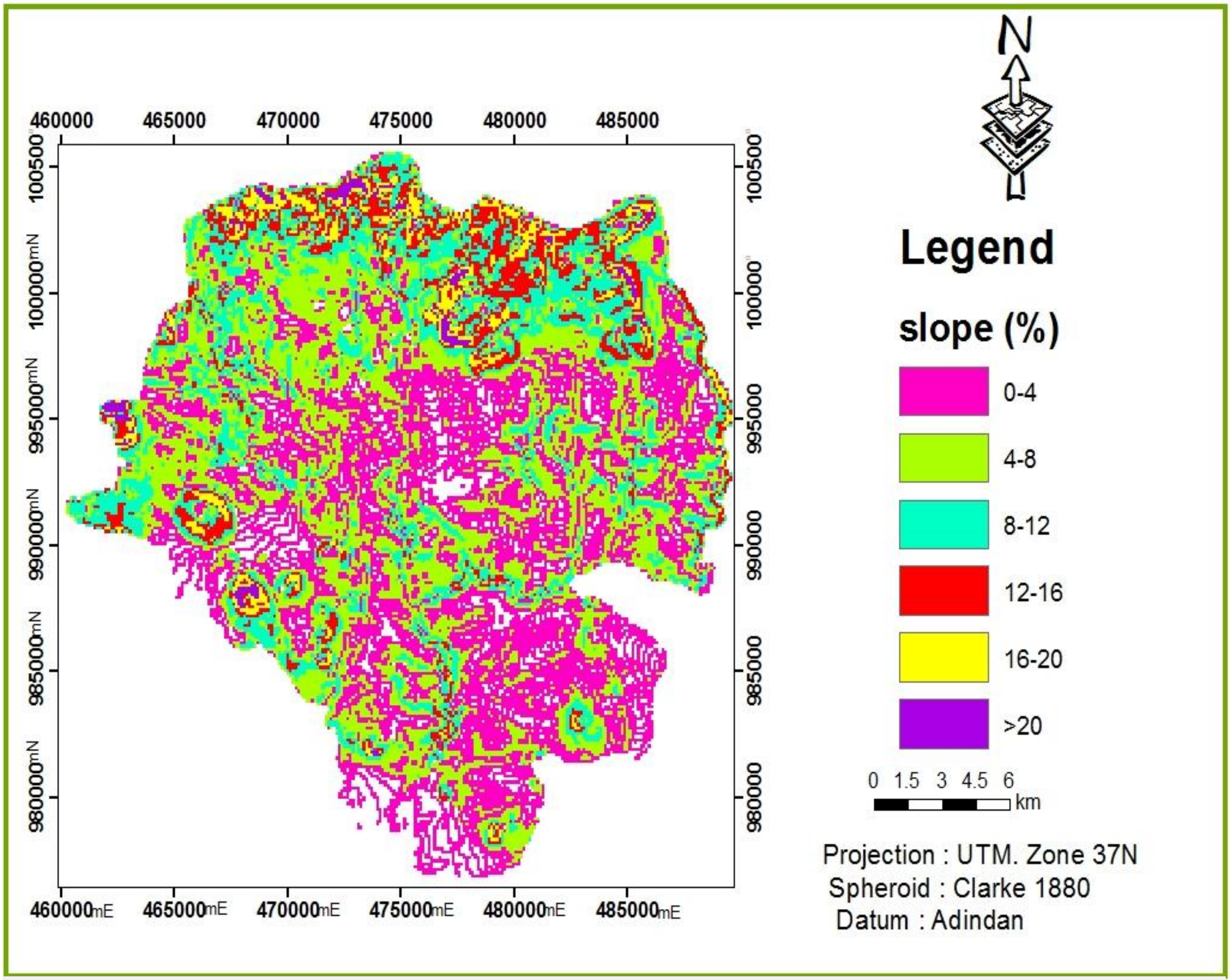


Figure 6 : Slope Categories map of the Study area.

Table 8: Slope suitability and area coverage

S.N	lope Class (%)	Suitability	Rank	Area (km2)	Area (%)
1	0-4 &>20	Unsuitable	1	114.4	21.7
2	4-8	Poorly suitable	2	111.1	21.1
3	8-12	Most suitable	5	102.9	19.6
4	12-16	Suitable	4	99.8	18.9
5	16-20	Moderately suitable	3	98.8	18.7
Total				527	100

Table 8 shows that 19.6%, 18.9%,18.7% and 21.1% of the total area are most suitable, suitable, moderately suitable and poorly suitable for landfill site respectively. The remaining part of the area (21.7%) is unsuitable for landfill, this shows that the area is steep and flat. The suitability map of the study area is indicated in figure 7.

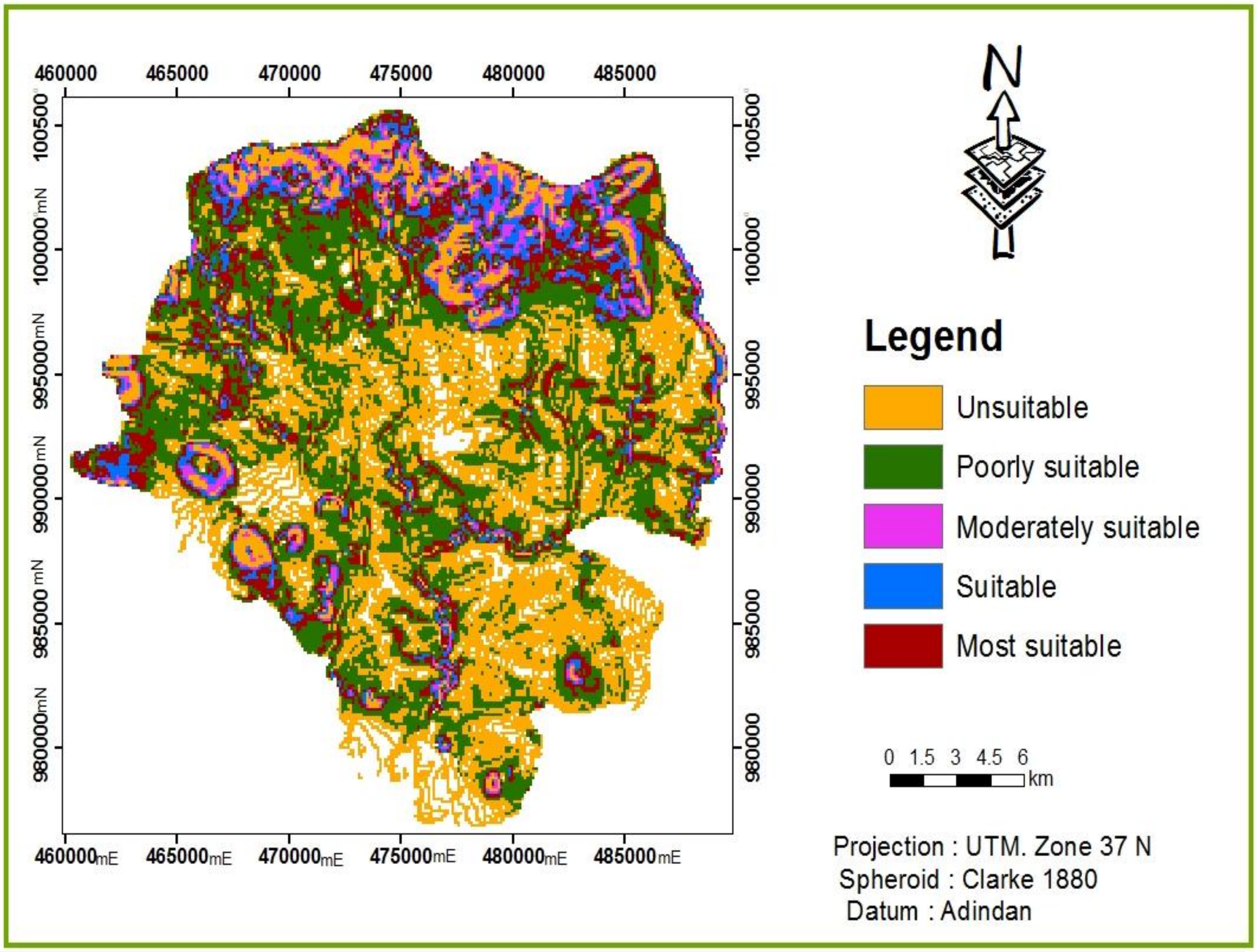


Figure 7 : Slope suitability map of the study area.

B. Geology

The geological map of the study area was compiled from available reports and maps obtained from Ethiopian geological survey. Geology map prepared was scanned, registered and digitized. A database including lithology, symbol and description was created and attached to the map. In the study area, there were twelve different lithologies and a database including symbol, lithology and description was prepared (Figure 5) in the GIS environment. The lithologies were grouped and ranked according to their suitability for a landfill site which is given in Table 10. The vector map of lithology was then converted to a raster map to be finalized for analysis. The raster map is shown in Figure 8.

Geology is one of the important environmental factors that should be considered during landfill site selection processes. Impermeable strata and consolidated material are suitable for landfill site as they do not allow movement of leachate and hence minimize the risk of groundwater contamination from landfill leachate Ersoy and Bulut ,(2009). For this study, previous study and lithology log data were used to assess the permeability and stability of the rocks. According to Tamiru *et al*.(2003), cited by Gizachew, (2011), the permeability of formation in the region not only depends on primary porosity, but also on secondary porosity resulted from weathering and fracture. The more the weathering and fracture, the more permeable and instable the rocks will be. Hence, such formations are not suitable for solid waste landfill siting because of the high probability of the underground water to be contaminated (Tsegaye, 1995). In the study area, Quaternary Basalts and Wechecha_Yerer_Furi Trachyte are permeable due to high degree of weathering and fractures and thus are marginally suitable for landfill site. Moreover, Quaternary Eluvial Sediments and Tertiary Sediments are highly permeable due to their primary porosity hence, unsuitable for landfill sites. However, Wechecha_Yerer_Furi Ignimbrite, Lower Ignimbrite, Intoto Mixed Rocks, Intoto Trachyte and Repi Basalt are very low permeable due to less degree of weathering and fracture. Siting landfill in such areas is the best option to protection ground water from pollution. Therefore, based on the nature of rock, degree of weathering and fracture the study area were categorized in to five permeability and landfill suitability classes (Kebede, 1990).

Table 9: Geology units and the respective area coverage in Addis Ababa.

S.N	Geology Name	Area (km^2)	Area (%)
1	Quaternary Basalt	95.4	18.1
2	Quaternary Eluvial Sediments	1.7	0.3
3	Quaternary Scoria	0.7	0.1
4	Foota Basalt	8.7	1.7
5	Chelekleka Basalt	33.2	6.3
6	Repi Basalt	81.2	15.4
7	Intoto Mixed Rocks	68.7	13.1
8	Lower Ignimbrite	45.1	8.6
9	Wechecha-_Yerer-_Furi -Ignimbrite	137.4	26.1
10	Tertiary Sediments	6.2	1.8
11	Intoto Trachyte	6.9	1.3
12	Wechecha-_Yerer-_Furi -Trachyte	41.8	7.9
	Total	527	100

Table 9 shows as, most parts of Addis Ababa (26.1%) is covered by Wechecha _Yerer _Furi Ignimbrite. This unit is mostly found in the south western, central and eastern parts of the city and characterized by their low permeability due to low degree of weathering and fracture (Tsegaye, 1995.). The second most dominant geologic unit in the study area is Quaternary Basalt which covers 18.1% of the total area found in the southern and northern parts of Addis Ababa. It is characterized by high degree of weathering and fractures hence, described as high permeable rock. The smallest unit in the region is Quaternary Scoria, which covers only 0.1% and found in the Southern part of Addis Ababa. It is moderately permeable due to moderate degree of weathering and fracture. Tertiary Sediments (1.8%) and Quaternary Eluvial Sediments (0.3%) are found in the southern part of the city. These units are unconsolidated materials and hence are highly permeable (Tsegaye, 1995). It is believed as potential source of groundwater for the city and the surrounding areas. The spatial distribution of all geologic units of Addis Ababa is shown in (Fig.5).

Table 10: Suitability and permeability classes of geologic units

Geology unit	Permeability	Suitability	Rank	rea (km^2)	Area (%)
Wecheca-Yere-Furi-Ignimbrite,Intoto mixed rock, Intoto trachyte, Repi basalt, Lower ignimbrite	Very low	Most suitable	5	337.6	64
Foota basalt, Chalaklaka basalt	Low	Suitable	4	44.8	8.5
Wechecha-Yerer-Furi-Trachyte, Quaternary basalt	Moderate	Moderately suitable	3	132.0	25
Quaternary scoria	High	Poorly suitable	2	0.7	0.1
Quaternary eluvial sediments, Tertiary sediments	Very high	unsuitable	1	11.9	2.3
Total				527	100

Table 10 shows that, Wecheca-Yere-Furi-Ignimbrite (Ti3), Intoto mixed rock (Ti1), Intoto trachyte (Tt1), Repi basalt (Tb3) and Lower ignimbrite (Ti2) covered 337.6 km^2 (64%) of the study area are Most suitable; Foota basalt (Tb1) and Chalaklaka basalt (Tb2) covered 44.8 km^2 (8.5%) of the study area are Suitable; Wechecha-Yerer-Furi-Trachyte (Tt2), Quaternary basalt (Qb) covered 132 km^2 (25%) of the study area are moderately suitable; Quaternary scoria (Qsc) which covers 0.7 km^2

(0.1%) is Poorly suitable and Quaternary eluvial sediments (Qs) and Tertiary sediments (Ts) covered 11.9 km^2 (2.3%) of the study area are unsuitable for landfill site.

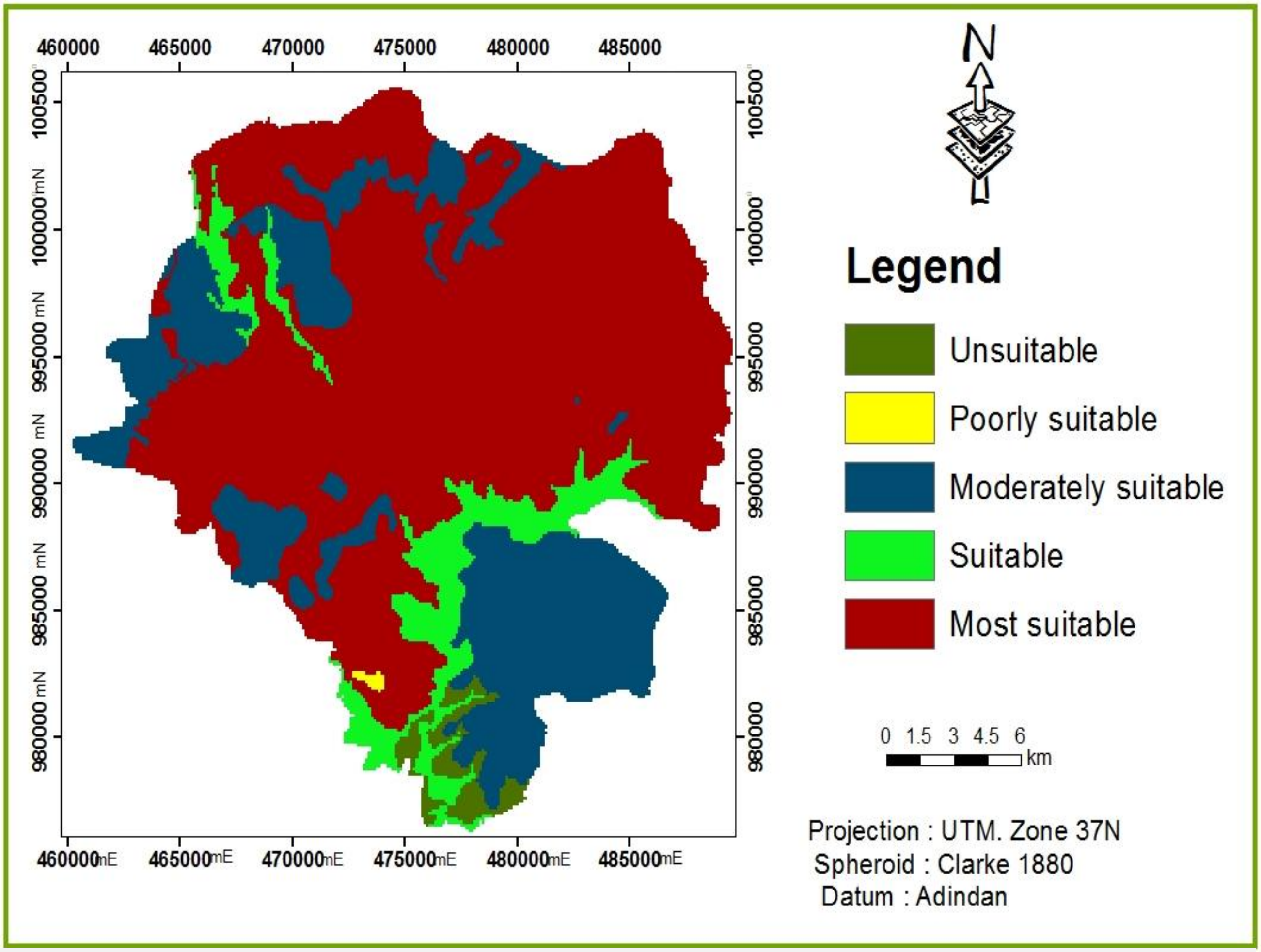


Figure 8 : Geologic suitability map of the study area.

C. Surface water

This criterion is important from the point view of both environmental and economic concerns because in addition to causing pollution problems, it may require an efficient drainage system with high expenses (Gemitzi *et al*., 2007) and (Hasan *et al*., 2009) used minimum of 100 m buffer distance. Areas located within distances less than 100 m from permanent and seasonal rivers were excluded due to the possible interaction between the landfill and the rivers, so Boolean logic were given 0 value. For the rest sits have high value with their increasing distances. The suitability increases from 0 to 255 as the distance increases from rivers. Based on this rule sites which have more than 100m distance away from the rivers have high values and they were considered as most suitable, in order to prevent surface water from landfill contamination (Fig. 10). In this research, 200 m buffer distance was used as a minimum distance from which landfill can be sited. Accordingly, Multiple Ring Buffer from Analysis Tools was used to prepare multiple polygons around each streams and rivers within the following distances: 0-200,200-400, 400- 700,700-1000 and > 1000m. To minimize the effect of landfill leachate on surface water pollution, 0-200 m buffer area was excluded from siting process. The rest of the areas were analyzed based on the distance from the streams and rivers. The proximity map was standardized and reclassified in to five classes (Fig.9).

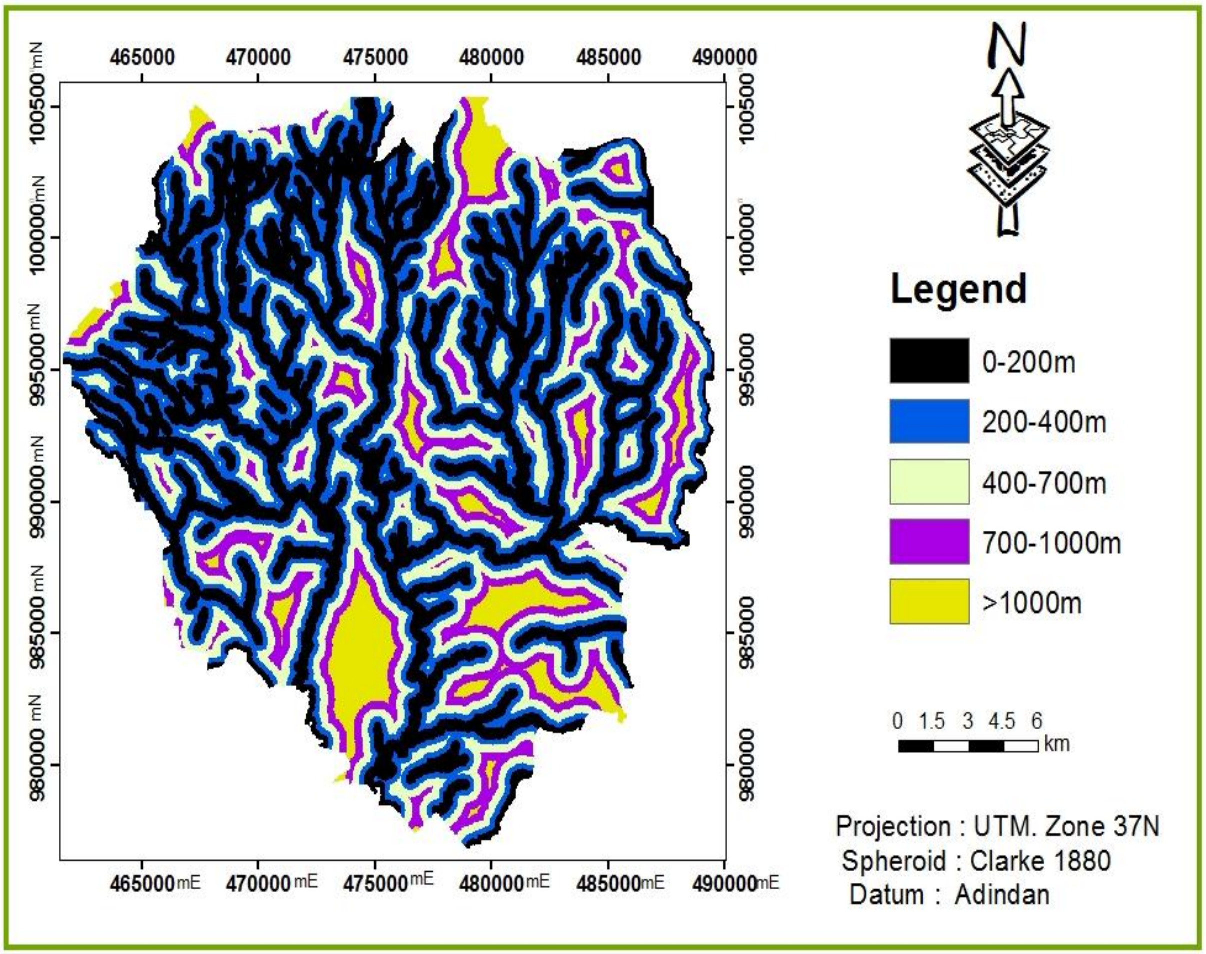


Figure 9 : Sites proximity to surface water map of the study area.

Table 11: proximity to rivers and streams suitability site.

S.N	Distance from landfill site(m)	Suitability	Rank	Area(km^2)	Area (%)
1	>1000	Most suitable	5	165.1	31.3
2	700-1000	Suitable	4	27.9	5.3
4	400-700	Moderately suitable	3	85.4	16.2
5	200-400	Poorly suitable	2	94.8	18
5	0-200	Unsuitable	1	153.8	29.2
Total				527	100

Table 11 shows that, 153.8km^2 (29.2%) of the study area was excluded from the siting processes due to the vicinity to the streams and rivers and hence unsuitable for landfill and given a 1 value, the area covers 94.8 km^2 (18%) of the study area is poorly suitable and given a 2 value, the area of 85.4 km^2 (16.2%) of the study area is moderately suitable and given 3 value, the area of 27.9 km^2 (5.3%) of the study area is suitable and given 4 value. An extent of 165.1Km^2 (31.3%) of the area is the most suitable for landfill siting because of the minimum effect on surface water due to the area is far from the river. The following map shows suitability level and weights, standardized thematic map of rivers/streams.

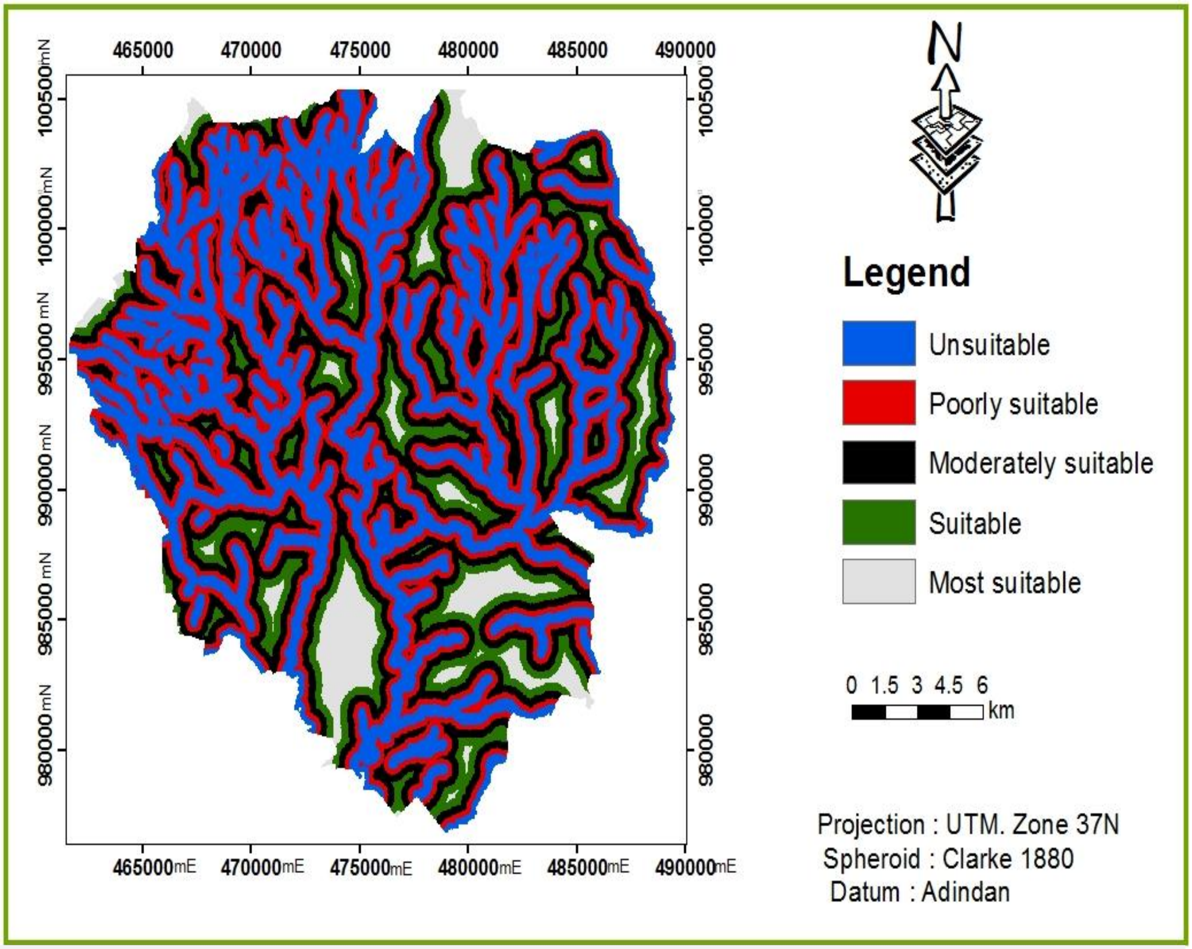


Figure 10 : Site suitability with respect to surface water proximity map of the study area.

D. Groundwater depth

In areas where solid wastes are put directly on groundwater table, groundwater will be polluted strictly (Omrani, 2004). This pollution is caused basically from contact with water and leachate (Soupios, 2007). For the preparation of groundwater table map, data statistics analysis of observed wells obtained from AWSA was conducted and interpolation was performed. Moreover, Mahini and Gholamalifard, (2006) stated as areas with greater than 50m ground water depth is most suitable for landfill site but unsuitable in areas with less than10m groundwater depth, so the suitability increases the value given from 1 to 5. Sites were classified in to five as 0-10m,10-20, 20-40m,40-50m,and >50m. Accordingly the suitability increases with increasing depths (Fig. 11).

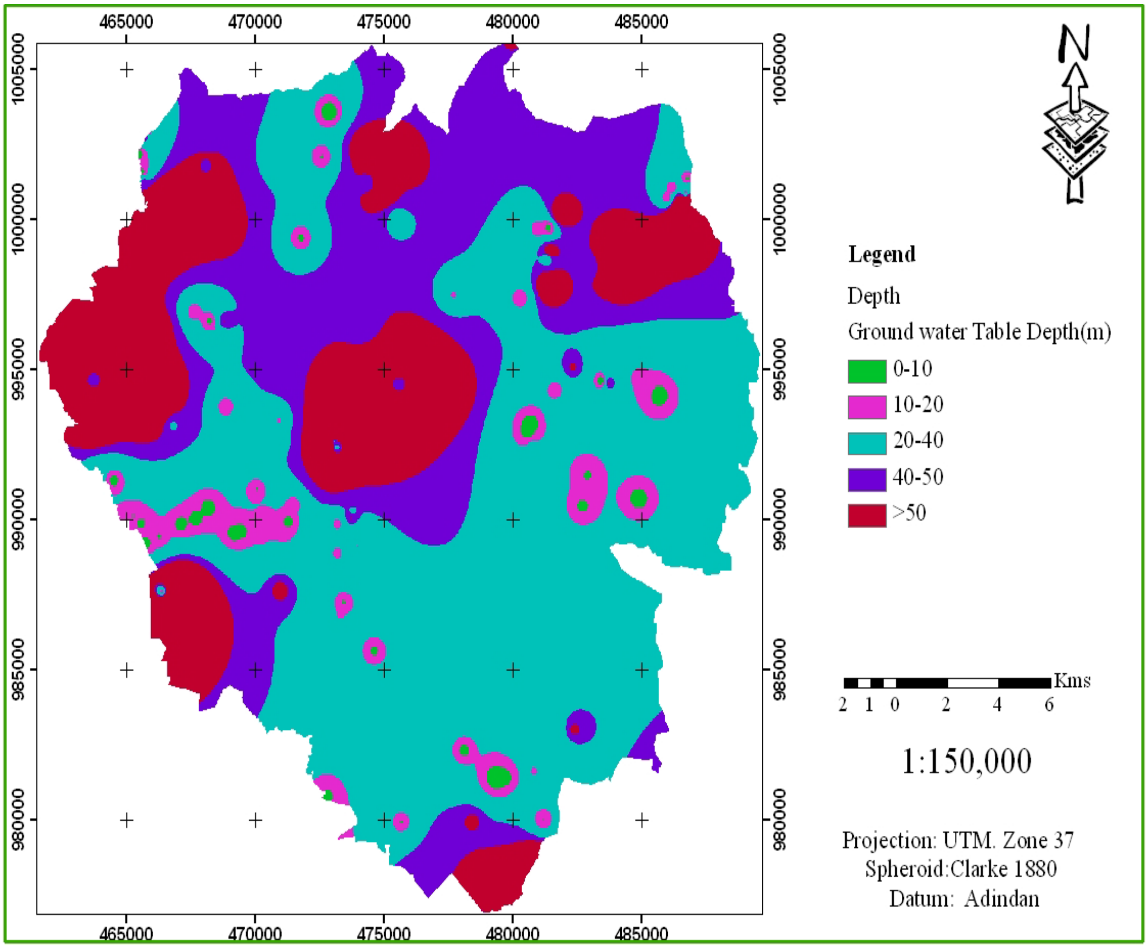


Figure 11 : Ground water depth class map of the study area.

Table 12: ground water depth suitability and area coverage

S.N	Depth to Ground Water Table (m)	Suitability	Rank	Area(km^2)	Area (%)
1	0-10	Unsuitable	1	78.4	14.9
2	10-20	Poorly suitable	2	87.8	16.7
3	20-40	Moderately suitable	3	124.1	23.5
4	40-50	Suitable	4	151.8	28.8
5	>50	Most suitable	5	84.9	16.1
Total				527	100

Table 12 shows that, 16.1% of the study areas is the most suitable and hence given higher rank (5) while 14.9% of the study area is unsuitable and hence given least rank (1). The remaining part of the study areas are, 28.8%, 23.5% and 16.7% of the areas are suitable, moderately suitable and poorly suitable for landfill site respectively. Therefore, this table was used to reclassify and standardized depth to ground water table map. Accordingly, thematic map of ground water depth of the study area was prepared as indicated in Fig.12.

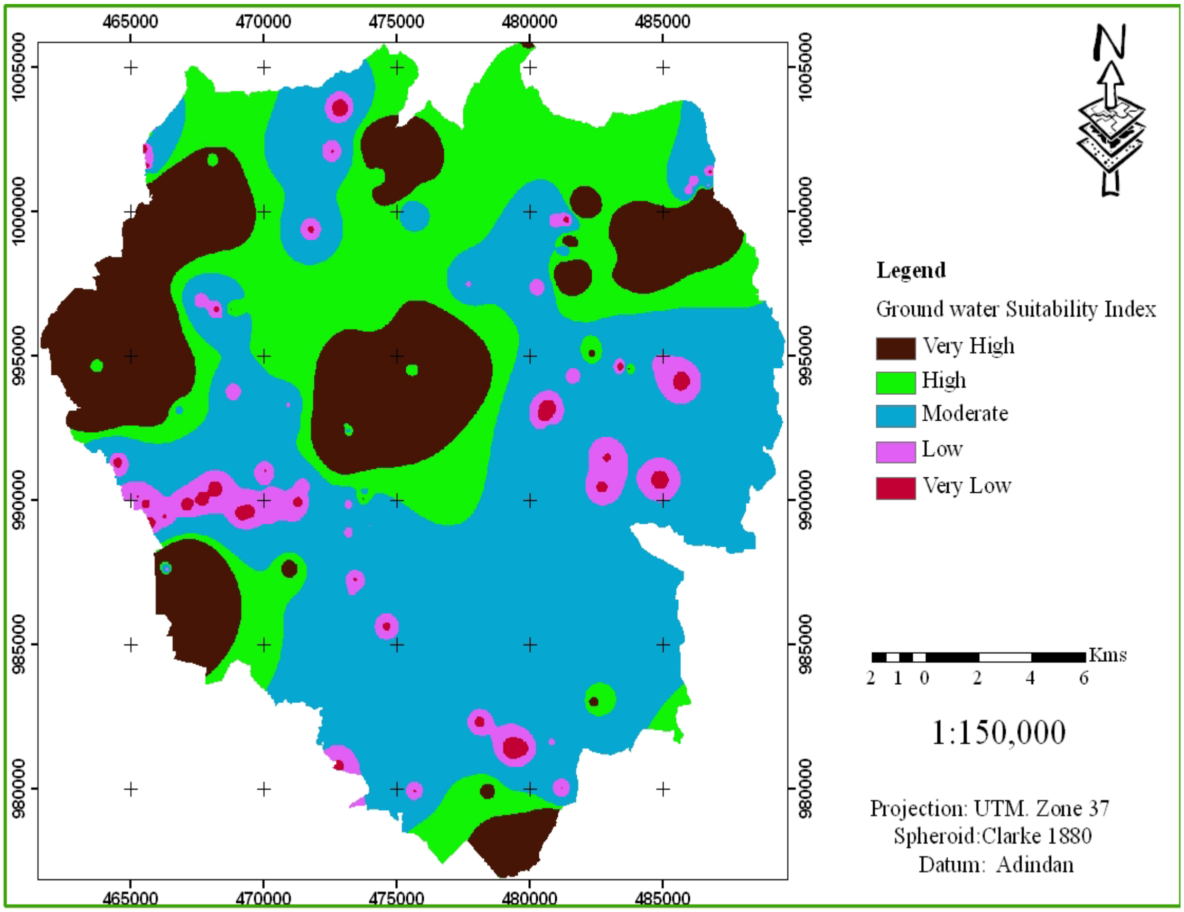


Figure 12 : Suitability sites map with respect to ground water depth of the study area.

E. Borehole proximity

The Ground water well points Which are existingly in use for drinking purpose were demarcated by ASWA. Contamination of ground/surface water resources by leachate is a principal concern in relation to disposal site (Ekmekcioglu *et al.*, 2010). By considering the contamination, the landfill far from the water well and the minimum buffer zone is 500m and the suitability was increased with increasing distance. The study area was classified in to 0-500m, 500-800m, 800-1200m, 1200-2000m and > 2000m (Fig. 13).

Table 13: Sites to borehole proximity and their respective area coverage.

S.N	Distance(m)	Area(km^2)	Area (%)
1	0-500	6.3	1.2
2	500-800	9.8	1.9
3	800-1200	20.0	3.8
4	1200-2000	58.4	11.1
5	>2000	432.5	82.0
Total		527	100

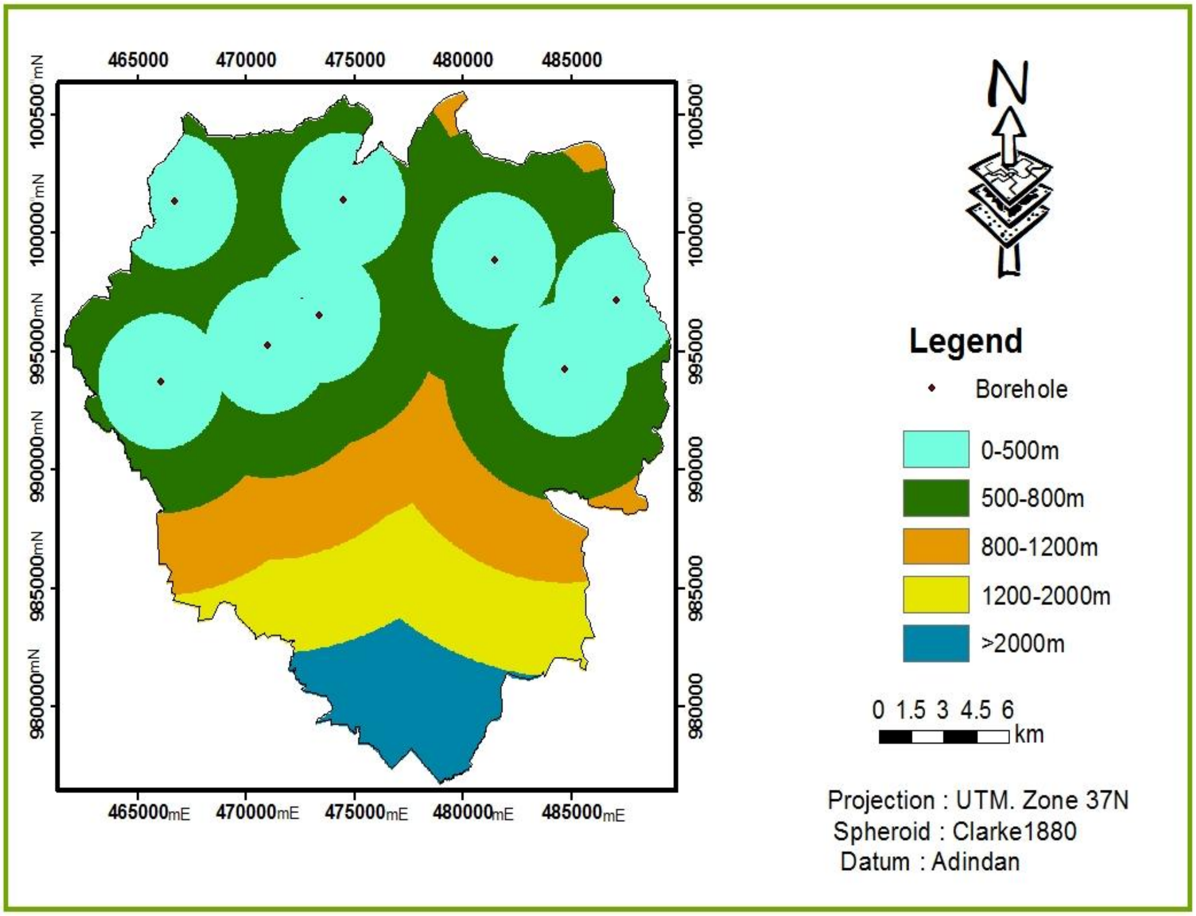


Figure 13 : Sites proximity to borehole map of the study area.

Table 14: Site suitability from borehole distance and area coverage.

S.N	Distances from landfill(m)	Suitability	Rank	Area(km^2)	Area (%)
1	0-500	Unsuitable	1	6.3	1.2
2	500-800	Poorly suitable	2	9.8	1.9
3	800-1200	Moderately suitable	3	20.0	3.8
4	1200-2000	Suitable	4	58.4	11.1
5	>2000	Most suitable	5	432.5	82.0
Total				527	100

Table 14 shows that, 82% of the total area is given more weight as most suitability for landfill site. However, 1.2% of the total area is unsuitable as near to borehole and hence excluded from siting processes. Generally, suitability level and weights were increased as one move away from the borehole site. As a result, 11.1%, 3.8% and 1.9% of the total area was suitable, moderately suitable and poorly suitable, respectively. According to their weight, borehole proximity map of the study area was standardized and suitability map was prepared (Fig. 14).

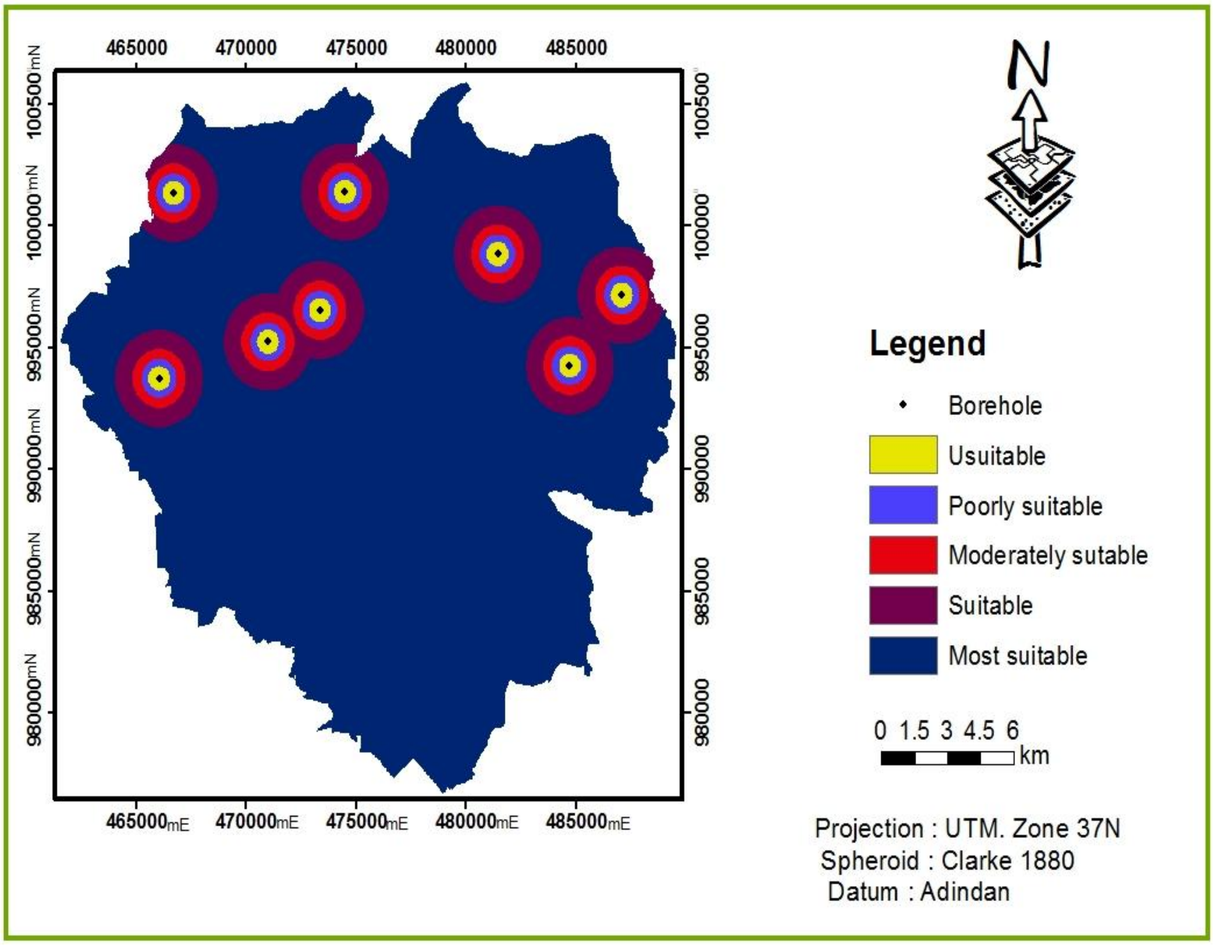


Figure 14 : Site suitability map with respect to borehole proximity of the study area.

F. Soil permeability

The most the amount of soil permeability, the most probable the flow of leachate to pollute the environment. In soils with low permeability, the producing leachate may stay within landfill area (Abdoli, 1993). The soil texture characteristics are considered for classifying the study area according to user defined membership. Rocks were considered unsuitable with 0 value. Soils with light to moderate, moderate to light, moderate and moderate to heavy textures were assigned 100, 150, 180 and 230 values respectively. Soils with heavy and heavy to very heavy texture were preferred for landfill establishment with value of 255 according to Boolean rule. Based on this evidence in the present study given 1 to 5 value for their respective texture, (Fig. 15).

Table 15: Soil types and their permeability with area coverage.

S.N	**Soil type**	**Permeability**	**Suitability**	Rank	Area(km^2)	Area (%)
1	PellicVertisol& Chromic Vertisol	Very low	Most suitable	5	321.5	61
2	Chromic Luvisols	Low	suitable	4	11.7	2.2
3	Eutric Nitisols	Moderately low	Moderately suitable	3	112	21.3
4	Orthic Solonckaks	High	Poorly suitable	2	39.2	7.4
5	Calcic Xerosols& Leptosols	Very high	unsuitable	1	42.6	8.1
Total					527	100

According to different researcher, for example (Abdoli, 1993), the amount of soil permeability is increase, the suitability site will decrease because the very high permeable soil, the most probable the entrance of leachate into groundwater and their pollution. Therefore 61% of the study area is most suitable (which is covered by Pellic Vertisol& Chromic Vertisol), 8.1% of the study area (Calcic Xerosols &Leptosols) is unsuitable for landfill site selection. The remaining 2.2%, 21.3% and 7.4% of the study area are suitable, moderately suitable and poorly suitable for landfill site respectively. The suitability soil map shows in the following figure.

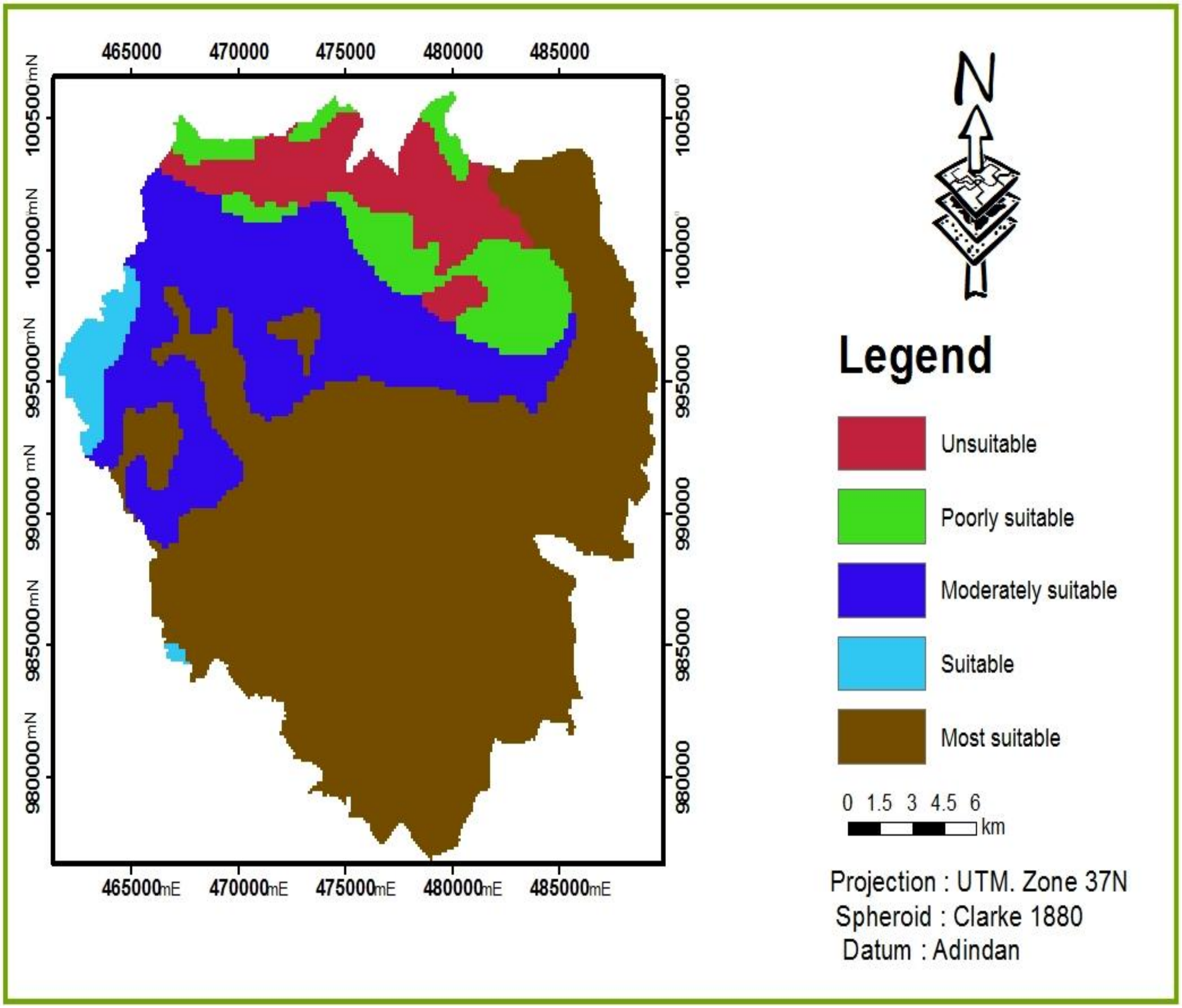


Figure 15 : Soil suitability map of the study area.

G. Faults

Faults were digitized from the geologic map. Faults can pose serious environmental threats in general and reduce the life span of the landfill in particular. GIS was used to generate multiple buffers around each fault and an extent of 100 m around landfill was taken as the minimum buffer zone. Waste disposal should also be away from faults (Akbari, 2008). Accordingly the city area was reclassified in to 0-100m, 100-2000m, 2000-4000m, 4000-6000m and >6000m buffer zone around each fault.(Fig.16).

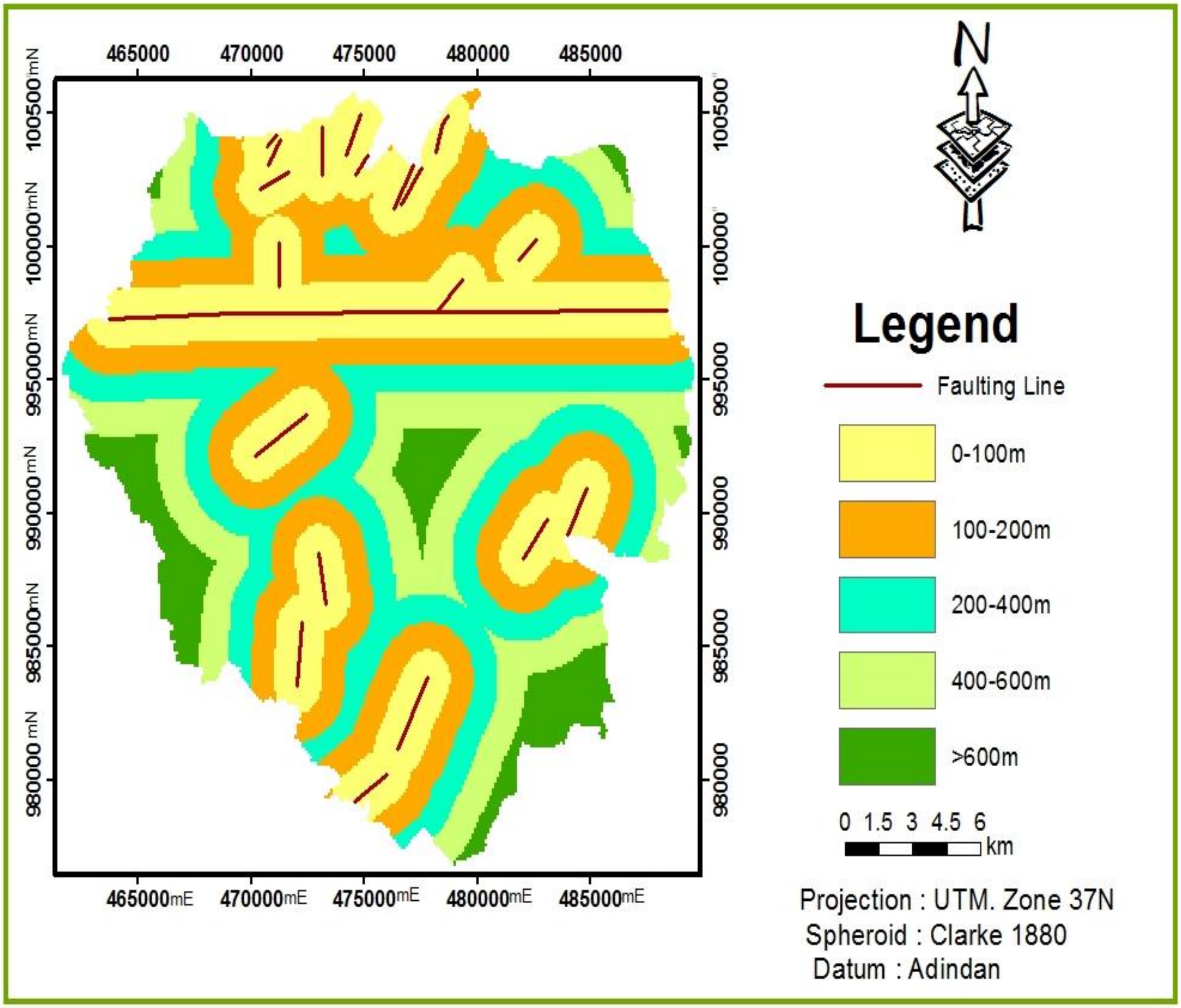


Figure 16 : Sites category from fault proximity map of the study area.

The major faults in the study area running east west via Kesem to Ambo crossing Addis Ababa were the longest fault digitized in the area. According to Zanettin *et al*. (1974), as cited by Tamiru (2003), this fault marks the upper (outer) boundary of the western Ethiopian rift margin immediately north of Addis Ababa-Ambo road. Moreover, Filowha fault that has a trend of NE-SW was also digitized, buffered and mapped.

Table 16: Sites to fault proximity and area coverage.

S.N	Distance(m)	Area(km^2)	Area (%)
1	0-100	104.6	19.8
2	100-2000	106.8	20.3
3	2000-4000	106.1	20.1
4	4000-6000	105.0	19.9
5	>6000	104.5	19.8
Total		527	100

Faults are geological conditions that cause limitation for siting a landfill (Gemitzi *et al*., 2007). As there is no complete and exact information about all faults in the city the preliminary background is that all the faults in geology map are active (Fathi, 2007). This criterion is considered as constraint, because it decreases the life span of the landfill. therefore faults and their 100 m buffer were considered unsuitable with value 1 and the other areas were considered suitable with value 2 to 5.

Table 17: Site suitability with respect to fault proximity and area coverage.

S.N	Distance	Suitability	Rank	Area(km^2)	Area (%)
1	0-100	Unsuitable	1	104.6	19.8
2	100-2000	Poorly suitable	2	106.8	20.3
3	2000-4000	Moderately Suitable	3	106.1	20.1
4	4000-6000	Suitable	4	105.0	19.9
5	>6000	Most suitable	5	104.5	19.8
Total				527	100

Table 17 show that, 19.8% of the total area is given more weight as most suitability for landfill site and the same percent (19.8%) of the total area is unsuitable as near to fault and hence excluded from siting processes. Generally, suitability level and weights were increased as one move away from the fault site. As a result, 19.9%, 20.1% and 20.3% of the total area were suitable, moderately suitable and poorly suitable, respectively. According to their weight, fault proximity map of the study area was standardized and suitability map was prepared (Fig.17).

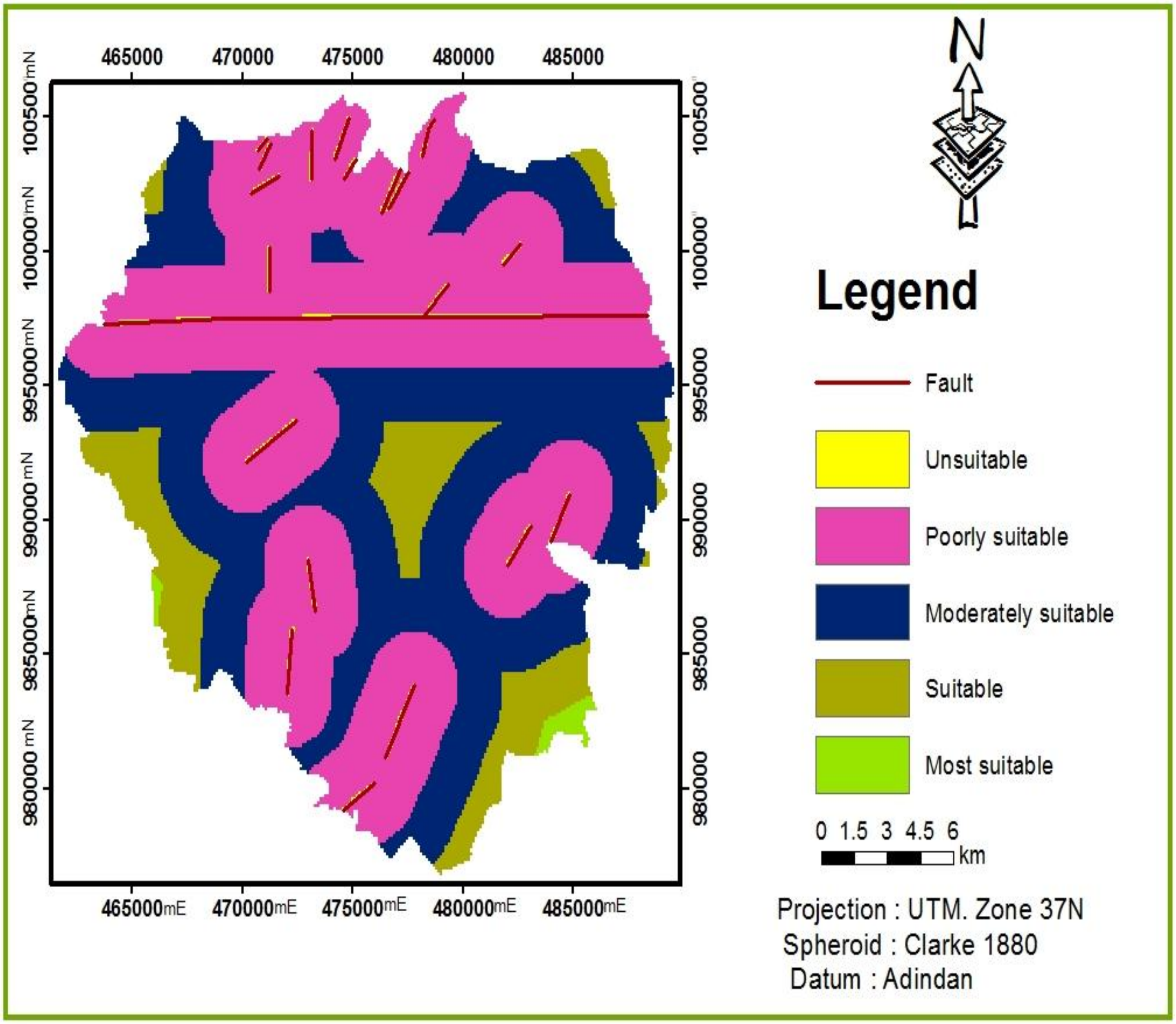


Figure 17 : site suitability with respect to fault proximity map of the study area.

Environmental criteria

In the present study only the sensitive habitats sub criterion was included in this category.

A. Sensitive habitat

Giving special attention for this criterion different from other land use type is important, because leachate will produces from landfill, so constructing landfill very close to sensitive habitat causes degradation and potential pollution to sensitive ecosystems (Fathi, 2007). In Addis Ababa, it has been attempted to conserve the nature of the areas which are under the management of the environmental department. These areas are protected areas, wildlife refuges like 6 kilo lion compound, national monuments and national parks (forexample Gulele Botanic Garden National

Park) are as a sensitive habitat that causes constraint for landfill establishment and therefore theses area and their 500 m buffer zone were excluded from the landfill site in the land use /land cover classification criteria .

Socio economic criteria

Socio economic criteria are composed of residential areas, road network, land use and airport runway.

A. Residential areas

Landfill site should be located far from populated centers of the city. Otherwise it causes decreasing the aesthetic and land value of the surrounding area and bad odors (Chang *et al*, 2008). By considering sufficient landfill capacity for the city long term requirements, landfill site should not be affected by the development plans of the city (Abdoli, 1993). Due to its negative effects the areas of 2 kilometers distance around the residential areas were omitted from the potential areas and according to the Boolean logic were given 0 value. The greater the distance from residential areas the more suitable the area is for landfill site selection. According to Allen (2000), it should be located at least 5 km distance from urban centers. On the other hand, the landfill site should be located within 10 km of an urban area due to the economic considerations (Serwan *et al*., 1998).

By considering all the suggested safe distances in the literature, minimum distances for the study area were determined as 5 km for urban centers. These distances were used to create buffer zones around settlement areas and excluded from the study area within 5km and more than 10km . generally areas were classified as 0-5000m, 5000-6000m, 6000-7000m, 7000-8000m, 8000-1000m and >10000m according to their suitability by ranking with the help of literature review.

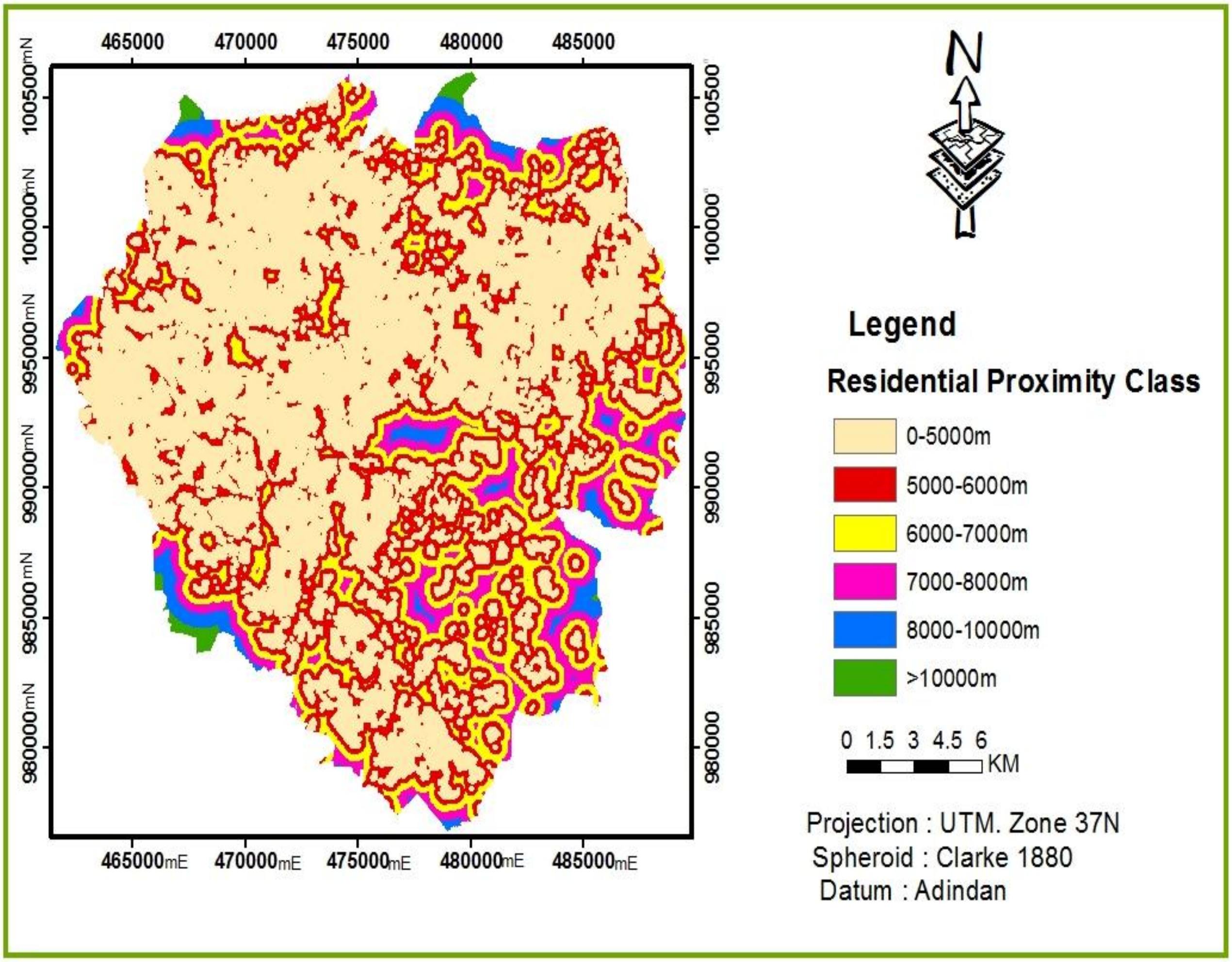


Figure 18: Site proximity to residential map of the study area.

Table 18: Site suitability with respect to residential proximity and area coverage.

S.N	Distance(m)1	Suitability	Rank	Area(km^2)	Area (%)
1	0 m - 5000 m, >10000	unsuitable	1	202.1	38.3
2	5000 m - 6000	Poorly suitable	2	96.5	18.3
3	6000 m - 7000	Moderately suitable	3	90.1	17.1
4	7000 m - 8000	suitable	4	74.1	14.1
5	8000-10000	Most suitable	5	64.2	12.2
Total				527	100

Table 18 shows that, 12.2% of the total area was given more weight as most suitability for landfill site. However 38.3% of the total area was unsuitable as very near to and very far away from the residential area and hence excluded from siting processes. Generally, suitability level and weights were decreased as very far away from the residential area and very close to the residential area. As a result, 14.1%, 17.1% and 18.3% of the total area were suitable and moderately suitable and poorly suitable respectively. According to their weight, residential proximity map of the study area was standardized and suitability map was prepared (Fig.19).

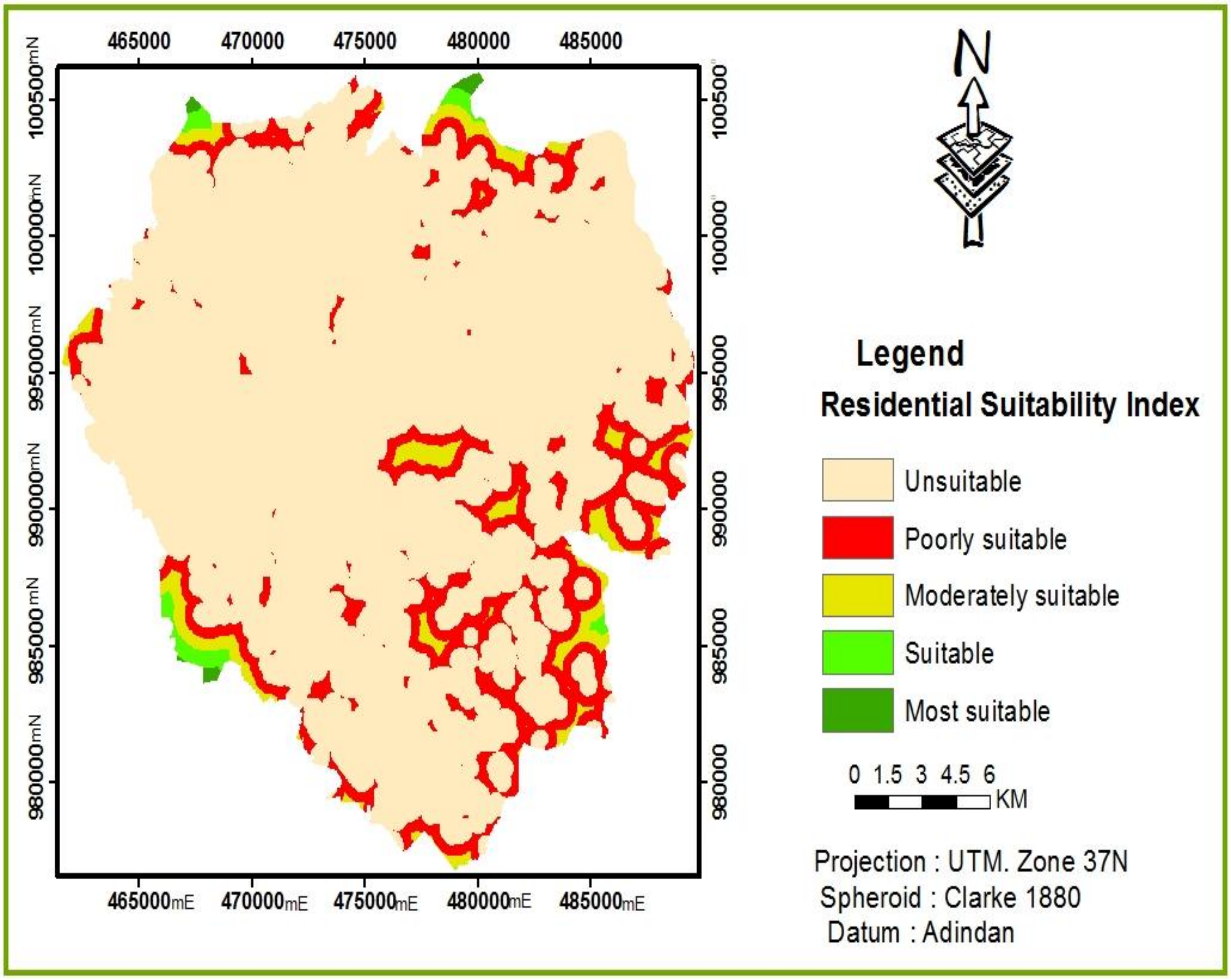


Figure 19 : Sites suitability with respect to residential proximity map of the study area.

B. Road network

The selected site should be close to the highways and main roads, because building roads for landfill access especially in long distances requires huge preliminary expenses (Abdoli, 1993). For the connection road map, to prevent the interference of solid waste transferring vehicles with the main traffic, the lowest pixel value allocated to 100m distance from existed roads. On the other hand a distances of more than 1000 m were considered unsuitable due to the more transportation expenses. The existing road network map of the study area was shown below.

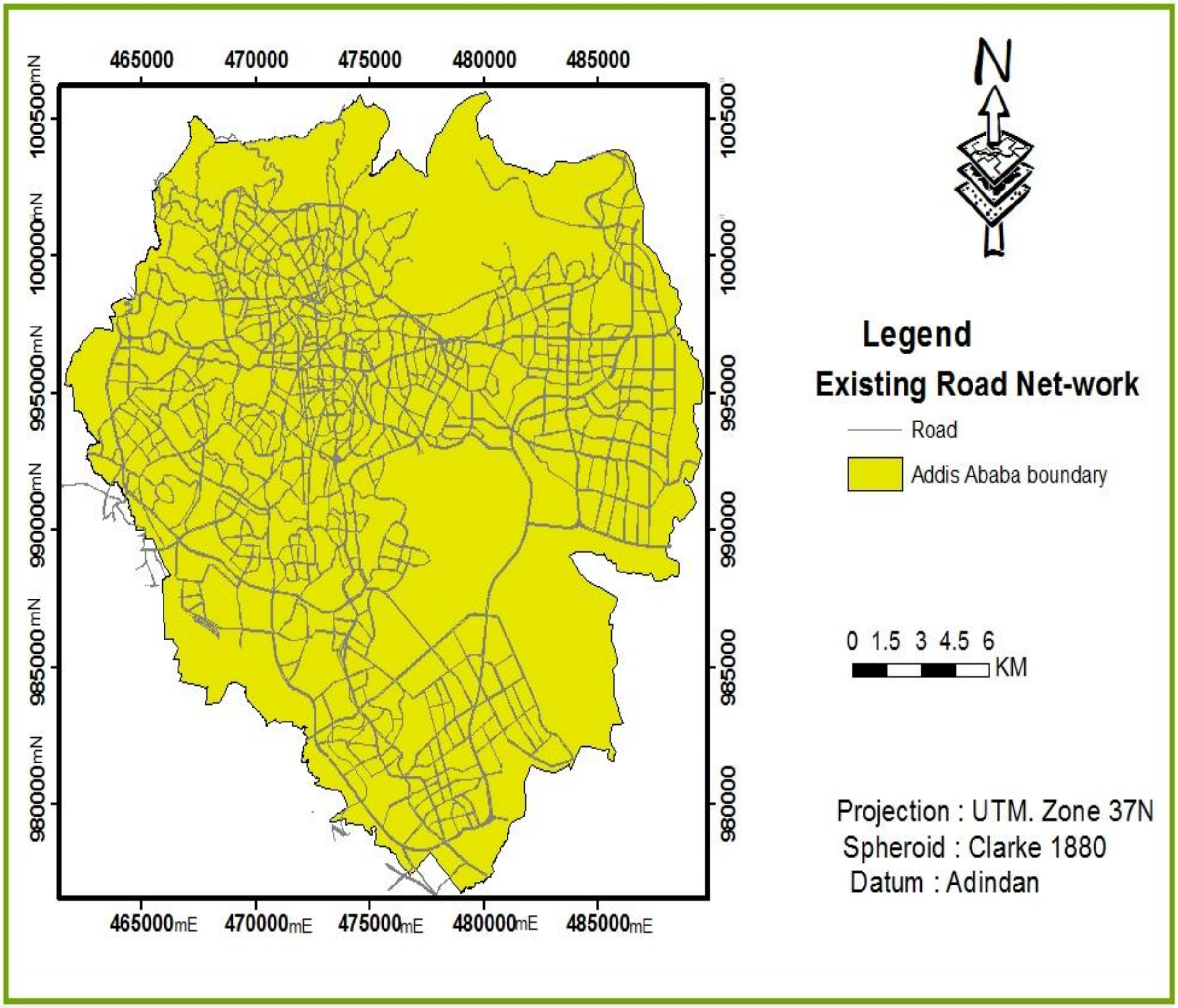


Figure 20 : Existing road network map of Addis Ababa

Source, Ethiopian Road Construction Authority, 2014.

In the present study by considering the two extreme, the suitability of road network classified as 0-100m, 100-300m, 300-500m, 500-700m,700-1000m and >1000m (Fig. 21),the suitability is low vey near to the road and very far from it, because of traffic congestion and more transportation expense respectively.

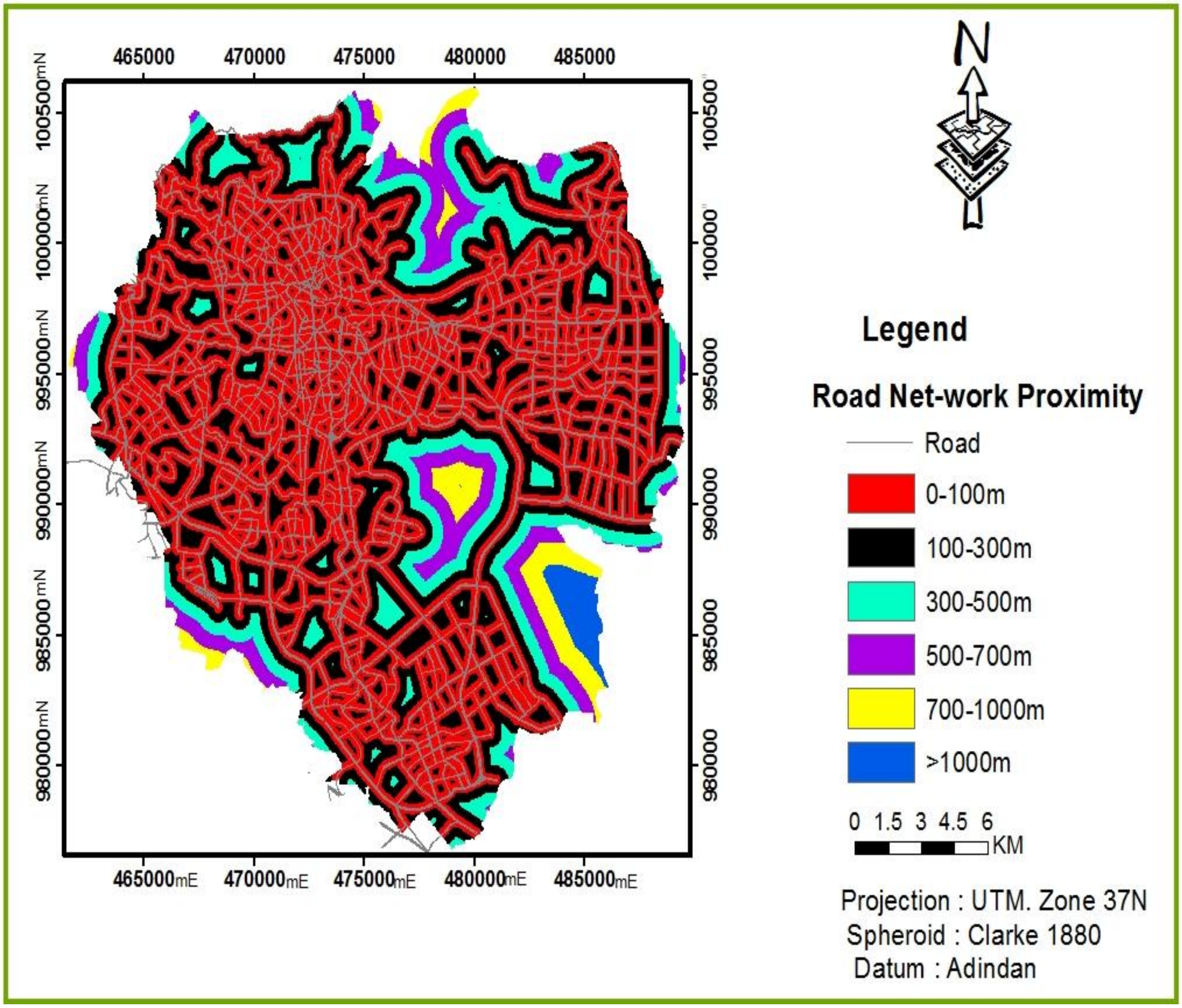


Figure 21 : Sites proximity to road network map of the study area.

Table 19: Sites suitability with respect to road network proximity and area coverage.

S.N	Distance(m)	Suitability	Rank	Area(km^2)	Area (%)
1	0- 100, > 1000	Unsuitable	1	268.2	50.9
2	100- 300	Poorly suitable	2	155.7	29.5
3	300- 500	Moderately suitable	3	48.9	9.3
4	500- 700	Suitable	4	27.8	5.3
5	700-1000	Most suitable	5	26.4	5.0
Total				527	100

Table 19 shows, 5% of the total areas is the most suitable while, 50.9% of the study area is unsuitable for landfill. The remaining area 5.3%, 9.3% and 29.5% of the study areas are suitable, moderately suitable and poorly suitable for landfill siting respectively. The spatial distribution of road proximity suitability map is shown in the Figure 22.

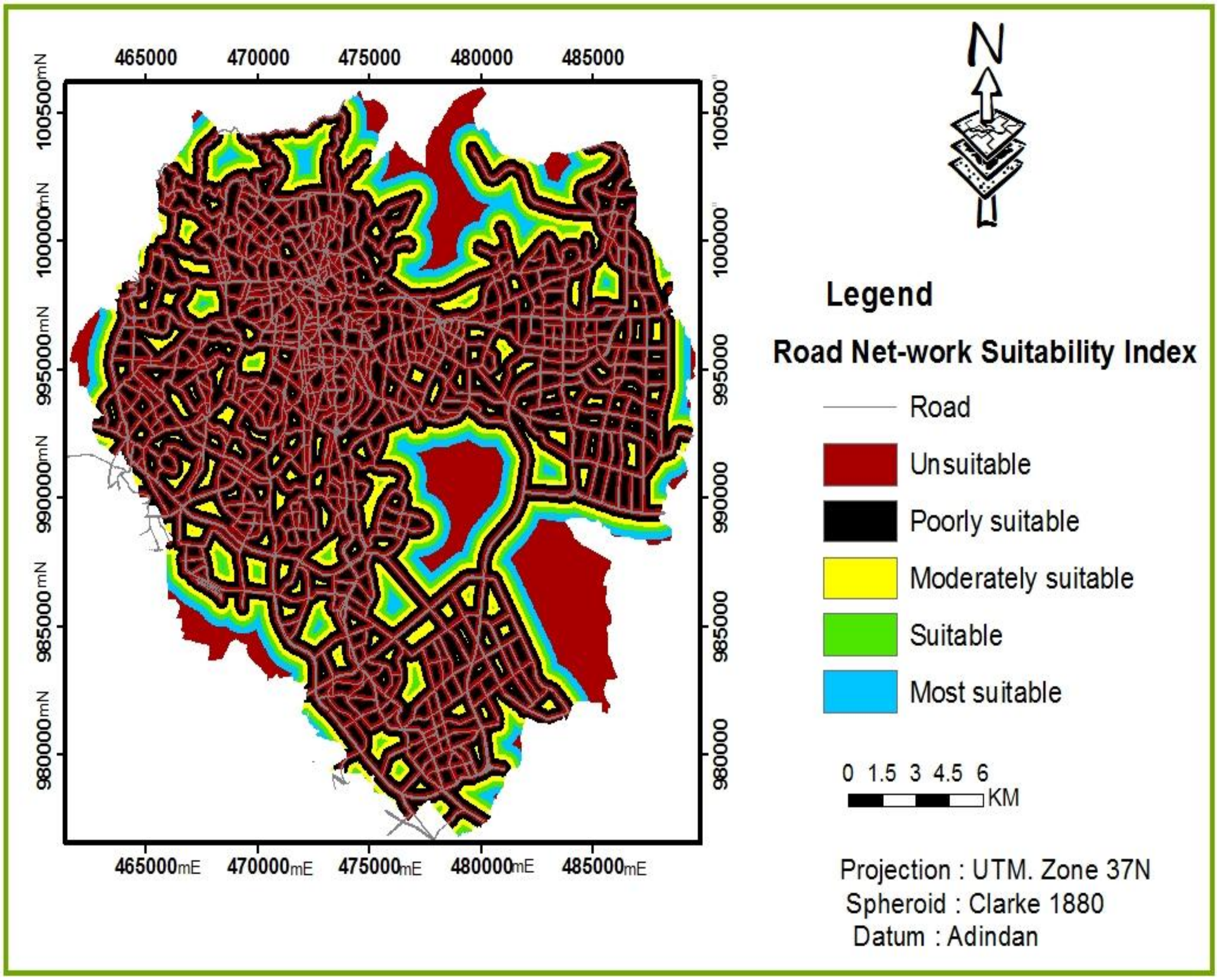


Figure 22 : Site suitability from road proximity map of the study area.

C. Land use/Land cover

Land use map Obtained from Addis Ababa municipality was used for this Analysis, and thirteen different land use types were included in this study (Figure 23).

This criterion is not on the basis of specific directions and may alter according to the study area (Kontos *et al*., 2005). From the stand point of economy it is better to choose Open space which can be used after landfill site completion or can be sold (Abdoli, 1993).

Sites with potential for higher value uses such as nature conservation, agriculture, residential development and institutions should not be used for landfill(Ekmekcioğlu *et al*.,2010).

The identified uses in the study area are consisted of open space, road network, agricultural area, forest area, built up area, cemetery area, festival site, social service area, recreational area, manufacturing area, parks, slaughter and rivers (source, attribute table of land use/land cover in Arcmap).

The land use vector map is then converted to a raster map, and then land use types are grouped and ranked according to their suitability for a landfill site according to user defined membership (Table 20).

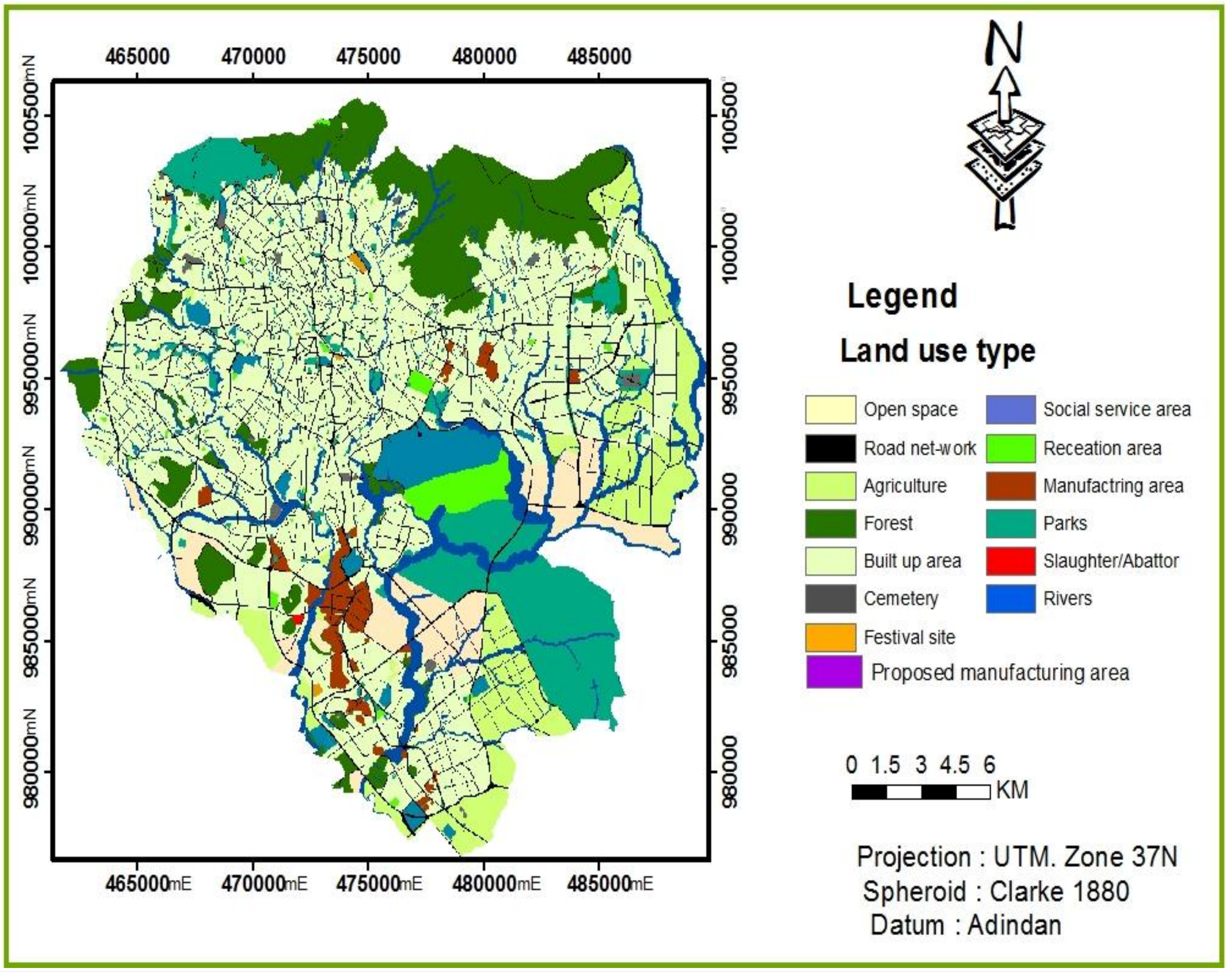


Figure 23 : Land use/Land cover map of Addis Ababa in 2014.

Source: Addis Ababa Municipality Shapefile format data, 2014.

Table 20 : Land use type and their suitability for landfill.

S.N	Land use/ Land cover	Suitability	Rank	Area (km^2)	Area (%)
1	Built up area, road, cemetery, festival site, social service area, recreational area, manufacturing area, park, abattor and rivers	Unsuitable	1	136.7	25.9
2	Agricultural area	Poorly suitable	2	89.1	16.9
3	Forest	Moderately suitable	3	119.6	22.7
4	Proposed Manufacturing area	Suitable	4	99.9	19.0
5	Open space	Most suitable	5	81.7	15.5
Total				527	100

Table 20 shows, in the land use /land cover suitability analysis 15.5% of the study area is the most suitable, 19.0% is suitable, 22.7% is moderately suitable, 16.9% is poorly suitable and 25.9% of the study area is unsuitable for landfill site. The Suitability of land use on the study area was indicated in figure 24.

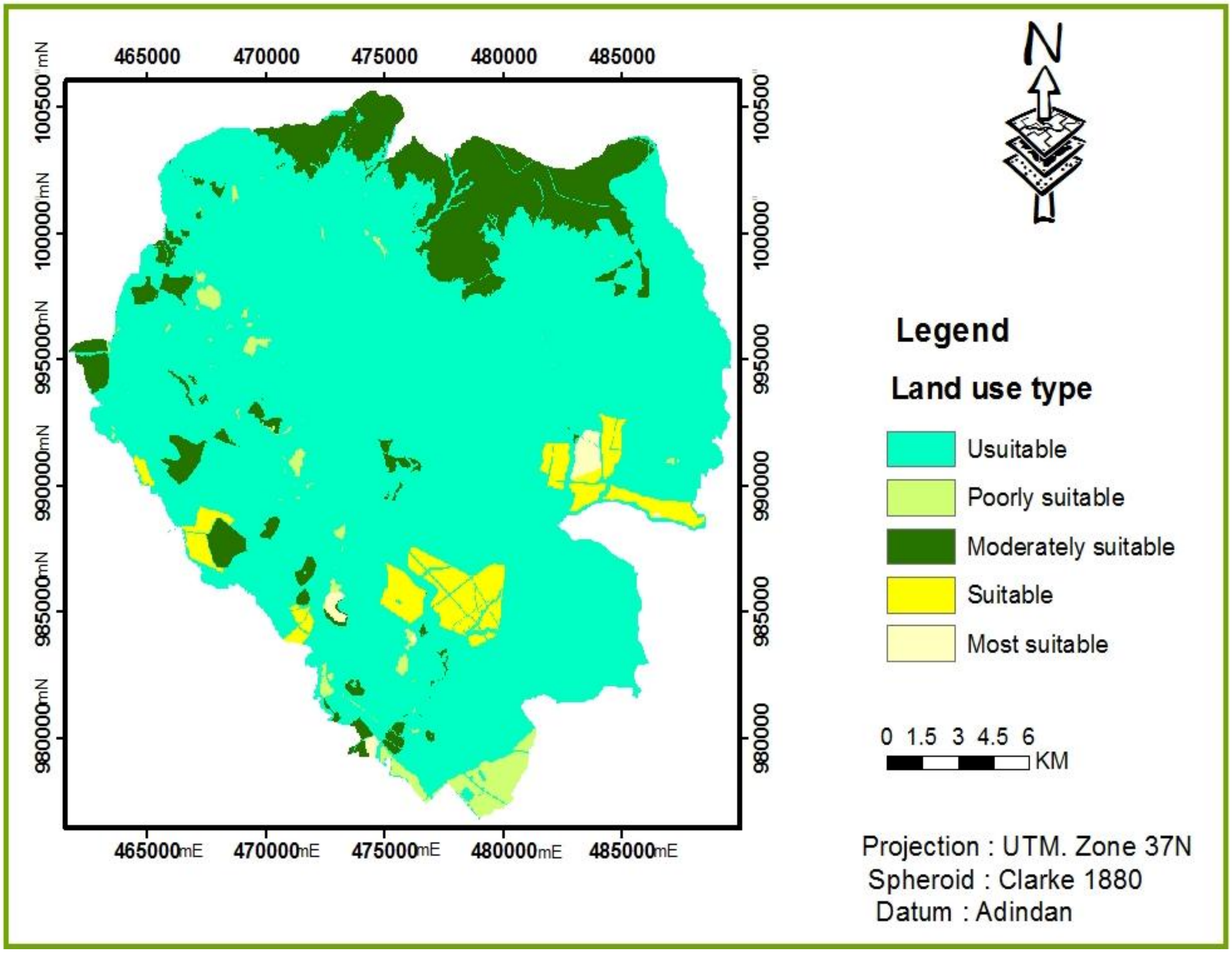


Figure 24 : Land use/Land cover suitability map of the study area.

D. Airport

Landfill sites attract variety of birds to be accumulated around. This issue may interfere with the operation of airplanes. So it is essential to consider suitable distance from landfill site according to airport and airplane types (Daneshvar, 2004). By considering this criterion as a constraint, for safety matters, 3 kilometer buffer around airport was omitted . In literature, there are different values related to the safe distances from airports like 3000 m according to (Chalkias ,1997) and 3048m according to (Bagchi, 1994).

By considering these suggested values, the safe distance for an airport was determined as a minimum of 3000m (3km) far from landfill site. The layer of airport was classified as most suitable, suitable, moderately suitable, poorly suitable and unsuitable for a landfill site by assigning values 5, 4, 3, 2 and 1 respectively (Table 22), which is shown in Figure 26. To finalize the map for analysis, the vector map was converted to raster map.

Table 21: Sits class proximity to airport and area coverage.

S.N	Distance(km)	Area (km2)	Area (%)
1	0-3	57.5	10.9
2	3-6	111.1	21.1
3	6-9	163.0	30.9
4	9-12	146.6	27.8
5	>12	48.8	9.3
Total		527	100

Table 21 shows, 30.9% of the study area had a distance of 6 to 9km far from the airport that it took the largest percentage, and 9.3% of the study area was the farthest area and it took the lowest area coverage of the study area.

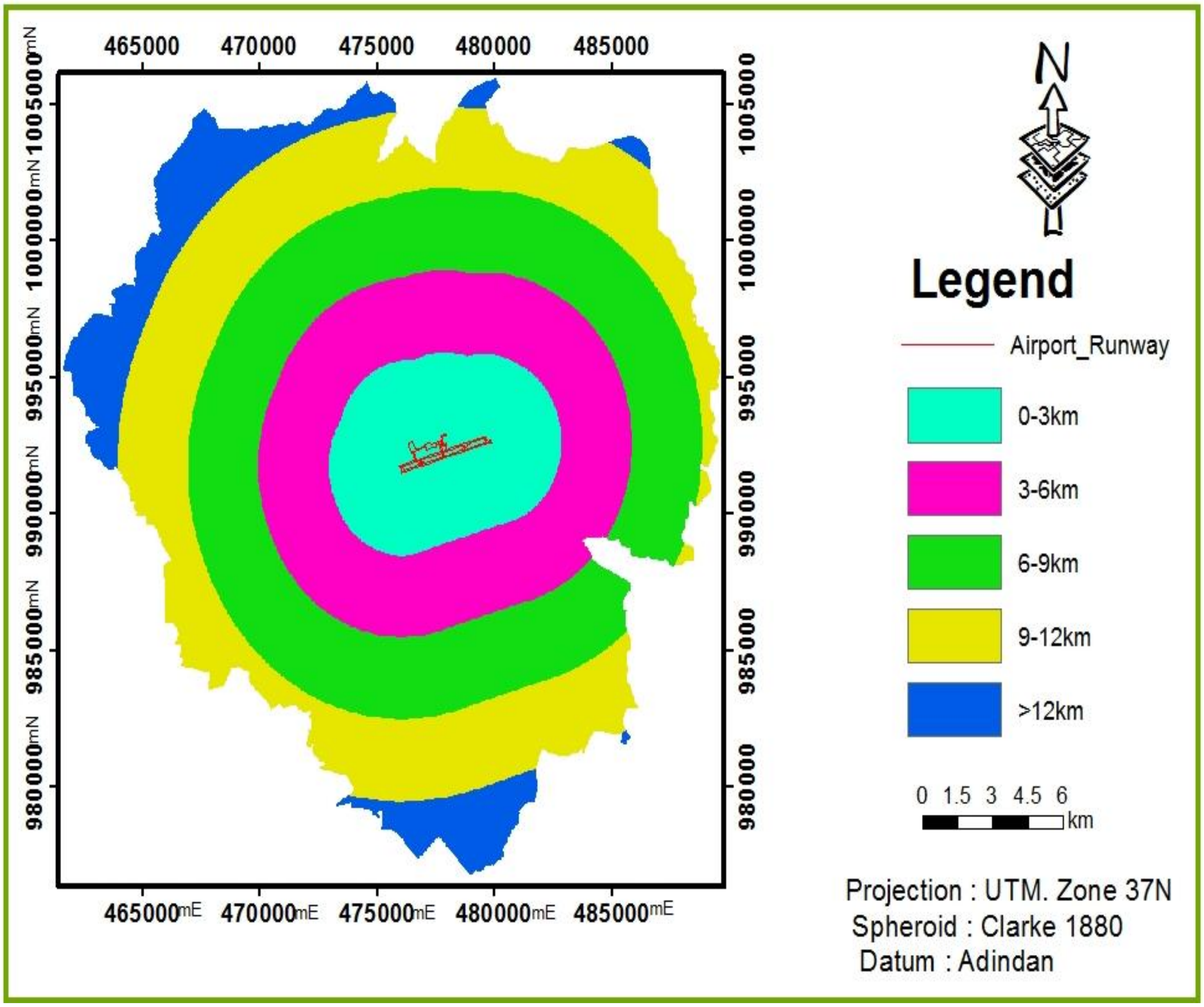


Figure 25 : Sites proximity to airport map of the study area.

Proximity from Bole International Airport was prepared to identify the most preferable site for solid waste landfill within Addis Ababa region. Based on the fact that areas far from airport were more preferred than near sites, more weight was given for far away site and vice versa. Accordingly, for areas >12000m (12km) away from airport was given more weight as very highly suitable. The least weight was given for areas within 3000m radius and considered as unsuitable for landfill site. The suitability and weight assigned to each buffer classes are summarized in (Table 22).

Table 22: Sites suitability with respect to airport proximity and area coverage.

S.N	Distance	Suitability	Rank	Area(km^2)	Area(%)
1	0-3km	Unsuitable	1	57.5	10.9
2	3-6km	Poorly suitable	2	111.1	21.1
3	6-9km	Moderately suitable	3	163.0	30.9
4	9-12km	Suitable	4	146.6	27.8
5	>12	Most suitable	5	48.8	9.3
Total				527	100

Table 22 shows that, 9.3% of the total area is given more weight as most suitability for landfill site. However, 10.9% of the total area is unsuitable as near to airport and hence excluded from siting processes. Generally, suitability level and weights increased as one move away from the airport site. As a result, 27.8%, 30.9% and 21.1% of the total area were suitable, moderately suitable and poorly suitable, respectively. According to their weight, airport proximity map of the study area was standardized and suitability map was prepared (Fig.26).

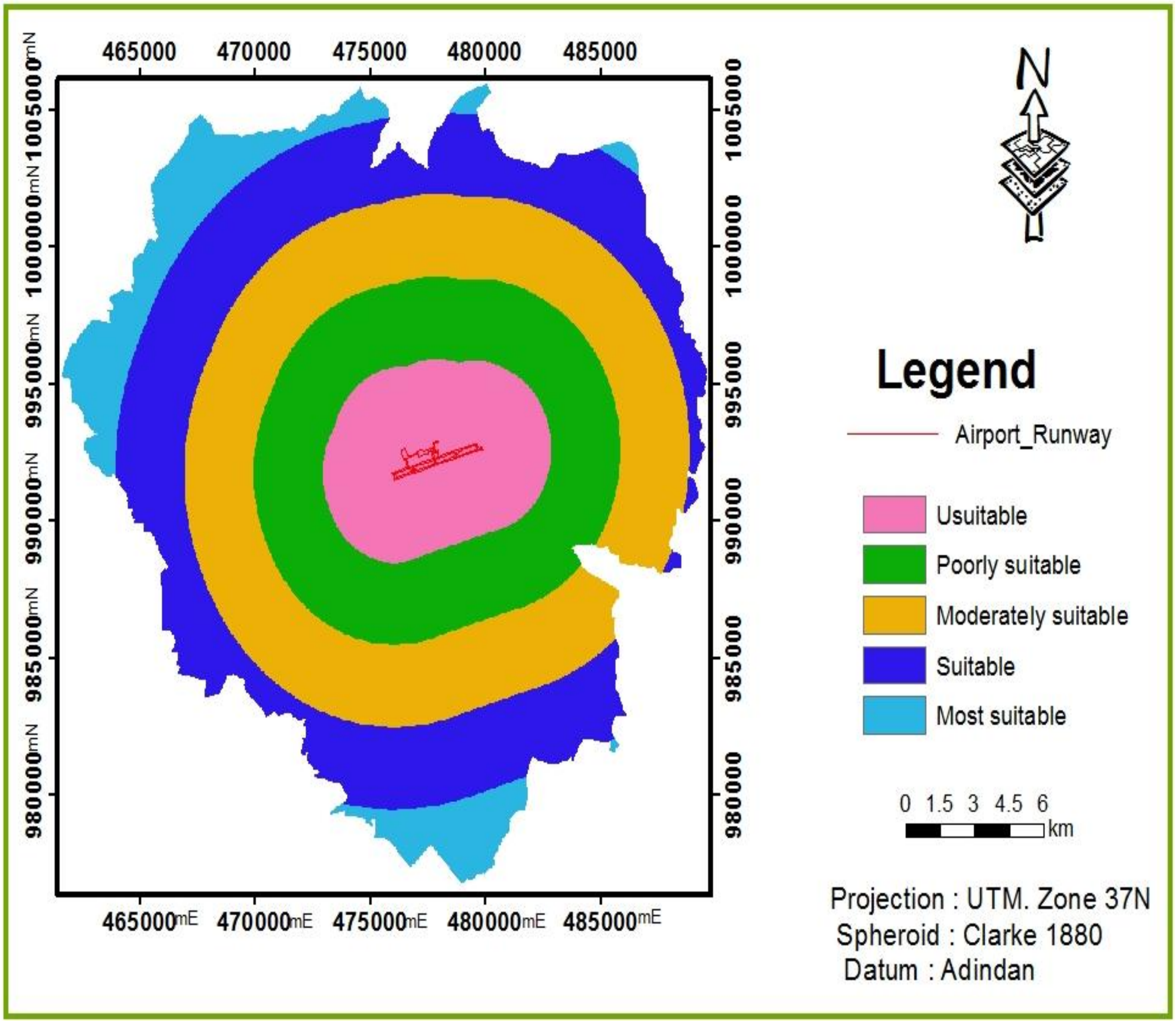
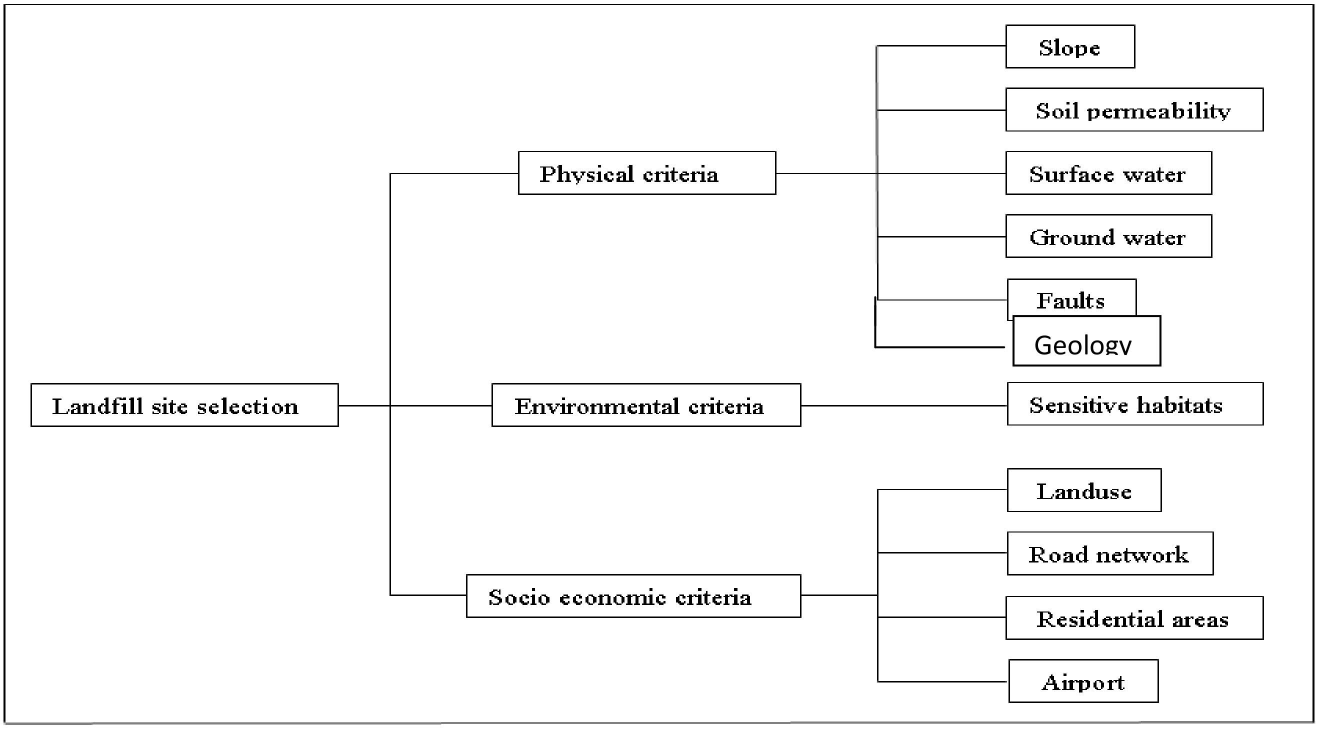


Figure 26 : Sites suitability to airport proximity map of the study area.

Table 23: Structure of landfill site selection criteria



3.4.4.2. Assigning Criteria 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 the changes in the range of variation for each evaluation criterion and the different degrees of importance being attached to these ranges of variation (Kirkwood, 1997.

Pairwise Comparison Method

The method involves pairwise comparisons to create a ratio matrix. It takes 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 26.

Table 24**:** 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. The 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 the 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 of 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; $CR = CI / RI$

Where RI is the random index and depends on the number of elements being compared

Table 25 :Assigning weight for each criteria.

	LU	RS	BH	GW	SW	SL	SO	GL	FL	AP	RD	N^{th} root	Eigen weight	Weight (%)	ST	AV
LU	1	2	3	3	3	5	5	5	7	7	7	3.79	0.25	25	2.7	10.8
RS	1/2	1	2	3	3	3	5	5	5	7	7	3.00	0.20	20	2.2	11
BH	1/3	1/2	1	1	2	3	3	3	5	5	5	1.89	0.13	13	1.4	10.8
GW	1/3	1/3	1/1	1	2	3	3	3	5	5	5	1.58	0.11	11	1.1	10
SW	1/3	1/3	1/2	1/2	1	3	3	3	3	5	5	1.44	0.10	10	0.8	8
SL	1/5	1/3	1/3	1/3	1/3	1	2	2	3	3	5	0.92	0.06	6	0.7	11.7
SO	1/5	1/5	1/3	1/3	1/3	1/2	1	2	3	3	3	0.75	0.05	5	0.7	14
GL	1/5	1/5	1/3	1/3	1/3	1/2	1/2	1	3	3	3	0.53	0.04	4	0.6	15
FL	1/7	1/5	1/5	1/5	1/3	1/3	1/3	1/3	1	2	3	0.43	0.03	3	0.3	10
AP	1/7	1/7	1/5	1/5	1/5	1/3	1/3	1/3	1/2	1	3	0.35	0.02	2	0.3	15
RD	1/7	1/7	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/3	1	0.26	0.01	1	0.2	20
TL												14.94	1.00	100	11	136.3

Where: Lu- Land use/Land cover
Rs- Residential
BH- Borehole
GW- Ground water depth
SW- Surface water
SL- Slope
SO- soil

GL- Geology
FL- Fault
AP- Airport runway
AD- Road
TL- Total
ST- Standardization
AV- Average

λ=136.3/11 =12.4

Consistency Index (CI)= (λ - n)/(n-1) = (12.4-11)/(11-1) =1.4/10 =0.14

Consistency ratio (CR) which is defined as follows:

$$CR = CI / RI = 0.14/1.51 = 0.09$$

If CR< 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if CR ≥ 0.10, the values of the ratio indicates inconsistent judgments(Saaty,1980).

In this study CR = 0.09 which is less than 0.10, so the weight which given for each criteria were more reasonable.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Landfill Suitability Analysis Results

A landfill must be situated and designed so as to meet the necessary conditions for preventing pollution of the soil, groundwater or surface water and ensuring efficient collection of leachate. Also a landfill site should be kept as far as possible away from population density, for reducing pollution impact to public health. On the other hand, the landfill site should be placed not as very close to the existing roads to avoid traffic congestion and degradation due to leachate flowing, and also it should be placed not very far from the existing road for transportation and collection costs. Furthermore, the landfill site with slope either too steep or too flat is not appropriate for constructing the landfill. Eleven suitability criteria (slope, surface water, Ground water depth, borehole, distance from residential area (distance from urban areas), transportation network, air port, soil permeability, geology, fault line and land use map) were used in this study. A map was created for each suitability criterion and a final composite map was finally produced by weighted overlaying of the individual maps. The definition of the layer's weights is shown in table 25. The weights were assessed by taking into account the possibility of modifying the natural conditions of the sites by appropriate engineering interventions (Delgado *et al*., 2008). For example, high weights were given to the land use and the ground water related criteria. On the contrary, the roads were considered less important, because it can be extended and modified, if required by a given project. Moreover, the railway of Addis Ababa was constructed passing through the road center. In this regard the suitability of land fill for road proximity and railway proximity are different. That means landfill must not be located within 500 m of a railway line (Sener *et al*., 2006). But in the case of road proximity it is suitable as it close to the main road (Abdoli, 1993). Therefore, in order to harmonious these contradictory criteria, the criteria of road were given less weight. The layers buffer zones used, and rankings are summarized in table 25 and the total result was presented in table 26.

Table 26 : Landfill suitability and area coverage.

S.N	Suitability	Area (km^2)	Area(%)
1	Most suitable	42.9	8.1
2	Suitable	4.8	0.9
3	Moderately suitable	72.1	13.7
4	Poorly suitable	350.2	66.4
5	Unsuitable	57.0	10.9
Total		527	100

Table 26 shows that, 8.1% of the total area is most suitable for landfill site. whereas, 10.9 % is unsuitable. The remaining parts of 0.9%, 13.7%, 13.7% and 66.4% are suitable, moderately suitable and poorly suitable respectively. Accordingly the overall suitability of the study area was standardized and suitability map was prepared (Fig.27).

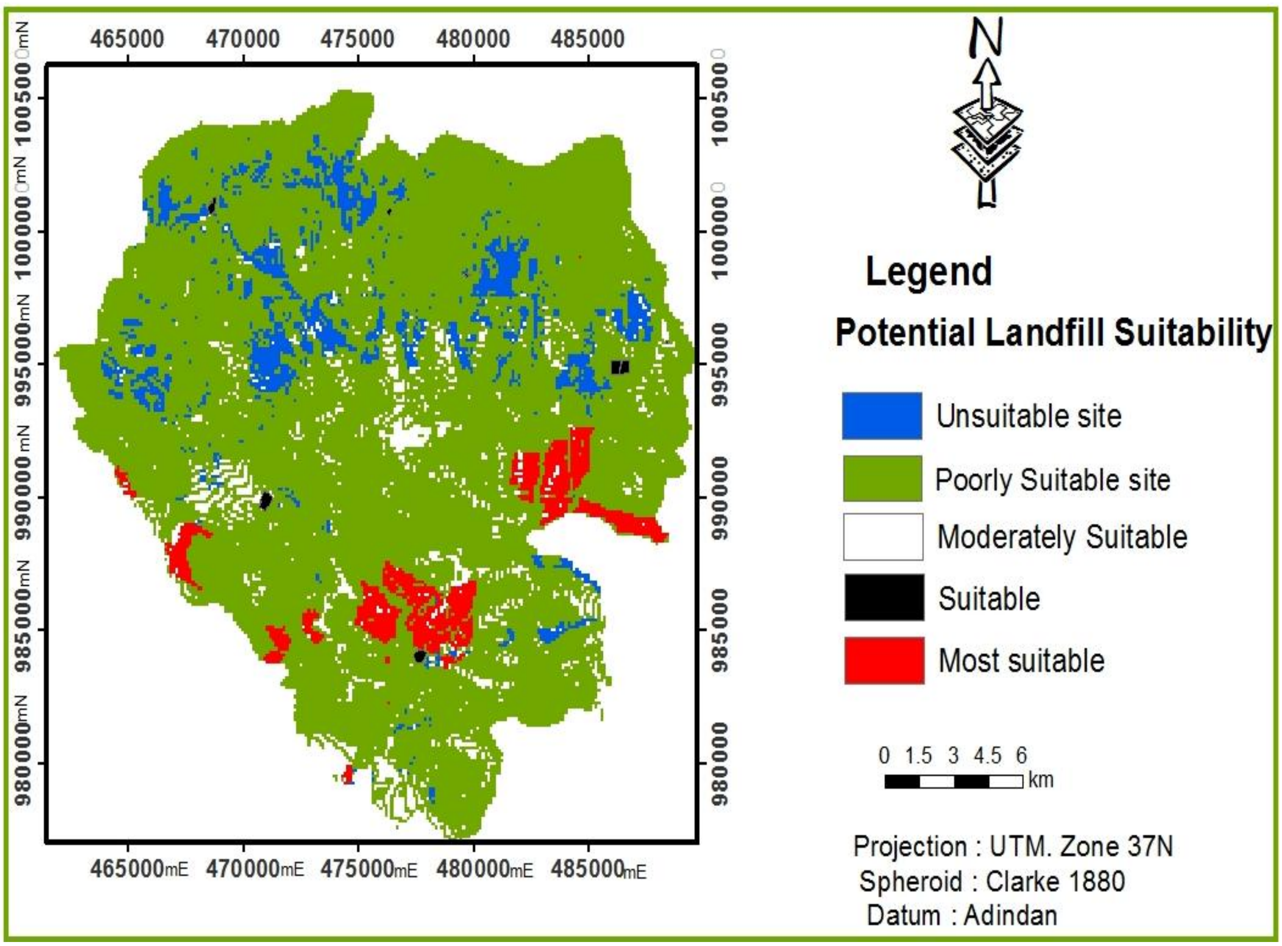


Figure 27 : Potential Landfill Suitability Map for Addis Ababa City Administration.

The overall site suitability analysis showed five landfill suitability class as unsuitable, poorly suitable, moderately suitable, suitable and most suitable. The importance of environmental and socio-economic factors like geology, permeability, ground water table depth, fault, slope, proximity from groundwater well, airport and streams/rivers, for determining landfill sites was not the same.

The geology map of the study area initially twelve rock type could be recognized. These are Wecheca-Yere-Furi-Ignimbrite (Ti3), Intoto mixed rock (Ti1), Intoto trachyte (Tt1), Repi basalt (Tb3), Lower ignimbrite (Ti2), Foota basalt (Tb1), Chalaklaka basalt (Tb2), Wechecha-Yerer-Furi-Trachyte (Tt2), Quaternary basalt (Qb), Quaternary scoria (Qsc), Quaternary elluvial sediments (Qs), Tertiary sediments (Ts).Together with the nature of rock, degree of weathering and extent of fractures the study area was reclassified in to five suitability landfill class (Fig. 8).

Land use/Land cover map was considered in this analysis. Accordingly fourteen classes were identified. These are open space, road network, agricultural , forest , built up area, cemetery, festival site, proposed manufacturing area, social service area, recreational area, existing manufacturing area, parks slaughter (abattor) and rivers (Fig. 23).

Besides,the effect of slope on the possibility of ground water pollution was considered for landfill site selection and it was reclassified in to six classes as 0-4%, 4-8%, 8-12%, 12-16%, 16-20% and > 20% (Fig. 6).

In addition, soil map of the study area also considered and initially seven soil class could be recognized within the study area. These are PellicVertisol, Chromic Vertisol, Chromic Luvisols, EutricNitisols, OrthicSolonckaks, Calcic Xerosols and Leptosols.

The permeability and infiltration of each soil depends on its textural composition. Accordingly,

(Pellic Vertisol and Chromic Vertisols) is characterized by fine textured soil with >60% clay in composition. As a result, the porosity of such soil is very fine making the movement of material difficult within the soil. Hence, the permeability of Vertisol is very low except within the cracks that are formed during dry seasons. The permeability of Eutric-Nitisol is moderate as its texture is generally characterized as moderately fine textured and with relatively less clay content than Vertisol. The permeability of Chromic Luvisol, which is found in the north-western part, is also moderate like the case of EutricNitisol. Leptosol is characterized by shallow depth underlined by hard rock and with less developed soil. This type of soil is found in the Northern part. The textural class is moderately coarse textured soil with high permeability (Haile silasse, *et al.*, 1989).

By considering the flowing of leachate to prevent ground water contamination clay content soil (fine texture soil) is most suitable, whereas soil which has course texture size is unsuitable for landfill site. Based on the suitability of landfill the study area is reclassified in to five groups (Fig. 15).

By considering the cost transporting solid waste to landfill, traffic congestion effect and aesthetic considerations distance was generated around each road. Accordingly the study area was classified in to five as 0-100m, 100-300m, 300-500m,500-700m, 700-1000m and > 1000m (Fig. 21).

By considering the residence safety, to protect the general public from possible environmental hazards released from landfill, to avoid adversely affecting land value and future development sites, it should not be placed near a residential or an urban area. But by considering the transport cost landfill must be located within 10km of an urban area (Baban and Flannagan,1998). By taking all these consideration the study area classified as 0-5000m, 5000-6000m, 6000-7000m, 7000-8000m, 8000-10000m and >10000m (Fig. 18).

This criteria was taken by considering a contaminated runoff in the adversely landfill affect on the surface water. In the water bodies, buffers zones of 0-200m, 200-400m, 400-700m, 700-1000m and > 1000m were generated around each water course considering 200m as the minimum buffer distance from which a landfill can be sited. Accordingly the study area was reclassified in to five (Fig. 9).

By considering the adverse effect of birds around the airport and for safety matter the area was classified in to five zones as 0-3km, 3-6km, 6-9km,9-12km and >12km buffers were generated. By considering the effect of landfill on air craft the study area was reclassified in to five and accordingly the suitability increases far away from the airport (Fig.26).

Faults were digitized from the geologic map. As faults can pose serious environmental threats to landfill site, GIS was used to generate buffers around each fault and an extent of 100 m was taken as the minimum buffer zone. Accordingly the city area was reclassified in to five zones as 0-100m, 100-2000m, 2000-4000m, 4000-6000m and >6000m (Fig.16).

Borehole data on different points were interpolated using inverse distance weighted technique to distinguish deep water table areas from shallow water table area. Accordingly the study area was classified in to five depth zone as 0-10m, 10-20m, 20-40m, 40-50m and > 50m (Fig.11).

The borehole points were demarcated by Addis Ababa Water and Sewerage Authority. By considering the water well contamination, the landfill was suited far from them and the minimum of 500m buffer zone was generated and the suitability was increased with increasing distance. The study area was classified in to 0-500m, 500-800m, 800-1200m,1200-2000m and > 2000m (Fig.13).

4.2. Discussion

Situation of the existing landfill

All the waste collected from skip points is hauled and dumped in the existing landfill site. It is located in the South Western part of the city, in Kolfe-Keranyo, Woreda 6, about 13 kilometers away from the city center. It's coordinate is 8° 58/57//N and 38°41/18//E.

Plate 3 : Physical situation of existing landfill (Rappi).

Source: Field survey, Jan. 2015 photo taken by author.

Note that it is insufficient to ensure even basic landfill management. Furthermore, low maintenance and curative results in considerable downtime, mostly due to strenuous conditions of operation.This open dumping site has been posing negative impacts on the environment and public health like downstream water pollution, soil pollution and health problems to the surrounding community (Tamiru *et al*., 2003) The problems resulted due to not considering, environmental and social factors during site selection.

The site is located near main road and surrounded by residential area (Plates 3) resulted in health and social .Furthermore, there are no daily covering of solid waste after disposal to reduce environmental and public health problem. These practices signify the risk to the public health and the environment. Hence, the location of dumping site does not satisfy the international landfill standards. The only practice after dumping is to compact with bulldozer so as to reduce the volume of solid waste. This practice increases the environmental and social risk resulted from the site.

Landfill site suitability map (Fig. 27) of Addis Ababa done in this study showed that the existing dumping site falls in poorly suitable sites and hence excluded from the siting process. In the present study selection process, the land use area such as built up area, road, cemetery, festival site, social service area, recreational area, existing manufacturing area and agricultural areas were excluded from the selection processes due to their social effects and values. Open spaces were identified as best option for solid waste landfill sites. Areas with slope >20% and <4% were excluded as they are unsuitable due to challenges during landfill construction or maintenance and affect the runoff drainage respectively, whereas areas with slope 8-12% were found to be the best for landfill sites because it preventing the leachate flowing (Khorasani and Nejadkorki, 2000). Based on settlement related criteria areas within 5000m and >10000m of distance were excluded to minimize public health effect and transportation cost respectively. Likewise areas with distance of <100 and >1000m to road proximity criteria was excluded due to traffic congestion and high transportation cost respectively.

Area-wise calculation of the suitability class showed that 407.2 km^2 (77.3%) of the study area is almost unsuitable for landfill sites. The unsuitable areas included near to residential area, rivers, groundwater level and ground water wells in the first order followed by permeable location, faults, permeable rocks, steep slope and plain area, areas very close to and very far from road, and close to airport. That means ground water/ surface water related criteria and residential areas are more influential than the rest of the criteria as they need good protection landfill disturbance and against leachate contamination from a landfill. As against this, proximity to road was assigned least importance due to the present reconstruction processes of the city, it may expand or modified in the future and merging with the rail way line which has contradictory criteria with road proximity. To clarify the two contradictory criteria the landfill must not be located within 500m of a railway line (Sener et al. 2006), on the other hand the landfill site should not be placed too far away from existed road networks to avoid the expensive cost of constructing connecting roads and transportation, therefore to harmonize these criteria proximity to road has given less weight.

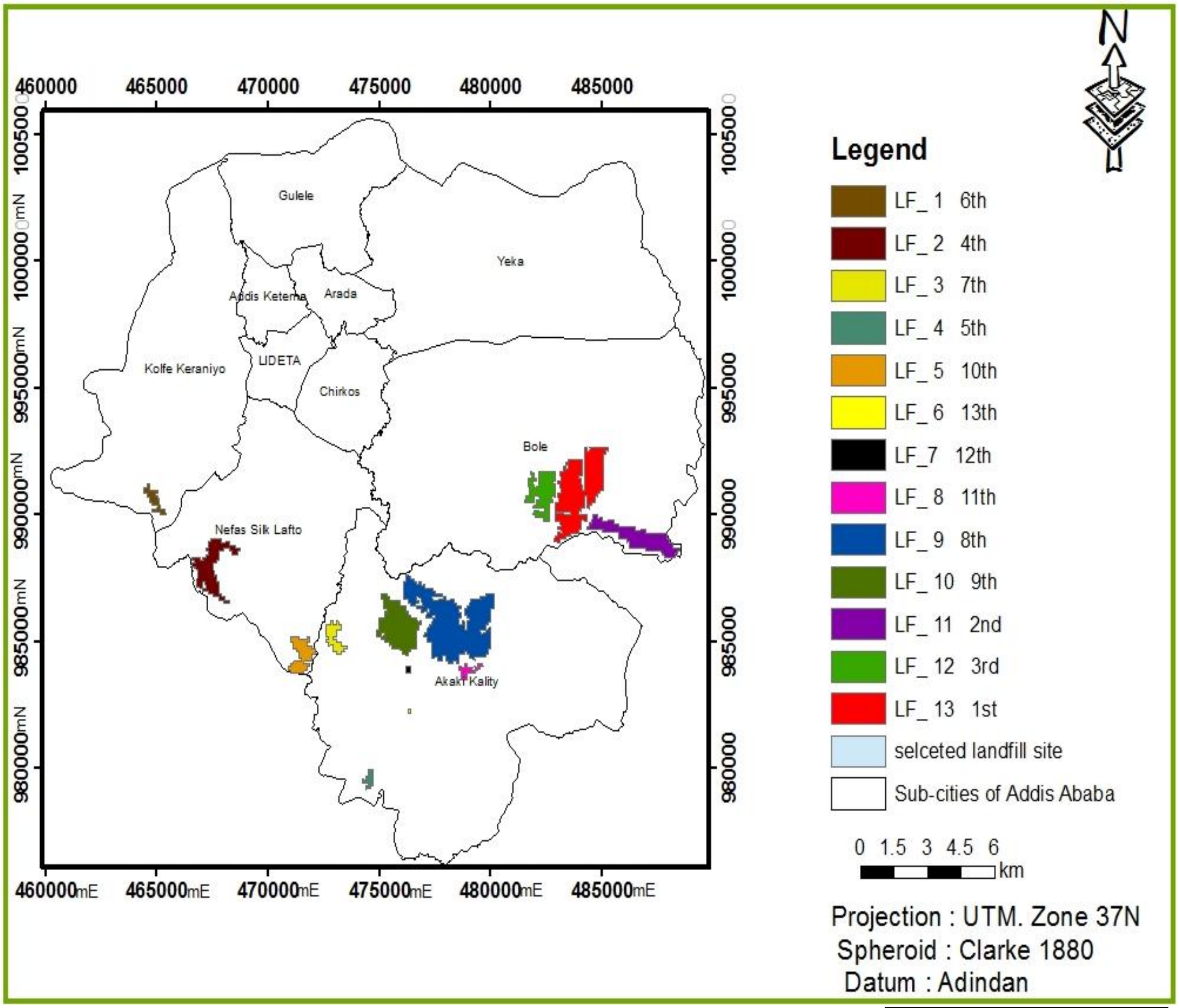
According to Ekmekcioglu et al., (2010), contamination of ground/surface water resources by leachate is a principal concern in relation to disposal site. Deep ground water table areas are preferable as chances of ground water pollution will be minimized with increasing depth (Augustin, 2008). Waste disposal should also be away from faults (Akbari, 2008). Further, sites with potential for higher value and uses such as natural conservation, agriculture and residential development should not be used for landfill (Ekmekciogluet al., 2010).

The unsuitable area and poorly suitable area could not be used due to their sensitivity coupled with very meager extent.

After eliminating the above mentioned land, only 42.9 km^2(8.1%) of the area could be identified as most suitable together with their few limitation. So it is important to give rank by considering all the criteria to be satisfied. Off course landfills in the selected area is preferable over others use because of the least effect they cause on the environment and public health beside being cost effective. Most of the highly suitable landfill sites are suited in the eastern, western and southern part of the study area (Fig. 27).

From the overall suitable area it is important to give ranks, therefore, the 1st , 2nd and 3rd suitable landfill should be identified most preferably from the eastern part in Bole sub-city wereda10 particularly its local place is "Bole Arabssa" (checked by taking x & y cordinates) , because they satisfy the most important criteria like the requirement of the landfill size, the criteria designed with respect to settlement, ground water and surface water related criteria and others . Evaluation of among the selected sites in relation to their size shows that landfill site at Bole sub-city (Landfill /LF13) with area coverage of 7.2km^2 is the most suitable site as it will serve for longer years followed by LF11 and LF12, while sites which are selected at Nifas silk-Lafto area of 1.9km^2 and Kolfe-Keraniyo area of 0.4km^2 are less preferred due to its smaller area coverage, because landfill should serve at least for 10 years (Zain, 2009 & UNEP, 2005).

The southern part of the study area having near to the center of Akaki-Kality areas may be used for landfill following a careful management system that incorporates lining the base of landfill and constructing leachate and gas collectors to minimize their negative effects on environment and public health. Similarly, this part of the study area is a potential source of ground water for the city and its surroundings, so it needs a special care for landfill site.



where, LF is

Figure28 : Ranks for the selected landfill site map of the study area.

CHAPTER FIVE

5. CONCLUSIONs AND RECOMMENDATIONS

5.1. Conclusions

Landfill site selection is a complex procedure which involves evaluating numerous factors like, physical, environmental and socio- economical factors.

A GIS is a good tool to help aid in the finding of suitable sites for landfill sitting purposes. The use of GIS for evaluation of future waste disposal sites has shown to save time when there is a need for fast evaluation. A landfill siting process requires evaluating many factors and criteria and processing much spatial information.

This study considered eleven criteria, namely geology, slope, ground water depth, surface water, borehole, soil permeability, land use/ land cover, slope, road proximity, proximity to residential and air proximity; for proper landfill site selection in Addis Ababa and prepared as input map layers. The output maps were divide into five classes from unsuitable to most suitable areas. In addition, field check was implemented to determine the selected sites. A method which integrates both GIS and MCDA is used for the analysis. To compare the results and check the accuracy, one methods of MCDA which is Analytic Hierarchy Process was used. Multi-criteria Evaluation results showed that residential, land use/land cover and ground water related factor are more important in landfill site selection, as ground water needs protection from leachates arising out of landfills and protecting the residence from any kind of waste disturbance. About 8.1% of the study areas are satisfied the environmental, economic and social criteria set for the site selection and hence have the most suitable. Accordingly 13 landfill sites were selected. The site are found in the eastern, western and southern part of the study area. A Site which is found in Bole sub-cities Woreda10 (LF13) is the most suitable of all due to the fulfillment of landfill size and minimum environmental and social effects from it. The 2nd and 3rd suitable site lies in the same sub-city like LF13 which are LF11 and LF12 respectively followed by sites found in the western and south western part of the study area particularly in kolfe-keraniyo and Nifas silk-lafto sub-cities, but the southern part (center of Akaki-kality) needs special protection for landfill due to close to the residential area and the presence of ground water.

5.2. Recommendations

- The present study considers physical, environmental and socio-economical factors, so all factors with related to these are influence for landfill site selection and therefore, should be included as evaluating criteria.
- To protect downstream surface water pollution, runoff must not flow into and out of the sanitary landfill. Hence, drainage system should be constructed around the landfill.
- The selected landfill site should serve at minimum life span of 10 years to reduce the cost of landfill site selection, construction and closure. Therefore, the rates ,type and volumes of solid waste produced from the city should be known in order to determine the dimension of the landfill site during construction.
- The selected landfill site was only for non-hazardous solid waste. Therefore, hazardous wastes should not be deposited in this site. Hazardous wastes should separated from non-hazardous solid waste in the transfer station site before transporting to the landfill. Hence, special treatment should be designed for such hazardous solid waste as siting parameters.

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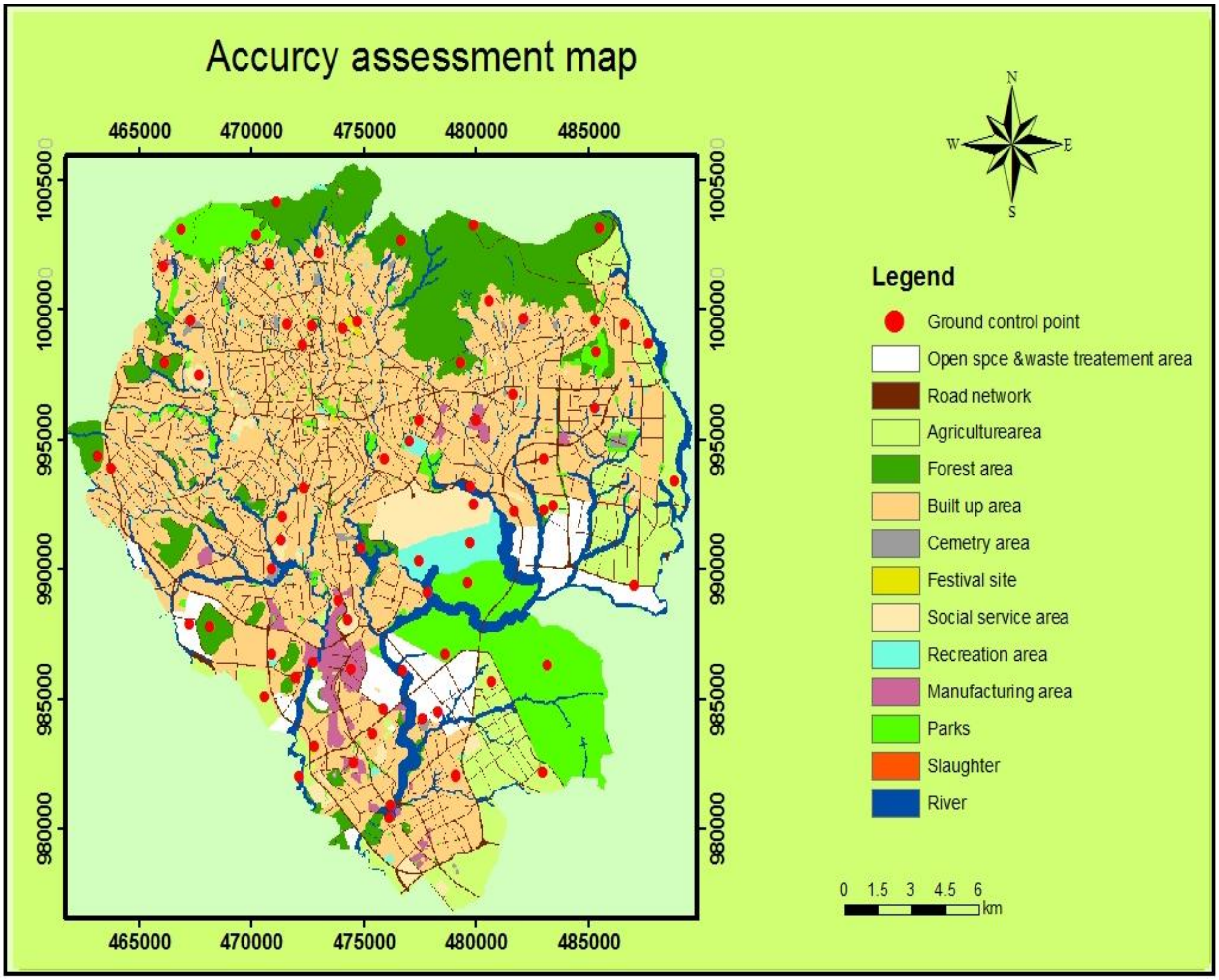
Appendix

Ground control points used for the study

S.N	Id	X- coordinate	Y- coordinate	S.N	ID	X- coordinate	Y- coordinate
1	OP & WS	483012.1	992282.9	39	BU	475397.3	983645.3
2	OP & WS	487046.8	989384.8	40	BU	479091.1	981997.4
3	OP & WS	478636.4	986713.9	41	BU	483012.1	994271.9
4	OP & WS	478295.5	984497.7	42	BU	479091.1	982054.2
5	OP & WS	4727783.3	985236.5	43	CM	467271.1	999613.6
6	OP & WS	467214.3	987907.3	44	CM	470851.2	989995.3
7	RD	470794.4	1001773.1	45	CM	482102.9	999670.5
8	RD	463747.9	993874.1	46	CM	477613.6	984270.4
9	RD	472271.8	998647.6	47	FS	474715.4	999556.8
10	RD	485285.2	999613.6	48	FS	472783.3	983190.7
11	RD	481705.1	992226.2	49	SS	479886.6	992510.3
12	RD	475851.9	984611.4	50	SS	467668.9	997511.1
13	RD	472328.7	993135.4	51	SS	471305.8	991146.5
14	AG	487671.9	998704.4	52	SS	474260.8	988077.8
15	AG	488808.4	993419.5	53	RC	477045.3	994953.8
16	AG	483409.9	992453.5	54	RC	479716.1	991032.8
17	AG	480682.2	985691.1	55	RC	477443.1	990350.9
18	AG	482955.3	982167.8	56	RC	485285.2	996204.1
19	AG	470567.1	985112.8	57	RC	470851.2	986713.9
20	FR	471078.5	1004159.8	58	MN	480000.3	995749.4
21	FR	476647.5	1002682.3	59	MN	473862.9	988816.6
22	FR	479886.6	1003250.5	60	MN	474431.3	986145.7
23	FR	485512.5	1003136.9	61	MN	474544.9	982565.6
24	FR	479318.4	997965.7	62	PR	466873.3	1003080.1
25	FR	466134.6	997965.7	63	PR	470169.3	1002909.6
26	FR	463122.8	994385.6	64	PR	485341.9	998363.4
27	FR	468123.5	987793.7	65	PR	479602.5	989498.5
28	BU	466077.7	1001659.9	66	PR	483182.6	986316.2
29	BU	473010.6	1002227.7	67	SL	471930.8	985861.6
30	BU	480568.5	1000352.4	68	RV	479716.1	993192.2
31	BU	486592.2	999443.2	69	RV	477840.9	989100.7
32	BU	481648.3	996772.3	70	RV	476704.3	986088.9
33	BU	477443.1	995749.4	71	RV	476192.7	980917.7
34	BU	474033.5	999272.7	72	RV	474829.1	990805.5
35	BU	471589.9	999443.2	73	RV	472726.5	986429.8
36	BU	472669.6	999386.3	74	RV	472101.4	981997.4
37	BU	475908.8	994271.9	75	RV	476136.1	980406.2
38	BU	471362.6	992055.7				


Accurcy assessment map
465000
470000
475000
480000
485000
100500
1000000
995000
990000
985000
980000
N
S
W
E
Legend
Ground control point
Open spce &waste treatement area
Road network
Agriculturearea
Forest area
Built up area
Cemetry area
Festival site
Social service area
Recreation area
Manufacturing area
Parks
Slaughter
River
0 1.5 3 4.5 6
km