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ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUTE STUDIES
COLLEGE OF NATURAL SCIENCES
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DEPARTMENT OF EARTH SCIENCES

**GIS AND REMOTE SENSING BASED SOLID WASTE LANDFILL SITE
SELECTION: A CASE OF ADDIS ABABA CITY, ETHIOPIA**

BY
GIZACHEW KABITE

ADVISORS: Dr. K. V. SURYABHAGAVAN
Dr. MEKURIA ARGAW

JANUARY, 2011

**GIS AND REMOTE SENSING BASED SOLID WASTE
LANDFILL SITE SELECTION: A CASE OF ADDIS ABABA
CITY, ETHIOPIA**

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OF MASTERS OF SCIENCE IN REMOTE SENSING AND
GEOGRAPHIC INFORMATION SYSTEM**

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GIZACHEW KABITE

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Approved by Board of Examiners

Dr. Tigistu Haile _____
Chairman, Department Head
Graduate Committee

Dr. K. V. Suryabhagavan _____
Advisor

Dr. Mekuria Argaw _____
Advisor

Dr. Dagnachew Legesse _____
Examiner

Prof. M. Balakrishnan _____
Examiner

DECLARATION

I hereby declare that the dissertation entitled “GIS and Remote Sensing Based Solid Waste Landfill Site Selection; A case of Addis Ababa City, Ethiopia” has been carried out by me under the supervision of Dr. K.V.Suryabhagavan and Dr. Mekuria Argaw, Department of Earth Sciences and Environmental Science respectively, Addis Ababa University during the year 2009-2011 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa

Date: February 1, 2011

(Gizachew Kabite)

CERTIFICATE

This is certified that the dissertation entitled “GIS and Remote Sensing Based Landfill Site Selection: A case of Addis Ababa City, Ethiopia” is bonafied work carried out by Gizachew Kabite under our guidance and supervision. This is the actual work done by Gizachew Kabite for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University, Addis Ababa.

Dr. K.V.Suryabhagavan

Assistant Professor

Department of Earth Sciences

Addis Ababa University

Addis Ababa

Dr. Mekuriya Argaw

Assistant Professor

Environmental Science Program

Addis Ababa University

Addis Ababa

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Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
AHP	Analytical Hierarchy Processes
CAE	Centre for Advanced Engineering
CR	Consistency Ratio
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EGS	Ethiopia Geologic Survey
EMA	Ethiopia Mapping Authority
EPA	Environmental Protection Authority
ETM+	Enhanced Thematic Mapper Plus
GCPs	Ground Control Points
GIS	Geographic Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
ISWM	Integrated Solid Waste Management
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
OWWDSE	Oromia Water Works, Design and Supervision Enterprise
SBPDA	Sanitation, Beautification and Parks Development Agency
SMCDA	Spatial Multi-Criteria Decision Analysis
SPOT	Systeme Probatoire d'Observation de la terre
SRTM	Shuttle Radar Topographic Mission
UNEP	United Nation Environment Program
USGS	United States Geologic Survey
WLC	Weighted Linear Combination

Abstract

Solid waste management system is the most difficult task that many countries, both developing and developed, are facing. Landfill method is one of the easy and cheap management systems which are always needed for sustainable management of solid waste. However, if not sited and managed properly, it will result in environmental pollution and public health problems. The open dumping system that the city of Addis Ababa has been using is not environmentally sound and socially acceptable as its location is in inappropriate site. Therefore, it is necessary to select new landfill site for the city that is environmentally sound, socially acceptable and economically feasible. The present study was conducted by integrating Geographic Information System and remote sensing for selecting suitable landfill sites. Factors such as geology, slope, depth to ground water table, permeability, land use/ land cover, proximity from roads, faults, airport, groundwater well and streams/rivers were used for selecting suitable landfill within the study area. GIS-based Multi-Criteria Evaluation methodology was followed to have advantages of both GIS and Multi-Criteria Evaluation method and solve spatial decision making problems. All the factor maps were reclassified and standardized in GIS environment followed by preparation of their suitability map. Analytical Hierarchy Processes pair-wise comparison module was used to derive internal and external weights for all factor parameters and factors respectively. More weight was given to groundwater related criteria so as to protect groundwater pollution from landfill negative effects. Weighted Linear Combination was also used to integrate the factor maps and produce overall landfill suitability map. Accordingly, 40.5km²(7.7%), 68.7km²(13%), 0.7km²(0.01%) and 417.8km²(79.3%) of the total study area is highly, moderately, marginally and unsuitable for landfill respectively. Among the highly suitable landfill sites, those with area greater than 0.5km² were also evaluated against other criteria like area, distance from the center of the city and distance from nearby settlements so as to choose the most suitable landfill sites. Analytical Hierarchy Processes was applied again to compare and derive weight for the 12 candidate sites in relation to those evaluating criteria. Landfill site 2 which is located in the north eastern part of the city in Yeka sub-city, north of road to Dessie is chosen as the most suitable site, because of the larger area and optimum distance from the nearby settlements and from the center besides their fulfillments of the environmental and socioeconomic factors set before. Landfill site 11 (located in the south eastern part in Bole sub-city) and landfill site 1(found in the northern part of the city in Yeka sub-city) is the second and third most suitable sites respectively due to their larger area and/or distance from nearby settlements and center than the rest of the sites. Landfill 11 is more suitable than landfill 1 due to its safe location from nearby settlements. Therefore, landfill sites 2, 11 and 1 are ranked from 1 to 3 based on their area and distance from the center and nearby settlements compared to the other sites hence their negative effects on the environment and public health will be minimum.

Key Words: *Landfill, Multi-Criteria Evaluation, Addis Ababa Solid Waste Management, GIS, Remote Sensing.*

1. INTRODUCTION

1.1 General Background

Solid wastes could be defined as non-liquid and non-gaseous products of human activities, regarded as being useless (Babayemi and Dauda, 2009). Its origin is mainly from households, municipal and construction (Munier, 2005). The generation and management of solid wastes are the problems facing both developing and developed countries. Generation of solid waste has become an increasing environmental and public health problem everywhere in the world, particularly in developing countries. Fast expansion of urban, agricultural and industrial activities spurred by rapid population growth has produced vast amounts of solid and liquid wastes that pollute the environment and destroy resources (UNEP, 2005). The management of solid waste in Africa is often weak due to lack of appropriate planning, inadequate governance, poor technology, weak enforcement of existing legislation and the absence of economic and fiscal incentives to promote environmentally sound development. The current practice of solid waste management system in Africa is open dumps without leachate and gas management over ecologically or hydro- logically sensitive areas (UNEP, 2005). According to Taddesa Kuma (2004) as cited in Bjerkli (2005), the insufficient handling of solid waste represents a source of water, land and air pollution affecting the urban environment and the health of the people living in the cities and is one of the most critical environmental problems that cities in Africa are facing today. Therefore, solid waste management is becoming a major public health and environmental concern in urban areas of many African countries like in Ethiopia, especially in Addis Ababa.

The capital city of Ethiopia, Addis Ababa, is facing solid waste management problems like other Africa cities. The growing population and economic activities of the city resulted in generation of high amount of solid wastes. The per capita generation rate of solid waste of the city is 0.4kg/capital/day and more than 200,000t are collected each year (Addis Ababa Municipal, 2010). The municipality spends large proportion of its budget on collection, transport and disposal of wastes. Currently, there is only one open dumpsite, Repi or Koshe, located at south west part of the city, which was established 47 years ago, where all collected waste have been deposited. However, open dumpsite is known to pose a significant risk to public health and the environment (UNEP, 2005). For example, there are environmental, social and ecological

problems associated with “Repi or Koshe” open dump disposal site. Moreover, the solid wastes disposed at Koshe is mostly from domestic, industry, markets, hospitals and commercial sources, which contain leachable toxic components such as methane, hydrogen, nitrogen, hydrogen sulfide and carbon dioxide (Geologic Survey of Ethiopia, 2010). One of the main problems is, as it is surrounded by housing areas and institutions, people living nearby are suffering from nuisance and hazard health. In addition, more than 200-300 waste collectors per day are continuously working and thus hamper the operation of societal activities practiced near the site (Addis Ababa Municipal, 2010). Runoff and leachate from landfill is the main cause of surface water and ground water pollution, respectively. Moreover, when the landfill was established, the only factors that were considered in selecting the site were hauling distance, availability of land and the distance from the city. There were no evaluations of the underling soil structure, topography, surface water and the hydro geological conditions of the area (Bjerkli, 2005). Nowadays, open dumping of wastes is no longer an acceptable practice from environmental or health perspective (Enger and Smith, 2008).

The uncontrolled and improper solid waste management in the city is polluting the environment and affecting public health. As indicated by UNEP (2005), improper solid waste management leads to substantial negative environmental impacts such as air, soil and water pollution, flooding due to the blockage of drainage system and generation of greenhouse gases from landfills. Furthermore, it will result in health and safety problems like diseases spread by vectors such as insects and rodents attracted by garbage heaps, and diseases associated with different forms of pollution.

Therefore, for sustainable environmental and public health protection, solid waste should be disposed in environmentally sound and socially acceptable sites. Hence, environmental protection and public health considerations should be the principal concerns in site selection. This is because selection of an appropriate site will minimize potential environmental impacts and provide a sound basis for effective management (Zain, 2009). Sound practice in design and siting of solid waste disposal can highly reduce the risk of environmental pollution and public health imposed by improper system which is common in developing countries. However, selecting safe site for solid waste disposal is not an easy task. It is tedious and costly requiring multiple criteria that are difficult to handle. Moreover, Biotto et.al (2009) describes identification of waste

disposal sites as a complex spatial problem, involving multiple criteria and objectives which require the use of spatial analysis models for its solution. Nevertheless, integrating Geographic Information System (GIS) and Remote Sensing is the best tool in selecting environmentally sound and socially acceptable disposal site/s with accurate precision, cost and time effectively. The development of GIS coupled with availability of digital data from Remote Sensing technology made landfill site selection easy.

GIS is used for landfill site selection processes because of its unique capabilities. The distinguishing feature of GIS is its capability to perform an integrated analysis of spatial and attributes data and it can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets (Malczewski, 2004). Moreover, GIS is used to perform a screening process that led to identification of a couple of suitable candidate sites based on given criteria. The suitability criteria are defined with the focus to minimize any potential health risk from direct or indirect contamination due to the proximity of a landfill site with respect to key geographic features. Thus, the first-stage analysis using GIS is essential for the initial identification of a couple of suitable landfill sites prior to undertaking further analyses or field investigations (Chang et al., 2007). This screening will minimize the cost and time of landfill site selection processes.

Remote sensing technology is capable of providing up to date geographic information and is the main source of input data for assessing and monitoring the environment in GIS environment. For example, the current land use/land cover information of the study area will be extracted and mapped from satellite images and used as an input data for the study. Thus, remote sensing serves as a tool for environmental resource assessment and monitoring. In addition, it has some fundamental advantages that make it a veritable tool in environmental monitoring and management and impact studies (Idowu and Ukoje, 2009). Furthermore, remote sensing techniques makes it possible to increase the speed and frequency with which one can analyses a landscape. Therefore, remote sensing can aid in making quick and focused decisions (Steininger and Horning, 2007).

Although, application of GIS is widely spread in resource inventory and mapping, the potential of GIS for planning and decision-making is not utilized fully due to its limited ability to represent

judgments, values, arguments and options of the decision makers. On the other hand, multi-criteria decision analysis (MCDA) has been found to be fruitful approach to solve such limitations. Moreover, MCDA solve the complexity and conflicting criteria for solid waste landfill site selection and help us to consider multiple alternative solutions and evaluation criteria (Cheng et al., 2002). Hence, Spatial Multi-criteria Decision Making (SMCDM) methods can overcome these limitations (Laskar, 2003). The accuracy of complexity and intractable decision making in environmental projects can be improved by using multi criteria decision making analysis with GIS. In this particular study, GIS and Remote Sensing were used to generate, manipulate and analyses geospatial data that were used as landfill site selection criteria. Moreover, SMCDM were integrated to select potential solid waste landfill site efficiently with better accuracy.

1.2 Statement of the Problem and Justification

The population of Addis Ababa is growing at an alarming rate due to both natural increase and through the immigration of people from rural areas to the city. Moreover, in the last two decades, development activities, mainly construction and industries, also have been growing. As a consequence of population growth and development activities, high amounts of household and industrial solid wastes are generated. High rate of wastes are facing problem of their disposal and have very high potential effect to pollute environment such as surface water, ground water, land (soil) and air. Public health is also highly affected by the uncontrolled solid waste generation and disposal.

The increased wastes from the growing population and industrial pressure have to be reduced via waste reduction, recycling and reuse techniques. Despite these solid waste management systems, collecting and depositing in safe site/s by landfill technique is the primary means of waste disposal. This is due to the difficulty or the impossibility of managing all solid wastes through waste reduction, recycling and reuse. The solid waste disposal system should be in an environmentally sound and socially acceptable way so as to protect the environment and safeguard public health. However, the traditional and manual method used to select suitable landfill site is inaccurate, tedious, time consuming and costly. Earlier, some researchers were tried to select solid waste disposal site for the city. However, they did not fully utilize GIS and remote

sensing technology and were unable to consider many of these factors. As a result, up to date geographic data such as land use/ land cover were not included in their analysis. Furthermore, the current waste disposal system of the city is open dump system and the site is filled out, causing social and environmental problems. When the site was selected, there were no evaluations of the underling soil structure, topography, surface water, and the hydro-geological conditions of the area. Therefore, it is mandatory to select new solid waste landfill site for the city by considering ecological, environmental and social factors so as to management solid wastes in an environmentally sound manner.

The study focused on integrating GIS and Remote Sensing techniques to provide appropriate information about geographic data to assist in selecting potential solid waste disposal site using different factors. Remote Sensing is the main source of digital data that can be further manipulated and analyzed in GIS environment. Moreover, GIS is capable of integrating geospatial data from different sources and thus help decision makers in environmental and public health protection. Hence, the present study employs GIS and remote sensing techniques for appropriate landfill site selection for Addis Ababa city.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of the present study is to determine suitable site for solid waste landfill site through integrating SMCDM and remote sensing that are/is environmentally sound, socially acceptable and economically feasible.

1.4.2 Specific Objectives

- To assess the current solid waste disposal system in the study area.
- To examine environmental, social and economic factors that are necessary for selecting landfill and prepare their suitability maps in GIS environment.
- To study and map land use/land cover of Addis Ababa city from solid waste landfill suitability point of views.
- To produce thematic map showing potential sites that are environmentally sound, economically feasible and socially acceptable for solid waste landfill.
- To prioritize and rank the identified suitable landfill sites according to their suitability.

2. LITERATURE REVIEW

2.1 Municipal Solid Waste Management System

Municipal solid waste management (MSWM) encompasses the functions of collection, transfer, resource recovery, recycling and treatment. The primary target of MSWM is to protect the health of the population, promote environmental quality, develop sustainability and provide support to economic productivity. Waste management is a problem for most countries around the world because of the increasing volume of waste material and the paucity of places to deposit (Soto, 2001). It has been a threat to environment and public health. However, proper waste management helps protect human health and the environment, as well preserve natural resources. Solid waste should be managed through a number of activities such as waste prevention, recycling, composting, controlled burning or landfill in the order of preference. Combination of these activities in a way that best protect the community and the local environments is referred to as integrated solid waste management (ISWM).

A sustainable waste management philosophy should encompass the following basic principles of solid waste management hierarchy which includes reduction in the generation of waste, waste streaming at source, recycling and reuse, pre-treatment of waste to minimize quantity and volume and landfill of residual waste (Allen, 2001). The hierarchy ranks those waste management operations according to their environmental or energy benefit and the purpose is to make waste management practices as environmentally sound as possible (UNEP, 2005).

In line with the internationally recognized waste management hierarchy, the first priority should be given to waste minimization (reduction at source). It should be followed by recycling, treatment and land disposal (landfill) in this order (WHO, 1996). Even though, landfill is the least in the waste management hierarchy, it is one of the most common solid waste management methods used in many countries. Landfill will be described in detail in the following section.

2.1.1 Landfill

Landfill is an engineered solid waste disposal process to minimize the environmental hazards and nuisances of waste disposal. In this method, a solid waste is delivered to a carefully selected and prepared site, deposited into a trench or controlled area, compacted and covered with soil or other materials daily (Department of the Army, the Navy and the Air Force, 1990; UNEP, 2005;

Jamjan, 2009). Landfills provide for the environmentally sound disposal of waste that cannot be reduced, recycled, composted, combusted or processed in some other manner. As a result, it is always needed for disposing of residues from recycling, composting, combustion or other processing facilities and can be used if the alternative facilities break down (EPA, 1995). Landfill remains the most commonly employed method of solid waste disposal in spite of the increasing stress towards the waste reduction at the source, recovery and recycling of solid waste (Ekmekçiog̃lu et al., 2010, Jason et al., 2005; Sumathi et al., 2008). Hence, landfill of solid waste will continue to be a necessary part of integrated solid waste management systems, since there will always be a need to dispose of waste that cannot be economically reused or recycled or incinerated for energy recovery (Chang et al., 2007).

According to Allen (2001), landfill is critical to most waste management strategies, because it is the simplest, cheapest and most cost-effective method of disposing waste relative to other waste management methods. However, if not suitably sited and managed it can lead to serious contamination of the environment. Landfill leachate and gases released from landfill will result in ground water, surface water and air pollution and have adverse effects on the local environment and is considered harmful to humans (Leao et al., 2010). According to Zafar and Alappat (2005), landfill leachate is a very harmful liquid for both surface and ground water. Furthermore, the primary gases, carbon dioxide and methane, produced by landfill can contribute for global warming. It is estimated that 7 percent of the total methane emissions in the world come from landfill sites (Corrales and Horton, 1995).

These adverse negative impacts from landfill can be minimized through selecting an appropriate site, which minimizes potential environmental impacts and provides a sound basis for effective management (Zain et al., 2009). Nevertheless, landfill siting is a difficult, complex, tedious, and protracted process requiring evaluation of many different criteria (Chang et al., 2007; Zamorano et al., 2008). Locating a sanitary landfill requires an extensive evaluation process in order to identify the best available disposal location. This location must comply with the requirements of governmental regulations and at the same time must minimize economic, environmental, health, and social costs (Siddiqui et al., 1996 as cited in Al-Jarrah and Abu-Qdais, 2006). Landfilling is thus endorsed, provided appropriate standards are ensured to protect the environment, public health and quality of life (Sardinia, 2005).

2.2 Landfill Siting

As described above, landfill siting is a difficult, complex, tedious and protracted process requiring evaluation of many different factors like environmental, social and economical factors. Those factors should be considered during siting processes in order to minimize the negative impact of landfill on the environment, public health and economy of the region (Siddiqui et al., 1996 as cited in Al-Jarrah and Abu-Qdais, 2006). Moreover, Sumathi et al. (2008) has stated as siting a sanitary landfill requires an extensive evaluation process in order to identify the best available disposal location. Zamorano et al. (2008) also described landfill siting as a complex process involving social, environmental and technical parameters as well as government regulations which requires the processing of a massive amount of spatial data. Furthermore, landfill has become more difficult to implement its increasing cost (especially because of the transport to distant sites), community opposition to landfill siting, and more restrictive environmental regulations regarding the siting and operation of landfills (Leao et al., 2010).

However, despite its complexity and difficulty, landfill selection in an urban area is a critical issue in the urban planning process because of its enormous impact on the economy, ecology and the environmental health of the area (Charnpratheep et al., 1997 as cited in Chang et al., 2007). Site selection of new landfills for municipal solid waste (MSW) disposal is a great concern of urban governments around the world as old landfill sites are being filled-up and demand for new sites is increasing (Hasan et al., 2009). Proper siting of landfill by considering many different criteria has paramount importance in reducing the negative impact on the environment and society. According to Fatta et al. (1998), siting of waste facility is a crucial step in reducing the risk of unacceptable environmental impacts during its entire lifetime.

Therefore, an important factor in determining whether or not a landfill poses significant threats to public health and the environment is its location. For example, groundwater contamination is less likely at a site that has clay soils and a groundwater table far below the disposal area while surface water contamination is less likely at sites distant from lakes and rivers. Air pollution is less of a threat to public health if the landfill is located far from human settlements. Furthermore, siting in wetlands or other sensitive areas can cause significant damage to local plant and animal species. In a similar way, siting in floodplains can cause a loss of floodwater retention capacity, resulting in higher flood levels and causing flood damage in the area (Corrales and Horton,

1995). Landfill site selection can generally be divided into two main steps: the identification of potential sites through preliminary screening and the evaluation of their suitability based on environmental impact assessment, economic feasibility and engineering design and cost construction (Charnpratheep et al., 1997 as cited in Chang et al., 2007). The criteria used for preliminary screening are primarily to examine the proximity of potential sites with respect to geographic objects that may be affected by the landfill siting (like groundwater wells and surface water) or that may affect landfill operations e.g. areas with steep slopes (Chang et al., 2007). In addition, careful siting and management is the key to a successful landfill project. Hence, a landfill should be planned, designed, constructed and managed not only to protect public health and the environment, but also to enhance the value and planned beneficial uses of the reclaimed land (WHO, 1996). To achieve a successful siting process, several significant environmental and political obstacles have to be considered (Al-Jarrah and Abu-Qdai, 2006).

2.2.1 Landfill Site Selection Criteria

For sustainable management of solid waste and safeguard the environment and public health, appropriate site for landfill should be selected through considering many criteria from environmental, social and economical point of view. Proper landfill site selection is the fundamental step in sound waste disposal and the protection of the environment, public health and quality of life (Sardinia, 2005). Nevertheless, according to Higgs (2006) locating waste facilities such as landfill sites can lead to major public concerns especially in relation to public health, environmental and economic considerations and can therefore be an extremely contentious issue. For example, Chang et al. (2007) indicates that proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection so that wells may be protected from the runoff and leaching of the landfill. Hence, according to Sardinia (2005), the criteria involved in landfill site selection include environmental, economic and sociopolitical criteria, some of which may conflict. This is because locating a landfill requires minimum or zero impact to environment components; water resources, air, soil, wildlife, as well as to lifeline utilities like transportation, social and economic factors (Moeinaddini et al., 2010).

Different authors describe the criteria that should be considered during landfill siting. For example, Ekmekçioğlu et al. (2010), EPA (2007) and Zamorano et al. (2008) consider hydrology, topography, adjacent land use, climate, flora and fauna, site capacity and road access

for siting landfill. According to Moeinaddini et al. (2010) and Al-Jarrah and Abu-Qdais (2006), faults, surface water, ground water, sensitive ecosystem, land use land cover, permeability of soil, depth of soil and slope should be given due attention as criteria for landfill site selection. Moreover, as described by the Centre for Advanced Engineering (2000), primary consideration should be given to key issues and potential fatal flaws with respect to geology, hydrogeology, surface hydrology and site stability in order to minimize future risk to the environment from landfill activities. The same source indicate that due to risk of off-site movement of leachate and landfill gas, it is generally undesirable to site a landfill in areas with the high permeability of soil or substrata, faults and/or karst geology (regions with highly soluble rocks, sinks and caverns); for example, limestone areas.

Waste Management Act (1996) restricts landfill locations in regionally important aquifers, national heritage areas and geologically unstable areas (EPA, 1996). Moreover, Resource Conservation and Recovery Act (RCRA) Subtitle D requirements place restrictions on locating landfills in the vicinity of airports, in floodplains, wetlands, fault areas, seismic impact zones and unstable areas (EPA, 1995).

Therefore, based on the availability of data, many of the criteria should be considered for proper siting of landfill. Most of these data are provided from geo-spatial technology (Remote Sensing, GIS and Global Positioning System (GPS)). Satellite images and GPS serve for providing input data for GIS to be further manipulated and analyzed so as to extract much of geographic information.

2.3 Application of GIS and Remote Sensing for Landfill Site Selection

2.3.1 Application of Remote Sensing

Remote sensing is defined as the science or art of obtaining information about an object, area or phenomenon through the analysis of the data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand et al., 2004). Remote sensing serves as a tool for environmental resources assessment and monitoring. The advancement of remote sensing technology to provide multi-spectral, multi-temporal and multi-spatial images is very helpful to increase the speed and frequency with which one can analyze a landscape (Idowu and Ukoje, 2009). Nishanth et al. (2010) also states remote sensing as one of the excellent tools for

inventory and analysis of environment and its resources, owing to its unique ability of providing the synoptic view of a large area of the earth's surface and its capacity of repetitive coverage. Furthermore, remote sensing contributes to the development of objective and comprehensive assessments over larger geographic extents and inaccessible area than is possible with fieldwork alone (Steininger and Horning, 2007). Moreover, the use of remotely-sensed data in natural resources mapping and as source of input data for environmental processes modeling has been popular in recent years. With the availability of remotely sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions has made remote sensing as one of the best source of data for large scale applications and study (Assefa Melesse et al., 2007).

The use of remote sensing is becoming increasingly frequent in environmental studies. In the recent years, no serious research of the environment performed without advanced image processing and analysis. One of the most important applications of remote sensing can be found in the case of solid waste landfill site selection where remote sensing data (satellite images) are used for extracting most of the site selection criteria used for siting landfill (Oštir et al.,2003) (example, mapping land use/land cover, geology and surface water), time and cost effectively. Moreover, remote sensing can provide digital data as an input for GIS. According to Dai et al. (2001), the most common inputs to a GIS are remotely sensed data from satellites or aircrafts. However, despite image interpretation can offer useful information, it is often used merely as a data source for the GIS analysis. Therefore, all available satellite images have to be integrated within a geographical database, together with other auxiliary data (Oštir et al., 2003) so as to fully utilize remote sensing data with good accuracy.

2.3.2 Application of GIS for Landfill Site Selection

GIS is defined as computerize system designed to store, retrieve, manipulate, analyze and map geographical data. The central element of a GIS is the use of a location referencing system so that data about a specific location can be analyzed in its relationship to other locations. This makes it possible to take data stored in one form and combine with data entered and stored in some other form (Church, 2002). Such powerful facilities of the GIS have been used to perform spatial analysis for different purposes like suitability analysis. Basically, it is used for screening the region for identification of the areas with the best promising characteristics after the

implementation of the criteria selected. In addition, using the proximity analysis, known as buffering and overlay, maps were created that show the areas that are in accordance with the criteria aforementioned (Fatta et al., 1998). Nishanth et al. (2010) also emphasize the capability of GIS to combine spatial data (maps, aerial photographs, satellite images) with the other quantitative, qualitative and descriptive information databases facilitating suitability analysis like site selection.

One of the benefits of GIS is its capability for landfill site selection. Landfill siting is complex, tedious and costly as it requires multiple criterions from environment, social and economic point of view. Moreover, landfill siting is a complicated process requiring a detailed assessment over a vast area to identify suitable location for constructing a landfill subject to many different criteria (Chang et al., 2007). However, with the advent of GIS and its decision support tools, preliminary screening and prospective site selection can be done effectively with high degree of accuracy (Hasan et al., 2009). According to Sumiani et al. (2009), GIS is widely used in landfill site selection to achieve the combination of the identified criteria in order to generate the suitability maps. Presently, it is the most reliable tool as it has capability to store, retrieve, and analyze a large amount of data as well as outputs visualization. According to Nishanth et al. (2010) and Sumathi et al. (2008), the role of GIS in solid waste management is very prominent as many aspects of its planning and operations are highly dependent on spatial data. GIS is a tool that not only reduces time and cost of the site selection but also provides digital data bank for future monitoring program of the site.

Therefore, GIS offers the spatial analytical capabilities to quickly eliminate parcel of land unsuitable for landfill site (Chang et al., 2007) and hence reduce cost and time of siting processes. Initial screening of unsuitable land by GIS is followed by utilization of a MCDA to identify the most suitable sites using the information provided by the regional experts with reference to new chosen criteria (Sharifi et al., 2009). However, for successful siting of landfill, accurate and timely spatial data are required. Remote Sensing technology is powerful in providing such data. Therefore, the most promising area seems to be the application of remote sensing in combination with geographical information systems (Oštir et al., 2003) in landfill site selection.

2.3.3 Integration of GIS and Remote Sensing for Landfill Site Selection

Since the 1990s, GIS and remote sensing have offered a sophisticated system of generating, storing and analyzing geometric and semantic information about spatial elements. GIS and remote sensing methods have been used in various scientific disciplines like in Environmental Science (Akar, 2009). For example, geospatial technology (GIS, Remote sensing and GPS) is an essential component of the Environmental Impact Assessment (EIA) process, as environmental resources are directly affected by changes in the shape and extent of the proposed disturbance. This is because, with the use of spatial techniques, EIA has enhanced substantial viewing, movement, query and even map-making capabilities (Satapathy et al., 2008). Moreover, they have the capacity to provide valuable and timely information about natural resources, urban change and the extent of environmental change being experienced in earth as an important basis for sustainable planning for land management and decision making. Therefore, geospatial information technologies are the key to planning, management and administration of land (Osei et al., 2006).

An integrated geo-spatial technology, i.e. remote sensing, geographic information system and GPS can contribute substantially in a more supplementary fashion to some of the interactive operations that should become an asset for assessing, understandings, mapping utility and service facility using GPS and solving complex urban environmental issues like solid waste management via aiding landfill siting (Rahman and Netzband, 2007). According to Zamorano et al. (2008), combination of the GIS and Remote Sensing systems provide multi-spectral, multi-temporal and multi-scales (spatial resolution), which can be adopted according to the degree of details needed. This technique plays an important role in regional screening for landfill sites.

2.4 Multi-Criteria Decision Analysis (MCDA) for Landfill Site Selection

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice (Chakhar and Mousseau, 2008). MCDA consists of a series of techniques (such as weighted summation or concordance analysis) that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by, for example, experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/siting a particular facility/service (Malczewski, 2004) like landfills. Analytic Hierarchy

Process (AHP) is one of the most commonly used MCDA tools. This tool is applied in site selection processes as it assists the decision making process by allowing decision-makers to organize the criteria and alternative solutions of a decision problem in a hierarchical decision model (Eldrandaly et al., 2005). Furthermore, Multi-criteria approaches have the potential to reduce the costs and time involved in siting facilities by narrowing down the potential choices based on predefined criteria and weights while also permitting sensitivity analysis of the results from these procedures (Higgs, 2006).

Hence, multi-criteria techniques could be particularly useful in situations where there are a large number of alternative sites for a development, where there are large number of potential criteria to be taken into consideration or where subjective judgments by different stakeholders of the different alternatives is needed to try to reach an objective consensus in the final decision-making process or to make these processes more open and accountable (Petts et al., 2003 as cited in Higgs, 2006). Many spatial decision-making problems, such as site selection or land use allocation require the decision-maker to consider the impacts of choice alternatives along multiple dimensions in order to choose the best alternative (Jankowski, 1995). Moreover, Eldrandaly et al. (2005) described exercises involving spatial decision-making such as industrial site selection, land use allocation, and solid waste landfill site selection as a challenge that are multi-faceted by nature and involve not only technical requirements, but also economical, social, environmental and political dimensions. According to Kiker et al. (2005), MCDA tools can be applied to assess value judgments of individual decision makers or multiple stakeholders. Such capability of MCDA methods is used to evaluate and choose among alternatives based on multiple criteria using systematic analysis that overcomes the limitations of unstructured individual or group decision making for complex site selection processes. Due to these capabilities, MCDA have primarily been employed to solve site selection problems in solid waste management (Vuk et al., 1991 as cited in Sumathi et al., 2008).

A solid waste management program often involves conflicting economical, environmental, and socio-ecological impacts. For example, locating a new site for landfill development at minimal cost is feasible, but the tradeoff could be the likelihood of groundwater pollution. The landfill selection problems have often been tackled using MCDA through defining the criteria for landfill siting. Therefore, Integrated MCDA solve the problems of past landfill site selection which were

process-redundancy and inefficient (Chenga et al., 2003). According to Moeinaddini et al., (2010) a siting Municipal Solid Waste (MSW) landfill is a spatial multi-criteria decision analysis (SMCDA) for which both GIS and MCDA methods should be used. Moreover, landfill site selection by GIS is a multi-criteria evaluation (MCE) and generally has four steps: 1) criterion establishment, 2) standardization of factors, 3) establishment of factors weight, and 4) weighted linear combination. With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of results to yield a suitability map (Hasan et al., 2009).

Therefore, the role of MCDA in landfill site selection can be completed by integrating it with GIS. Eldrandaly et al. (2005) emphasize, integrating GIS and MCDA can solve the challenges of site selection (landfill site selection) which involves highly complex spatial decision-making processes.

2.5 Spatial Multi-Criteria Decision Making (SMCDM) for Landfill Site Selection

Application of GIS is widely spreading in resource inventory and mapping. However, the potential of GIS for planning and decision-making couldn't be utilized fully due to its limited ability to represent judgments, values, arguments and options of the decision makers (Laskar, 2003). The functionality of GIS is limited to certain deterministic analyses in key application areas such as spatial search. The difficulties of land suitability evaluation due to huge number of alternatives and requiring many criteria can be solved by MCE (Brikci and Trache, 2000).

GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) is a process of decision making at which geographical data and value judgments are brought together to obtain more information for the decision makers. GIS and MCDA can benefit from each other. GIS techniques and procedures have an important role to play in analyzing MCDM problems through automating, managing and analyzing a variety of spatial data for decision making. Although an increasing numbers of GIS are described as systems for supporting spatial decision problems, most of GISs lack the kind of spatial analysis required by decision makers. On the other hand, MCDM methodologies provide a rich collection of techniques and procedures to reveal decision maker's preferences and to incorporate them into GIS based decision-making (Jankowski, 2006).

The integration of multi-criteria methods with GIS is forwarded to provide the user with the means to evaluate various alternatives on the basis of multiple and conflicting criteria and objectives and to solve the complexity of site selection (Brikci and Trache, 2000; Laskar, 2003).

Integrated GIS and MCDA can be used to solve the landfill site selection problem and developed a ranking of the potential landfill areas based on a variety of criteria. The suitability criteria are defined with the focus to minimize any potential health risks from direct or indirect contamination due to the proximity of a landfill site with respect to key geographic features (Chang et al., 2007). Integration of these technologies through an interactive and user-friendly interface provides the framework of spatial decision support systems (SDSS) and helps to improve the effectiveness of decision making by incorporating decision makers judgments and computer based program within the decision making process (Laskar, 2003). Hence, the integration of MCDM techniques with GIS has considerably advanced the map overlay approaches to site suitability analysis (Carver, 1991) and solves landfill site selection problems (Chenga et al., 2003).

2.6 Solid Waste Management System in Addis Ababa and Environmental Laws

Due to the enhanced concern for human health and the urban environment, Addis Ababa Municipality has been paying more attention to collect, transport and disposes the urban solid waste.

Collection systems

Three different municipal systems have been established to collect solid waste in Addis Ababa namely, collection through municipal containers, collection from different institutions and the house-to-house collection.

Municipal container system

The intention with this system is to collect waste from different waste generators, mainly the households. The purpose of the containers is to function as municipal collection stations and the containers are therefore located in open spaces near the main roads in the city, where the households and other generators deliver their waste. There are two types of containers, large 8 m³ open steel containers and 1.1 m³ plastic containers with covers. Totally, there are 512 steel containers and 479 plastic containers for the collection of the waste generated in the city. Transportation of the larger steel containers to the landfill is done by 38 collection trucks (Bjerkli, 2005).

Collection from institutions

Institutions have access to 10 large steel containers. These containers are delivered and picked up to order, which costs 11 birr/m³.

House-to-house collection

This collection service is available for those households which are located far from the main roads. Because of inadequate infrastructure in the city, it is impossible for the collection truck to access many areas of the city. Sixteen Nissan trucks collect the waste from the households twice a week. This collection service handles 33 percent of all the waste collected in the city. In addition to the collection systems mentioned above, street sweeping is performed every day all over the city. This activity accounts for 6 percent of the collected waste (SBPDA, 2003).

Transport

There are 72 lift trucks, but only 35 to 40 of them are used daily because the average age of the truck is more than 5 years and they are inadequately maintained. Moreover, one truck can only transport one container to the landfill site which lies 13 km outside the city centre. The transport system is therefore time-consuming because the truck has to drive 26 km in total to unload one container (SBPDA, 2003).

Final disposal

Currently, there is only one landfill site where all the waste collected from the municipality is disposed, namely the site known as 'Repi' or 'Koshe' and it is located in Kolfe sub-city, 13 km south-west from Addis Ababa city centre. It covers an area of 25 hectares of prime farmland. It is an open landfill, where the waste is deposited, spread out, leveled by a bulldozer, and then compacted by a steel studded wheeled compactor to reduce the volume (Tadesse Kuma, 2004 as cited in Bjerkli, 2005). The landfill was developed 47 years ago and until year 2002 the waste disposed on the landfill is estimated to have been 9.5 million m³ (SBPDA, 2003). The site was designed for only 25 years. Both domestic and industrial waste are dumped at the site without any form of special treatment and the waste is not covered with soil to prevent harboring of disease vectors, odour, air pollution and other hazards. There is no drainage system and fence to enclose from the surrounding environment. Furthermore, scientific report on the groundwater vulnerability mapping of the Addis Ababa water supply aquifers shows that the water that penetrates into the dumping area during rainy season infiltrates to depth and discharge on the southeast direction following the gradient of the topography. The rock units are highly fractured and there is thin soil cover in the area. These facilitate infiltration of leachate into the subsurface through fractures and interstitial porosity (Tamiru Alemayehu et al., 2003). As a result, the nearby surface water and groundwater is vulnerable to contamination by leaching and contains

high amounts of chloride, organics, metals, hydrates and other contaminants (Bjerkli, 2005). Moreover, public health is at risk as the site is near the main roads and surrounded by institutions and settlements.

Hence, current practice of solid waste management (open dumping system) in the city is not environmentally friendly and socially acceptable as it is posing negative impacts to both the environment and public health. Open dumping is contrary to the international and local environmental laws. Internationally it is not recommended to dispose solid wastes in an open dumping system. Moreover, Ethiopian government has also proclaimed to manage solid waste in an environmentally sound way via constructing solid waste disposal sites, yet not fully implemented. Solid Waste Management Proclamation No.513/2007 Article 14 Sub article (1) states that, each urban administration shall, in conformity with the relevant federal environmental standards, ensure that solid waste disposal sites are constructed and properly used. Moreover, sub-article (2) describe that, urban administrations shall ensure that a solid waste disposal site that was under construction or was constructed prior to the coming into force of this proclamation is subjected to environmental auditing as per the relevant law. Sub-article (3) of this proclamation also emphasize as urban administrations shall ensure that any new solid waste disposal site being constructed or an existing solid waste disposal site undergoing any modification has had an environmental impact assessment according to the relevant law.

Environmental Pollution Control Proclamation No.300/2002 article 5 sub articles (1) also emphasize the mandate of urban administration on management of municipal waste. The article says, all urban administrations shall ensure the collection, transportation and, as appropriate, the recycling, treatment or safe disposal of municipal waste through the institution of an integrated municipal waste management system. Therefore, for sustainable solid waste management and protect the environment, the above proclamations should be fully implemented. There is also international convention called Basel Convention, originally adopted to protect human health and the environment against the serious effects of mismanagement of hazardous and other wastes, in response to scandals involving uncontrolled waste dumping in Africa and elsewhere in the 1980s.

2.7 Review of Previous Landfill Site Studies for Addis Ababa City

There has been an effort from the Municipality to have proper landfill site for sustainable solid waste management and replace the Koshe open dump site. Accordingly, to construct a proper sanitary landfill site for the city, the Filidoro, Bole Arabsa and Fincha sites were studied by different groups. However, feasibility studies have revealed that these sites were found unsuitable to be used as sanitary landfills due to different reasons.

Filidoro landfill site

The Filidoro site is located north-west of the city close to little Akaki River bounded by coordinates 465781mE and 998637mN. From environmental point of view this is not recommended and it was discarded due to occurrence of nearby shallow wells, insufficient size, existence of forest land, potential to pollute little Akaki, settlement close to the site and proposed new highway near the site.

Bole Arabsa site

Bole Arabsa landfill is located on the south-east part of the city. Its UTM coordinate is 486080m E and 989890m N. The site was not suitable for sanitary landfill due to pollution downstream surface water, requires large number of people to be displaced and pollution of groundwater due to the high permeability of the geological formations.

Fincha Site

Fincha site is located 37 km south of Addis Ababa, very close to Akaki well field, which serve as one of the water supplies for the city. Fincha site is located at the recharge area for the Akaki well field and with high permeability of the geological formations which will result in groundwater pollution.

Chebi Worenenu

It is located at the North Eastern part of Addis Ababa, in the Oromia Regional State Finfinne surrounding Oromia Special Zone, east of Legetafo. This site is selected by task team with an involvement of Geological Survey of Ethiopia. The team has used hydrogeology, geology, ecology and engineering aspect to identify the site. However, the site is out of the boundary of Addis Ababa at about 26km from the center of the city and hence transportation cost will be high. Moreover, GIS and remote sensing were not fully utilized and hence large volumes of spatial and timely data were not correctly included in the study. Furthermore, values, judgment, qualitative and quantitative data were not included. These limitations can result inaccurate siting of landfill.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Geographic Location

Addis Ababa is the capital city of Ethiopia founded in 1887 and its geographic location is between 465000m and 485000m East and 980000m and 1005000m North. The city is located in the central highlands of Ethiopia covering an area extent of about 527km² with an average elevation of 2600m above sea level, which makes Addis Ababa the highest capital city in Africa. The administration of the city is divided into ten sub-cities (Fig.1): Bole, Yeka, Cherkos, Gullele, Kolfe Keraniyo, Arada, Lidata, Akaki-Kaliti, Nefas-Silk Lafto and Addis Ketema and 99 kebeles.

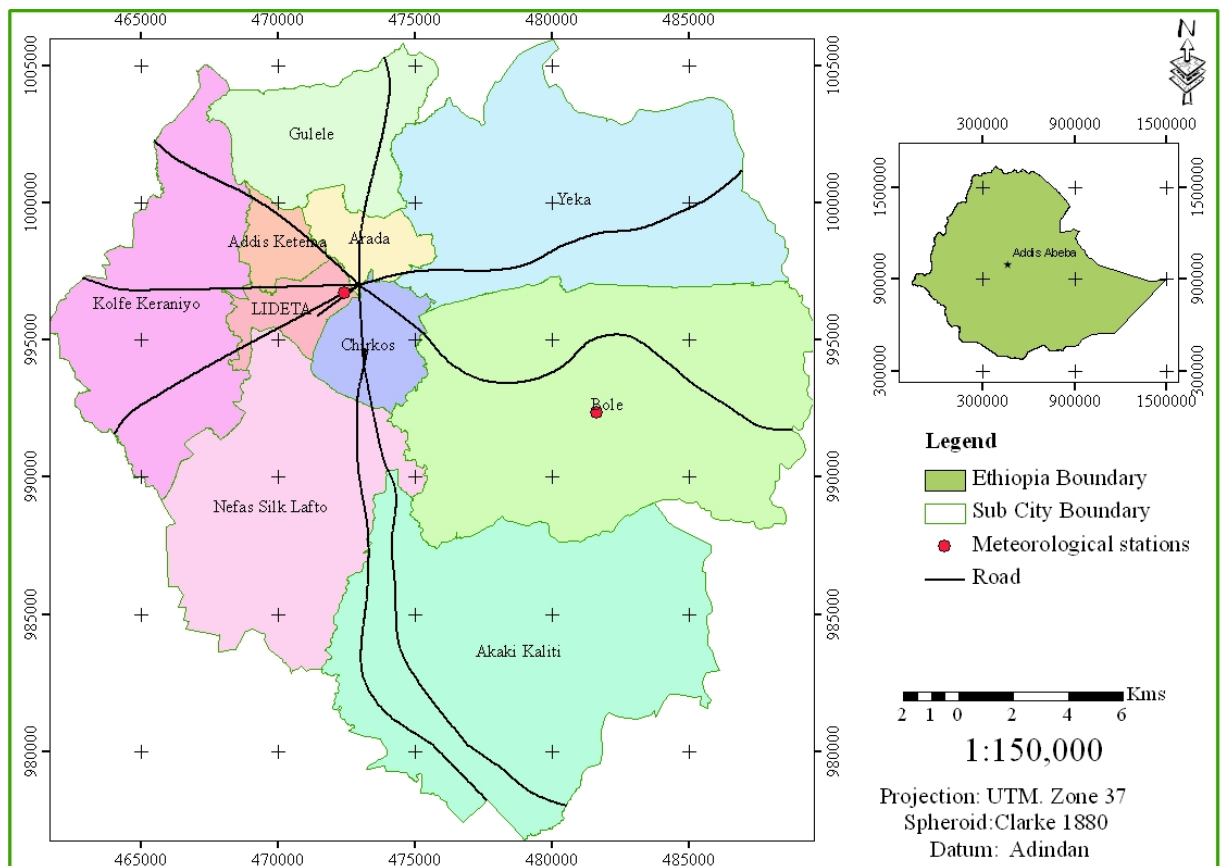


Fig. 1. Location Map of the Study Area

3.1.2 Physiography and Drainage

Addis Ababa was founded on the southern flank of Entoto ridge (3139m.a.s.l.) and expanded in all directions. Other prominent volcanic features surrounding the city are Mt. Wochacha in the west (3385m.a.s.l.), Mt. Furi (2839m.a.s.l.) in the southwest and Mt. Yerer (3100m.a.s.l.) in the

southeast. These typical volcanic features are mainly built-up of acidic and intermediate lava flows. Thus, they are characterized by rugged landscapes and steep slopes.

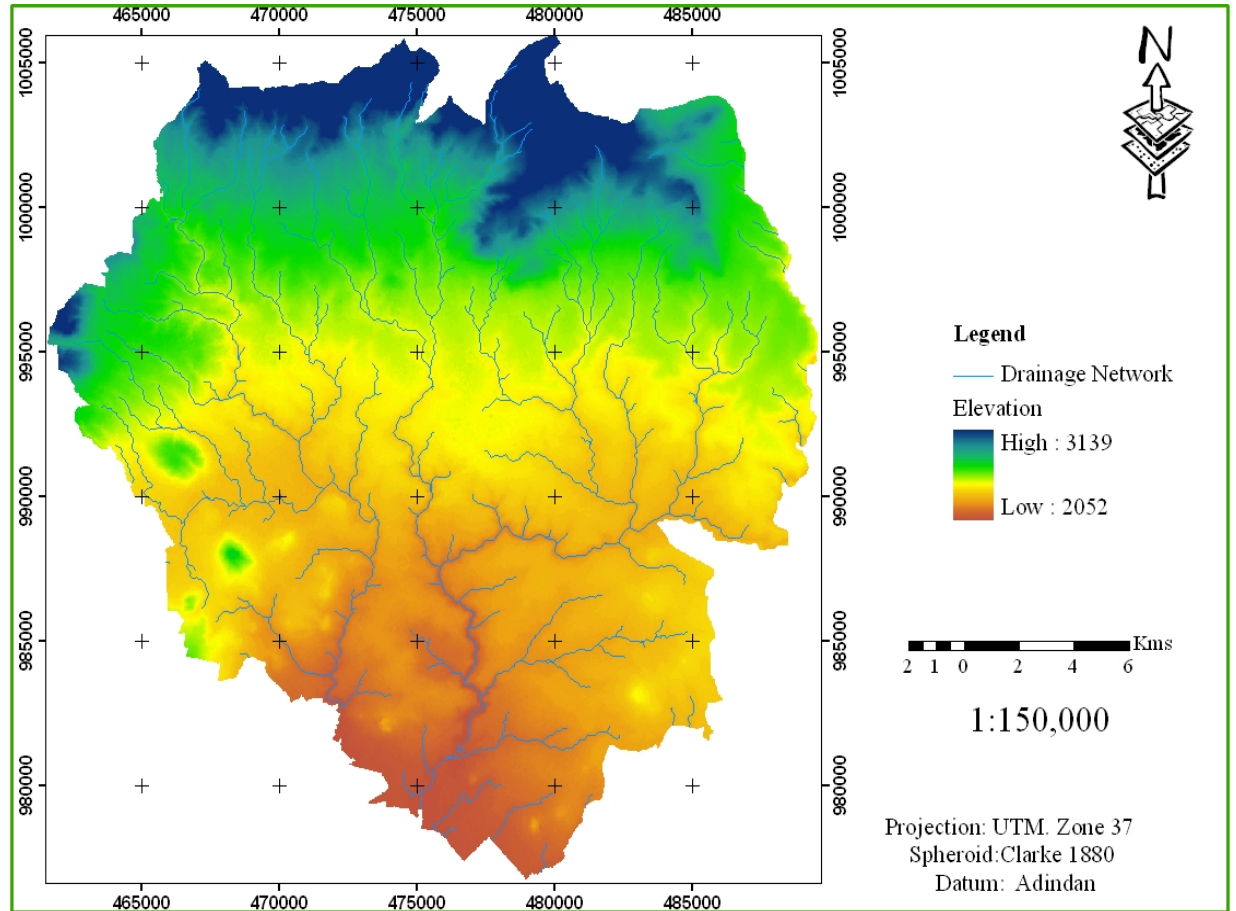


Fig. 2. Elevation Map Addis Ababa

The topography slopes down from the Entoto Mountain in the north to the southern border of the city, with a number of steep-sided valleys, rivers and streams. The center of Addis Ababa lies on an undulating topography with some flat land areas. The topography is undulating and form plateau in the northern, western and south-western parts of the city. However, Bole and south western part of the city are characterized by gentle morphology and flat land areas. As a result, the stream drains towards south from the Entoto ridge; southeast direction from Mt. Wechecha and Mt. Furi and towards southwest direction from Mt. Yerer and other elevated areas of the eastern outskirts of the city.

The region is also characterized by permanent and perennial rivers. On tops of the hills and ridges, streams are dense and form radial drainage pattern, whereas on the slope and most part of

the study area, they form dendritic pattern (Fig.2). The major perennial rivers of the study area are Kebana, Little Akaki, Big Akakai, Kotebe, Ginfile, Tafo and Harku. There are also several intermittent rivers in the study area.

3.1.3 Climate

As the study area is located at high altitude, the climate is comfortable with optimum temperature and rainfall. The meteorological data of the last ten years from two stations (Bole and Tikur Anbessa) show that the average rainfall of Addis Ababa is about 1127mm per year (Fig. 3), with the major rainfall occurring between July to September. The minimum mean monthly temperature of the region ranges between 8°C to 12°C, while the maximum mean monthly temperature varies between 20°C to 25°C, throughout the year in the last ten years (Fig. 4).

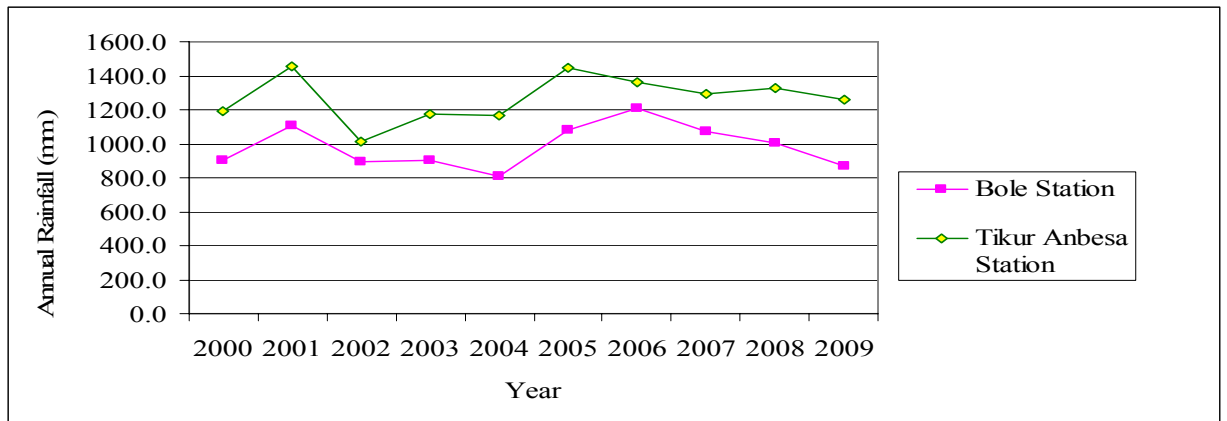


Fig. 3. Annual rainfall of Addis Ababa recorded in two stations

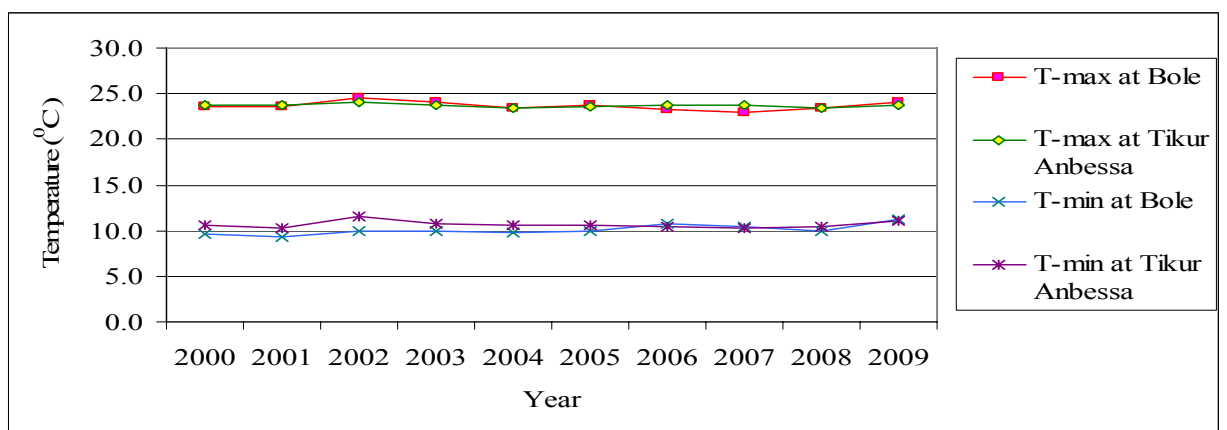


Fig. 4. Maximum and minimum temperature of Addis Ababa recorded in two stations

3.1.4 Population

The annual population growth of Ethiopia is at the rate of around 2.6 percent per year. The high growth rate is a result of the country's birth rate, which is 4.5 percent and is also among the highest in Sub-Saharan Africa. By contrast, the death rate has been falling from 3.1 in 1950 to 2.3 in 1975 and to 1.5 in 2000. The country's population will continue to grow for several decades as the large portion of the population is relatively young. Population forecast indicates that over the next 15 years the country's population will double. This means that the population will double from 73 million today to 146 million by the year 2025.

Currently, about 3.7 percent of the country's population is living in Addis Ababa city. During the last 40 years, the population in Addis Ababa has increased dramatically. The total population increased from 644,190 in 1967 to 1,423,182 in 1984. From 1984 to 2001, the population increased to 2,570,000 and has reached 2,805,000 in 2004 (Fig. 5). However, according to the Central Statistical Authority (CSA, 2007), the current population of the city is slightly decreased to 2,738,248. This decrease is due to the migration of the people of Addis Ababa to nearby towns such as Burayu, Sebeta, Legatafo and Sendafa.

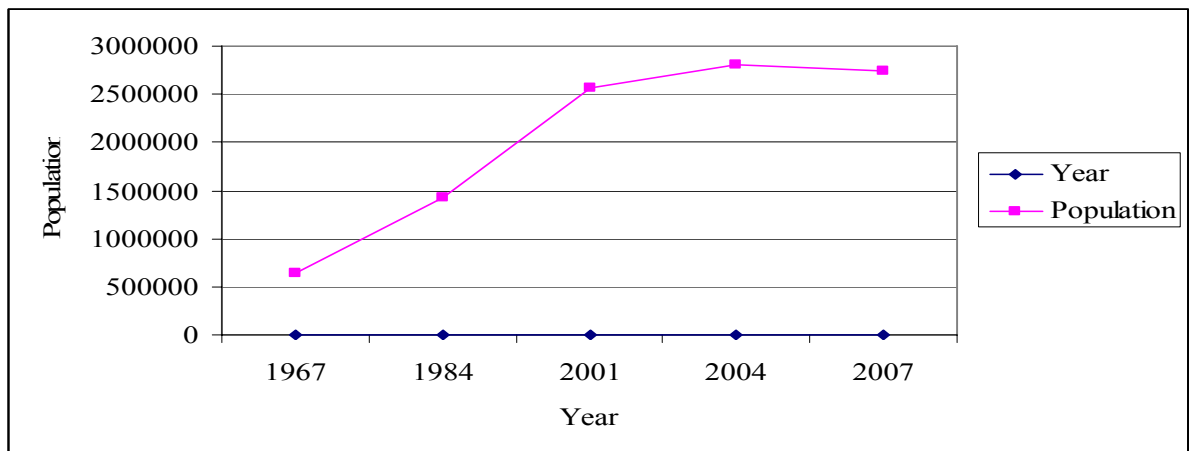


Fig. 5. Population of Addis Ababa from 1984 to 2007 (CSA, 2007).

3.1.5 Expansion of the City

Addis Ababa has shown a remarkable spatial expansion in the recent decades, due to natural population growth and increased migration from the rural areas. In the 1920s, the city was estimated to be around 33 km² in area. By 1984, the area had increased to 223.6 km², by 1990 it was 518.7 km² and in 1994 it had increased further to about 530.21 km² (Girma Kebede, 2004). This rapid expansion has resulted in an unplanned physical development of the city, with the

formation of informal settlements. A unique characteristic of Addis Ababa is that most parts of the city are not segregated according to income. In older neighborhoods, the rich, the middle classes and the poor are living side by side. However, the disparity in housing quality between these groups is conspicuous.

3.1.6 Geology

The geology of Addis Ababa and its surroundings has been studied by several researchers both locally and at the regional scale. The sequence of the rock units reveals the Miocene-Pleistocene volcanic succession ranging from older plateau volcanic to younger rift volcanic where from bottom to top are: Alaji basalt, Entoto silicics, Addis Ababa basalts, Nazareth group, and Bofa basalt (Tamiru et.al, 2005).

A) Alaji Basalt

Alaji Basalt group are volcanic rocks (Alaji rhyolite and Basalt) and parts of the escarpment were outpoured from the end of Oligocene until middle Miocene. This unit is composed of basalts, which show variation in texture from highly popyric to aphyric. Within this unit, there is an intercalation of gray and glassy welded tuff. The outcrop of Alaji basalt extends from the crest of Entoto (ridge bordering the northern parts of Addis Ababa) towards the north (Haileselassie Girmay and Getaneh Assefa, 1989).

The unit is underlain by tuffs and ignimbrites. Its stratigraphic relationship with the Entoto silicics is difficult to determine as they occur in a fault contact. Mohr (1967) as cited in Tamiru Alemayehu et al. (2003) proved that the Entoto trachyte overlies the Alaji basalt.

B) Entoto Silicics

These early Miocene age silicic volcanics could represent localized terminal episodes to massive Oligocene fissure-basalt activity in the Addis Ababa region (Tamiru et al., 2005). The thickness of the flow become maximum on the top of Entoto ridge and thin both towards the plateau and the plain east of Addis Ababa. According to Zanettin and Justin-Visentin (1974) as cited in (Tamiru Alemayehu et al., 2003), these lavas make up a thick pile of flows accumulated along east west fissures (eastwest fault running from Kassam River to Ambo) and uplifted northwards. This unit is uncomfortably overlain by Addis Ababa basalt on the foothills of Entoto and underlain by Alaji basalt. The Entoto silicics composed of rhyolite and trachyte with minor amount of welded tuff and obsidian (Haileselassie Girmay and Getaneh Assefa, 1989). It also

outcrops in the eastern part of the town from the Kokebe Tsebah School to the Benin Embassy. The thickness is quite variable as it frequently forms dome structure. In this rock unit, flow banding, folding and jointing are common. The rhyolites are overlain by feldspar porphyritic trachyte and underlain by a sequence of tuffs and ignimbrites. Tuffs and ignimbrites are welded and characterized by columnar jointing.

C) Addis Ababa Basalt

Addis Ababa basalt is the oldest visible rock post-dating the Entoto silicic. It is mainly found in the central part of the town and underlain by the Entoto silicics and overlain by Lower welded Tuff of the Nazareth group. The maximum thickness exceeding 130 meters is found at Ketchane stream. It is porphyritic in texture, composed of labradorite, bytownite, olivine and augite as phenocrysts. The ground mass is made of andesine, labradorite, olivine, agnetite and pyroxene (Haileselassie Girmay and Getaneh Assefa, 1989).

Olivine porphyritic basalts outcrop in the central part of the town that includes Mercato, Teklehaymanote and Sidist Kilo. The distribution of plagioclase porphyritic basalt is almost the same as that of the olivine porphyritic basalt, but only little more northwards. It outcrops in an area, which includes Sidist Kilo, General Winget School and French Embassy. The thickness of the former varies from 1m or less in the foothills of Entoto, Lideta Airfield and Filwoha to greater than 130 meters at Ketchane stream (Morton, 1974; Varnier et al., 1985 as cited in Tamiru Alemayehu et al., 2003). The Lower Welded Tuff overlies both types of basalt nearby the Building College, the Kolfe Police School, the Kokobe Tseba School and YecaMariam Church. On the other hand, only in the gorge of the Ketchane stream, the olivine porphyritic basalt is overlain by the plagioclase porphyritic basalt, while elsewhere the relationship between them is very difficult to determine (Varnier et al., 1985 as cited in Tamiru Alemayehu et al., 2003). Addis Ababa basalt yield ages clustering around 7my and seems to have no time /composition equivalent (Morton et al., 1974 as cited in Tamiru Alemayehu et al., 2003).

D) Nazareth Group

The units identified in this group are denoted as Lower Welded Tuff, Aphanitic basalt and Upper Welded Tuff. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly south of Filowha fault and extend towards Nazareth.

Lower Welded Tuff

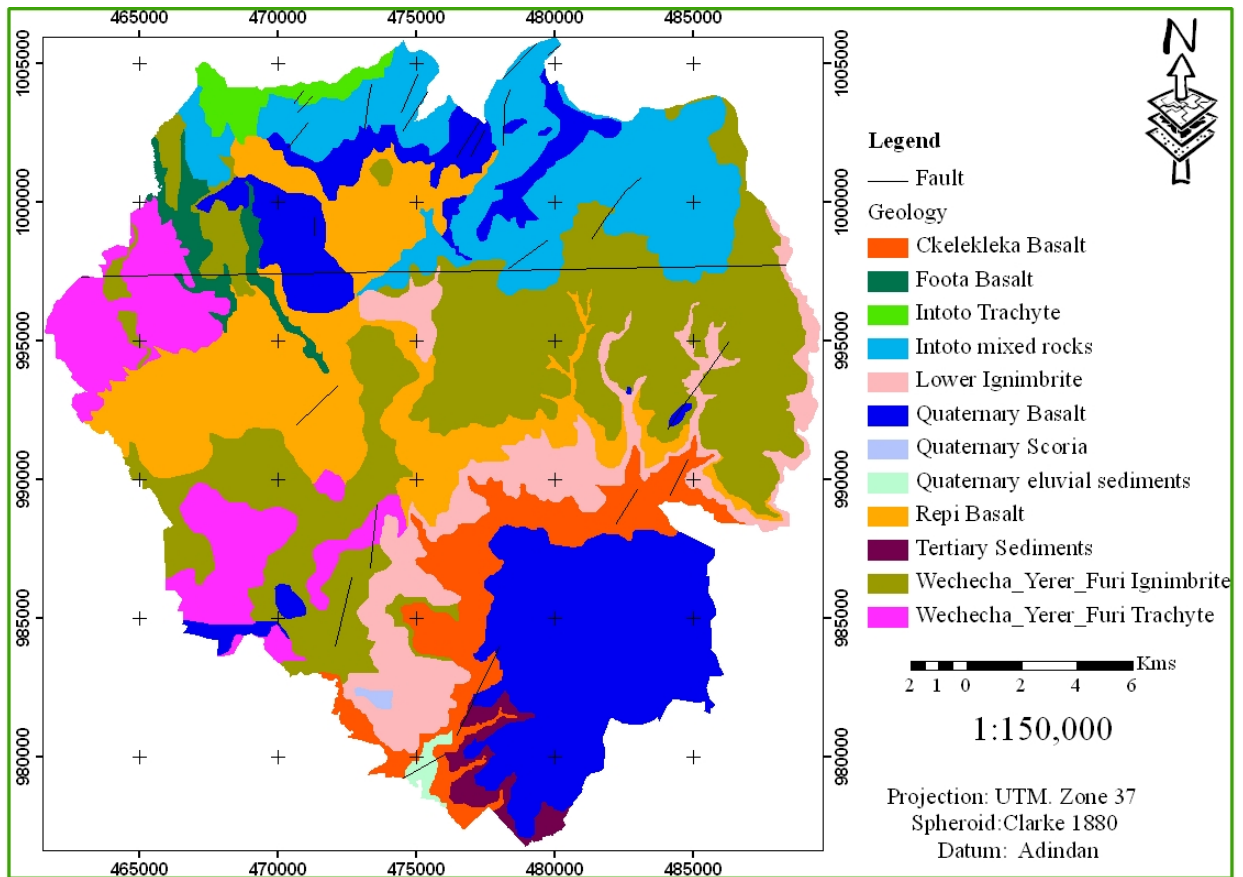
It is the rocky outcrops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta. Generally, it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase porphyritic basalt. The age of this rock as dated by Morton et al. (1979) as cited in Tamiru Alemayehu et al., (2003), as at Addis Ababa and Sululta is 5.1 and 5.4 million years, respectively. This age overlap with the period of the activity of Wachecha trachyte volcanoes, dated 4.6 million years. Wachecha is located 15 km west of Addis Ababa and probably the sources of the Lower welded tuff at both localities (Morton et al., 1979 as cited in Tamiru et al., 2005).

Aphanitic Basalt

This basalt covers the southern part of the town, especially the areas of Bole International Airport and Lideta Airfield. The rock body shows vertical curved columnar jointing together with sub-horizontal sheet jointing. Kaolin and lenses are present at the contact of this basalt with the younger ignimbrite. This makes an evidence for the hydrothermal alterations along a NE-SW fracture system, which may affects both the basalt and the Entoto trachyte. Moreover the basalt is overlain by pumaceous pyroclastic falls and the pyroclastic falls. It is underlain by a soil horizon that covers the plagioclase porphyritic basalt and overlain by soil horizon and tuff layers that lie below the young ignimbrite. The crystals of plagioclase show marked flow lineaments. Trachy-basalt outcrops around Repi and nearby General Wingate School. It is underlain by the plagioclase and olivine porphyritic basalt and overlain by the younger ignimbrite from which it is separated by tuffs and agglomerates. Its relation with the rocks of the group is not clear, but probably younger than the aphanitic basalt (Getaneh et al., 1985 as cited in Tamiru et al., 2005).

Upper Welded Tuff

This rock outcrops all over the southern part of the town including Bole, Nefas Silk and Railway station. Nevertheless, it is also present in the central and northern parts of the town. It is gray colored, vertically and horizontally jointed and composed of sandine, anorthoclase, rebecite, quartz, pumice and unidentified volcanic fragments (Getaneh Assefa et al., 1989 as cited in Tamiru et al., 2005). The welded tuff is underlain by aphanitic basalts and overlain by young olivine basalts. The geologic units of Addis Ababa area are shown in Fig. 6.



(Source: Mulugeta H/Mariam et al., 2007)

Fig. 6. Geology map of Addis Ababa

3.1.7 Geologic Structures

The study area is characterized by the occurrence of faults, joints and other structures within the different volcanic rocks. Long fault line running east west via Kassam river, Addis Ababa and Ambo, cut across the western rift escarpment and uplifted its northern block at about 8 My ago (Fig. 6). This fault marks the upper boundary of the western Ethiopia Rift margin immediately north of Addis Ababa-Ambo road (Zanettin et al., 1974 as cited in Tamiru Alemayehu et al., 2003). Another prominent normal fault in the city is the Filowha Fault. This fault has NE-SW trend (Haileselassie Girmay, 1989). However, the fault has a northwest down thrown side according to Tamiru Alemayehu et al. (2003).

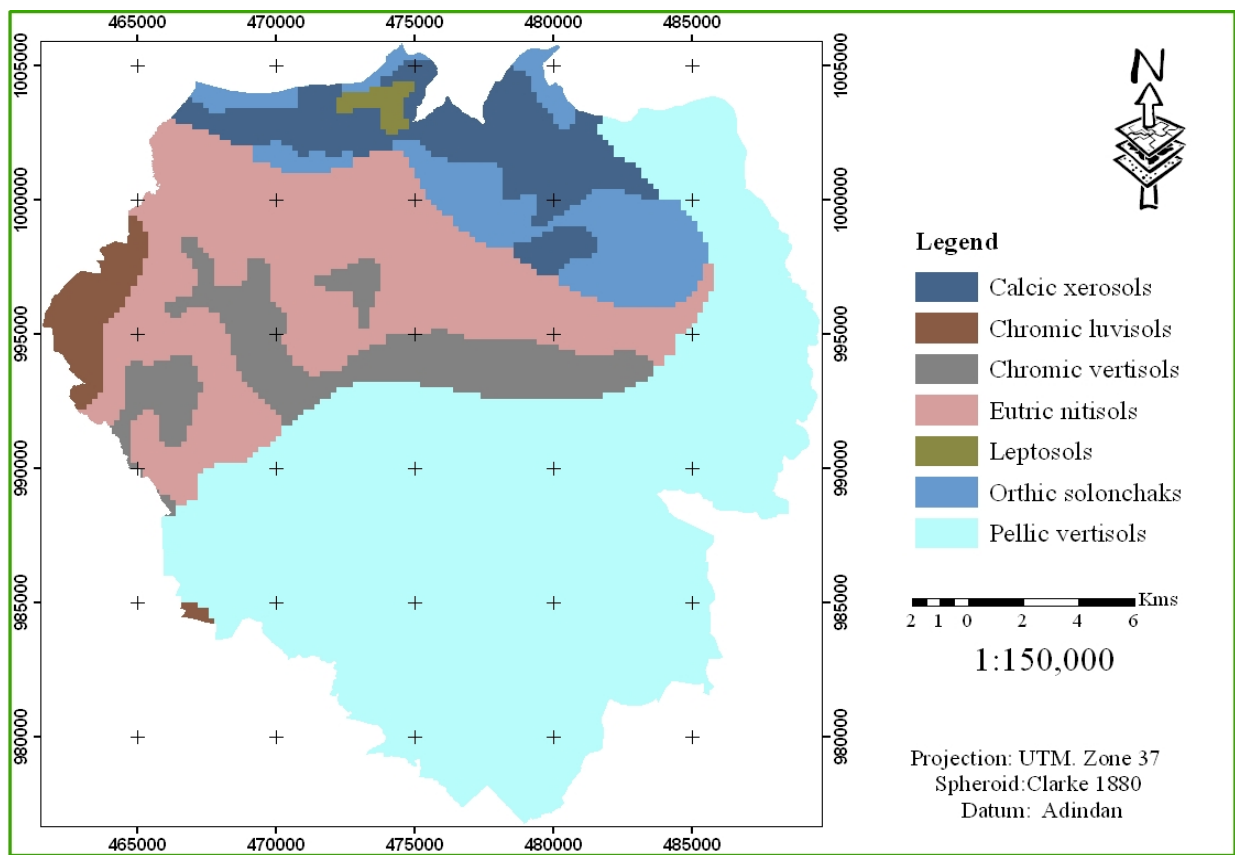
The other major structural feature in the study area is joints, with different spacing, opening and orientation (Tamiru Alemayehu et al., 2003). The dominant preferred orientation of joints occurring in different rock unit is NNE-SSW (Tamiru Alemayehu et al., 2003), which is sub

parallel with the general trend of rifting. They found joint spacing of 15-200 cm (in most basalt), 5-100 cm (in trachy basalt, trachyte and rhyolite) and 2-100 cm (in ignimbrite).

3.1.8 Soil

The five soil forming factors namely climate (temperature and rainfall), topography, parent material, biological activities (flora and fauna) and time determine the types of soil that are formed at 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, Orthic Solonchaks and Pellic Vertisols (Ministry of Water and Energy, 2004). The dominant soil of the region is Pellic Vertisol (277.23km²) which is found in the southern and north east part of the city. Eutric Nitisol (111.55km²) is the second most dominant soil found in the central and north west part of the region. Calcic Xerosols (39.79km²) is the third most dominant type of soil found in the northern part of the city. Chromic Vertisols are the fourth dominant soil of the region covering an area of about 34km² and found in the central part of the city center. The rest soil types are found in the northern part of the center covering smaller areas (Fig. 7).

The permeability and infiltration of each soil depends on its textural composition. Accordingly, Vertisol (Pellic 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 sized textured and with relatively less clay content than Vertisol. The permeability of Chromic Luvisol, which is found in the north-west part of the center, is also moderate like the case of Eutric Nitisol. 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 of the center. The textural class is moderately coarse textured soil with high permeability. 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 coarser the texture and vice versa.



(Source: Ministry of Water and Energy, 2004)
 Fig. 7. Soil Map of the Study area

3.2 Methods

3.2.1 Data Source

Table 1 summarizes the data and equipment used to execute the present study.

Table 1. List of data and equipment used.

S/N	Type	Description	Source
1	Maps	Geology Map	EGS(Ethiopia Geologic Survey)
		Topographic Map (1:50,000)	EMA
		Addis Ababa Master Plan (LULC)	Addis Ababa Municipality
		Digital Soil Map	Ministry of Water and Energy
		Road network Map and City shape file	CSA, SPOT image
2	Row data	Borehole data	AAWSA
		ETM+ images (2005 year; path 168 row 54) & SPOT(2005 years)	USGS and AAU GIS Lab.
		SRTM (30*30m resolution)	USGS
3	Equipments	GPS and Digital Camera	OWWDSE

3.2.2 Data Collection

Collecting accurate and reliable data is the most determinant factor for any research as it determines the quality of the research. In this particular research, the first steps were to identify the environmental, social and economical factors to be considered for siting landfills followed by setting criterion based on international and local rules. Accordingly, the necessary data were collected from the respective sources.

Borehole data like ground water depth, lithology, water supply well points and hydraulic conductivity were obtained from Addis Ababa Water Supply and Sewerage Authority (AAWSA) and the data were collected in GIS environment. Geology map of Addis Ababa was obtained from Geologic Survey of Ethiopia for mapping geologies and faults found in the study area. Landsat ETM+ of 2005 and master plan of Addis Ababa were used to map the current land use/land cover of the study area. SRTM (30*30m resolution) and Topographic map (1:50,000) were used to extract Digital Elevation Model (DEM). The DEM was used to derive slope and drainage pattern of the study area. Road networks were digitized from SPOT image and ready for use in GIS environment. GPS were used for collecting Ground Control Points (GCPs). All the above data were collected, manipulated and analyzed in GIS environment to be used for further analysis.

3.2.3 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 known Multi-Criteria Analysis methods that were used for this study.

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 pair 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.

Weighted Linear Combination (WLC)

WLC 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 much 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 methodology was followed. This methodology is best suited for siting landfills accurately in time and cost effective manner, hence 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 weighted linear combination. Landfill site selection methodology is a two step processes. 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 candidate landfill sites. In the second step MCDM, is used for ranking the candidate sites and identify the best site/s based on the weights assigned to each criterion. AHP is a powerful MCDM tool to assign weights and rank the candidate sites for selecting the best site among the candidates. 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. 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 is 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 layers, WLC techniques were apply 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. The general methodology used for the study is shown in Fig. 8.

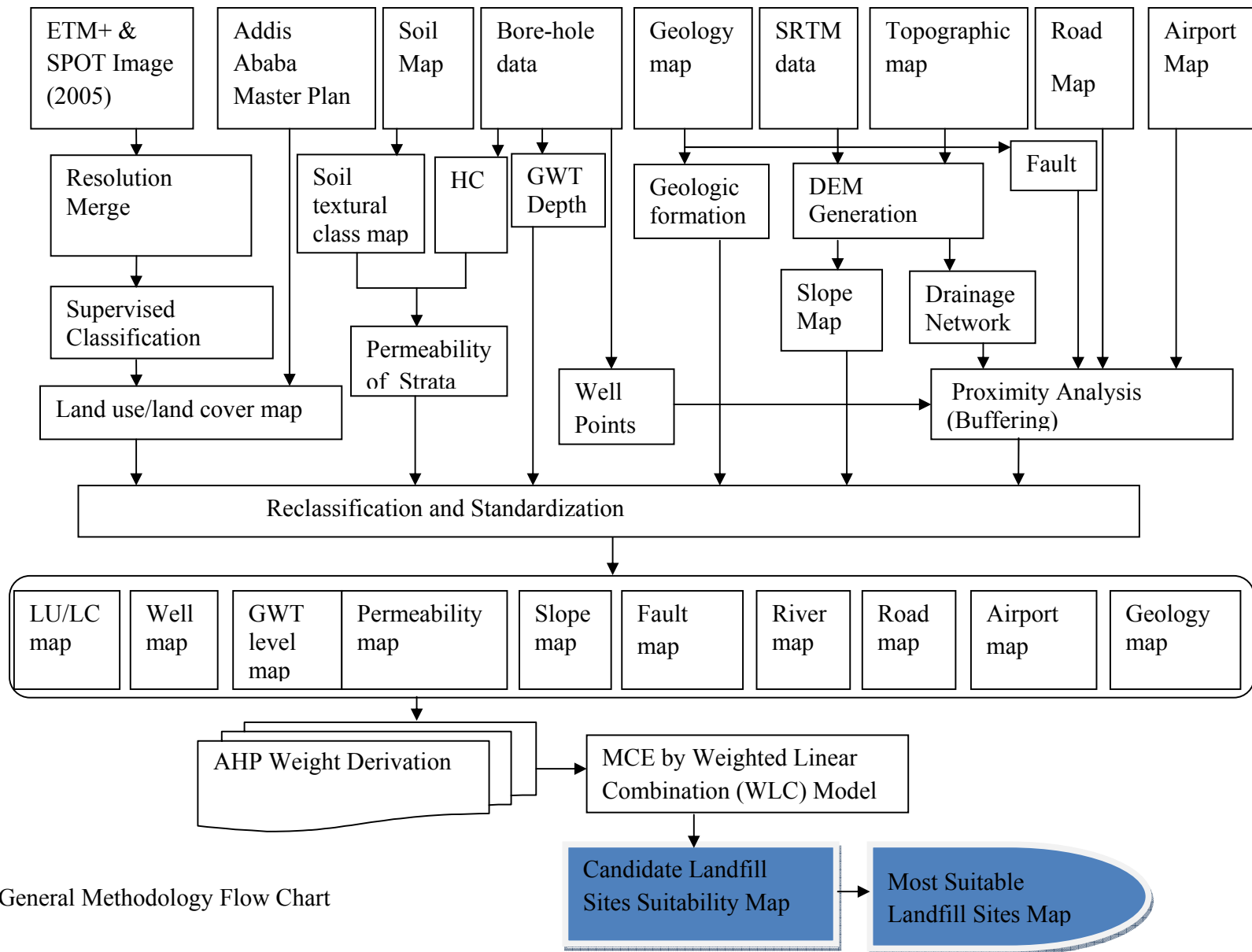


Fig. 8. General Methodology Flow Chart

3.2.4 Data Analysis

As described in the previous section, solid landfill site selection is the complex, tedious and costly process which needs to consider many conflicting criteria. In this research land use/land cover, soil, geology, groundwater depth, hydraulic conductivity and slope of Addis Ababa were used as factors. Moreover, proximity from road, proximity from rivers/streams, groundwater supply well point, airport and faults were also considered as landfill siting constrains. All the factors and constrains were internally classified in to five classes (very high, high, moderate, low and very low) with values ranging from 1 to 5, where value of 5 denotes the most suitable and value 1 denotes the least suitable for all factors and constrains considered. Weights for each class of criteria were derived in IDRISI software using AHP methods. The method uses the expert preferences for comparing the classes and prepare matrix table. Accordingly, weight was derived for each class giving total sum of 1 (Fig. 9). As all factors considered (except proximity from streams/rivers, permeability and land use/land cover) were reclassified in to five classes of very high, high, moderate, low and very low with values ranging from 5 to 1 respectively. The weight derived here was used for all factors considered (Table. 2). For proximity from streams/rivers, permeability and land use/land cover, weight were derived separately, which were classified in to 4 and 3 respectively.

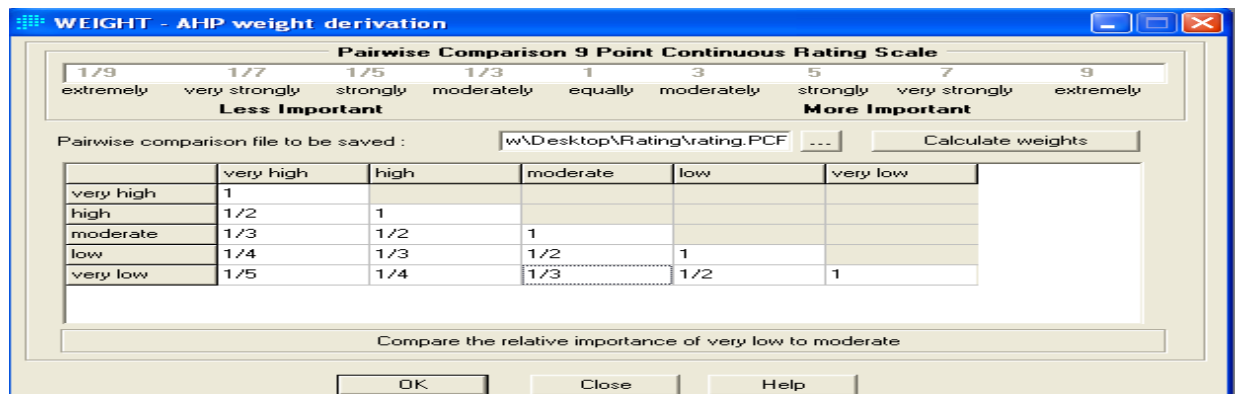


Fig. 9. AHP weight derivation method for criteria classes.

Table 2. Criteria weights calculated by AHP weight derivation module for suitability indexes.

Suitability Class	Rating /preference	Weight	Weight (%)
Very High	5	0.4185	41.8
High	4	0.2625	26.3
Moderate	3	0.1599	16.0
Low	2	0.0973	9.7
Very low	1	0.0618	6.2
Total		1.00	100.0
Contingency Ratio(CR)		0.02	2.0

CR=0.02<<0.1 → acceptable

Reclassification and rating of classes for each criterion considered was based on the international and national standards taken from different literatures (Table 3).

Table 3. Factors considered for landfill site selection with their factors/constrains.

Factors considered	Criterion(factor/constrain)	Sources
Groundwater Well	50m buffer 500-1000m 700m	Chang et al. (2007). (Hasan et al., 2009). Jamjan (2009)
Slope	<12% suitable, >12% unsuitable <20% <15-20%	Chang et al. (2007) Ersoy and Bulut (2009) (Hasan et al., 2009).
Distance from settlement	3000m 500-2000m 3000m	Chang et al. (2007) (Hasan et al., 2009). Map Asia (2004), Yahaya (2010), Ersoy and Bulut (2009), EPA (1995) & UNEP (2005).
Road	75m buffer 50-100m 100m	Chang et al. (2007). (Hasan et al., 2009). Map Asia (2004), Zain (2009), Yahaya (2010) & Ersoy and Bulut (2009), & EPA (1995).
Distance from water bodies (lake, wetlands, rivers and streams)	300-500m 100m 300m 200m	(Hasan et al., 2009). & UNEP (2005) & EPA (1995). Map Asia (2004) & Ersoy and Bulut (2009), Jamjan (2009). Akbari et al. (2009)
Subsoil & substrata Permeability	=<10-5m/s	(Hasan et al., 2009), UNEP (2005).
Land use	Low value lands Less economic importance of the site is more important	Jamjan (2009). UNEP (2005).
Characteristics of soil types	Poor drainage soil(clay textured)	Jamjan (2009)
Groundwater Depth	Should be deep enough >50m	Jamjan (2009) Mahini and Gholamalifard (2006)
Size of landfill	Required at least for 20yrs Enough for at least for 10 years	Jamjan (2009) Zain, T. (2009),UNEP (2005).
Airport boundary	5km buffer 3km	Jamjan (2009). UNEP (2005).
Distance from faults	>60m 100m buffer	Ersoy and Bulut (2009), Guam EPA (2004). Akbari et al.(2009)
Geology	Unconsolidated lithology are not suitable	Ersoy and Bulut (2009)

All factor considered for landfill siting were analyzed based on the Table 3 and all the factor maps and their description are as follows:

3.2.4.1 Geology

Geology map of Addis Ababa was procured from Geologic Survey of Ethiopia (GSE) in soft copy. The map was geo-referenced and then digitalized in GIS environment to utilize the raw data as information. Accordingly, 12 different geologic units of the study area were digitized and their thematic map was prepared section 3.1.6 (Fig. 6). The list of units and their respective total area was summarized in Table.4.

Table 4. Geology units and the respective areas of Addis Ababa

S.N	Geology Name	Area (km ²)	Area (%)
1	Chelekleka Basalt	33.2	6.3
2	Foota Basalt	8.7	1.7
3	Intoto Trachyte	6.9	1.3
4	Intoto Mixed Rocks	68.7	13.1
5	Lower Ignimbrite	45.1	8.6
6	Quaternary Basalt	95.4	18.1
7	Quaternary Scoria	0.7	0.1
8	Quaternary Eluvial Sediments	1.7	0.3
9	Repi Basalt	81.2	15.4
10	Tertiary Sediments	6.2	1.8
11	Wechecha Yerer Furi Ignimbrite	137.4	26.1
12	Wechecha Yerer Furi Trachyte	41.8	7.9
Total		527.0	100.0

(Source: Mulugeta H/Mariam et al., 2007)

According Table 4, most parts of Addis Ababa (26.08%) 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 (Tamiru Alemayehu et al., 2003). 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. According to Tamiru Alemayehu et al. (2003),

these units are unconsolidated materials and hence are highly permeable. 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 section 3.1.6 (Fig.6).

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 (Centre for Advanced Engineering, 2000). For this study, previous study and lithology log data were used to assess the permeability and stability of the rocks. According to Tamiru Alemayehu et al. (2003), 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. 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 (Table 5).

Table 5. Suitability and permeability classes of geologic units.

Geology Code	Permeability	Suitability	Rank	Weight	Area (%)
Ti3, Tb3, Tt1, Ti1 and Ti2	Very Low	Very high	5	0.4185	64.4
Tb1 & Tb2	Low	High	4	0.2625	7.9
Qb & Tt2	High	Low	3	0.1599	0.1
QSC	Moderate	Moderate	2	0.0973	26.1
Ts and Qs	Very High	Very Low	1	0.0618	1.5
Total				1.00	100.00

(Note: Ti3 = Wechecha_Yerer_Furi Ignimbrite, Tb3 = Repi Basalt, Tt1 = Intoto Trachyte, Ti1 = Intoto Mixed Rocks, Ti2 = Lower Ignimbrite, Tb1 = Foota Basalt, Tb2 = Chelekleka Basalt, Qb = Quaternary Basalts, Tt2 = Wechecha_Yerer_Furi Trachyte, Qs = Quaternary Eluvial Sediments, Ts = Tertiary Sediments, QSC = Quaternary Scoria).

Table 5 shows that the higher the permeability of the geologic units, the lower the suitability for landfill site and vice versa. Accordingly, Quaternary Eluvial Sediments and Tertiary Sediments are very highly permeable and thus unsuitable for landfill sites. However, Wechecha_Yerer_Furi Ignimbrite, Repi Basalt, Intoto Trachyte, Intoto Mixed Rocks and Lower Ignimbrite are with very low permeability, hence very highly suitable for landfill. As a result, more weight (0.4185) was given for very highly suitable class while least weight (0.0618) was given to very low suitable. Based on these classes, the geology map of the area were reclassified and standardized to five suitability classes (Fig. 10). About 64.4% of the total area is very highly suitable, 7.9% high, 26.1% moderate, 0.1% low and 1.5% unsuitable for landfill site.

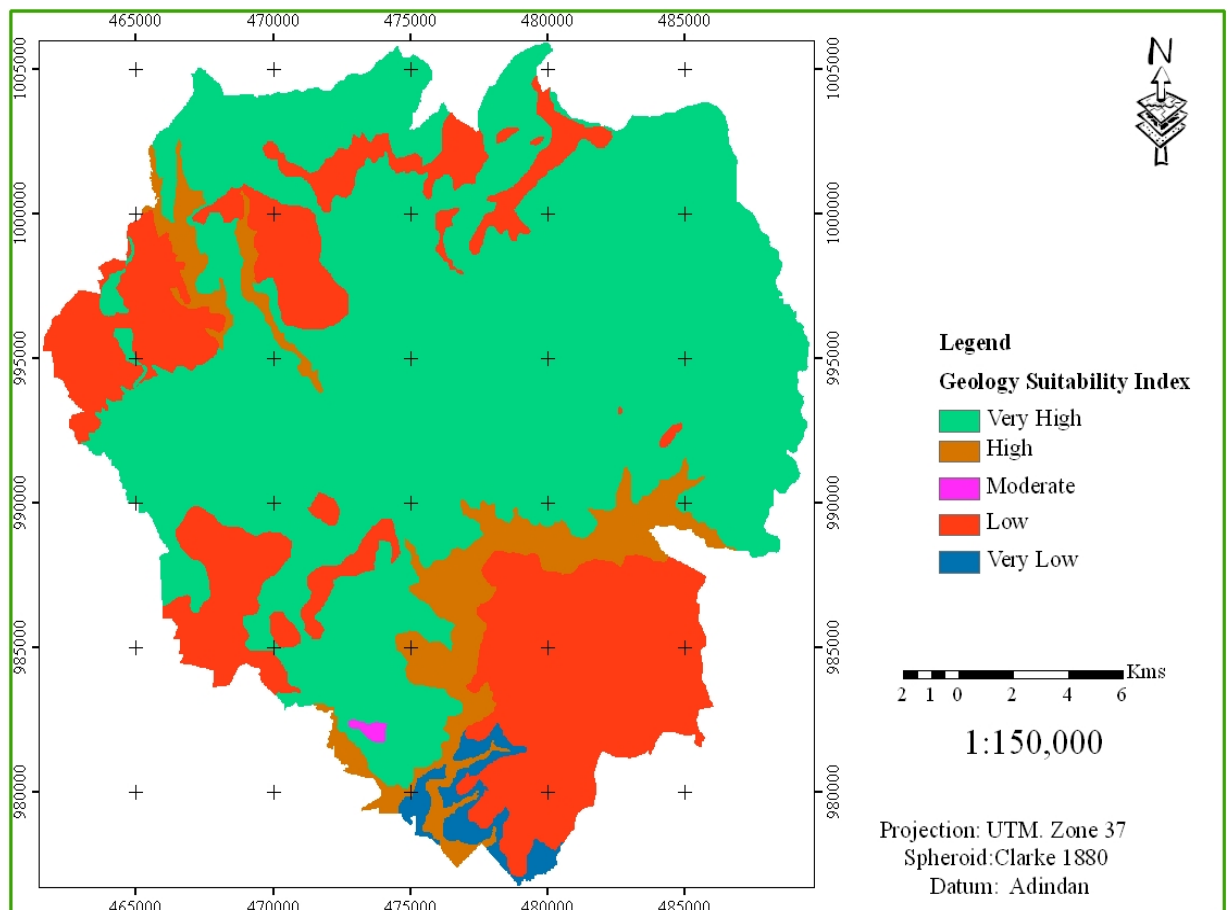


Fig. 10. Geologic suitability map of the study area.

3.2.4.2 Slope

Slope of the study area was calculated from DEM (30*30m resolution) and used in GIS environment as a thematic map. For slope calculation, 3dem, Global Mapper8 and GIS were integrated. Global Mapper8 were used to derive DEM from SRTM and generate contour while

3dem was used to fill missing SRTM values. Finally, slopes were calculated and reclassified in GIS environment. Topographic map (1:50,000) were used as an auxiliary data such calculation. Accordingly, the region was classified in to five slope classes: 0-2%, 2-8%, 8-15%, 15-30% and >30% (Fig. 11).

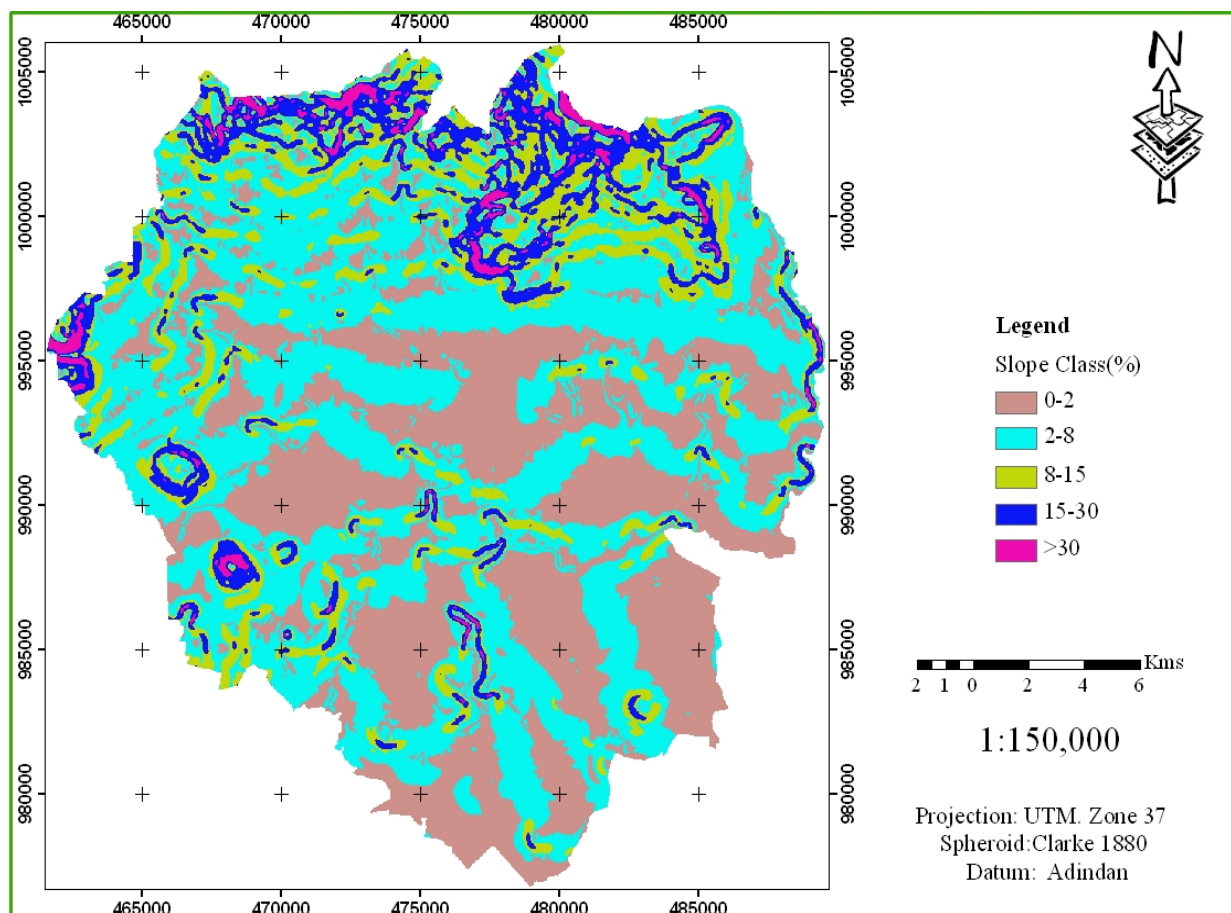


Fig. 11. Slope map of the study area

Total area coverage and slope classes of the study area are shown in Table 6.

Table 6. Slope Classes and area coverage

S. No.	Slope Class (%)	Area(km ²)	Area (%)
1	0-2	177.1	33.6
2	2-8	224.1	42.5
3	8-15	71.7	13.6
4	15-30	45.8	8.7
5	>30	8.2	1.6
Total		527.0	100.0

The topography of the region is dominated with slope of 2-8% which accounts 42.5% of the total area. However, only 1.6% of the area is with slope >30%, which is mainly found in the northern

part of the city. The second most dominant topography of the area is flat land (0-2%) found mainly in the central and southern parts of the city covering 33.6% of total area.

As described in the previous section, slope is one of the key criteria to be considered in landfill site selection. This is because site topography can reduce or increase adverse effects of landfill on the environment (Centre for Advanced Engineering, 2000). Flat land and depression topography not recommended for landfill due to water logging problem and downstream surface and ground water pollution. Moreover, steep slope is either not best option for solid disposal because of the difficulty posed in construction or leveling, which incur additional cost. Moreover, high topography areas reduces the stability of the side slopes (increase risk of landslides) and increase leachate movement. Therefore, the best slope for solid landfill should be modest slopes, which enable easier storm water control, leachate control and site stability measures, as well as facilitating the operation of the site. Different researchers set different slope criteria for landfill site selection. For example, Hasan et al. (2009) set areas with slope <15-20% as the best site for landfill, while Change et al. (2007) describe slope <12% as the best site and slope >12% unsuitable for landfill. Moreover, Ersoy and Bulul (2009) state that areas with slope <20% is optimum site for landfills.

In this study, areas with slope >30% were excluded as it is unsuitable for landfill and thus least weight (0.0618) was assigned and the rest of the slope classes were ranked from very highly suitable to low suitable. Accordingly, 2-8% slope was ranked in the first place and high weight (0.4185) was assigned because of its optimum suitability for easy control of runoff and operation. Areas with 8-15% slope were the second option for landfill and second higher weight (0.2625) was given, while 15-30% slope class was ranked as the third option. This is because as steepness increases, operation will be difficult and construction cost will be increased. However, 0-2% slope was ranked as a last option for landfill site due to water logging problem and thus low weight (0.0973) was given. Therefore, for the purpose of this study, 2-8% slope class was used as very highly suitable for landfill while slope >30% is unsuitable. The summary of slope class and their suitability are shown in Table 7.

Table 7. Slope suitability classes and area coverage

S. No.	Slope Class (%)	Suitability	Rank	Weight	Area (km ²)	Area (%)
1	0-2	Low	2	0.0973	177.1	33.6
2	2-8	Very High	5	0.4185	224.1	42.5
3	8-15	High	4	0.2625	71.7	13.6
4	15-30	Moderate	3	0.1599	45.8	8.7
5	>30	Very low	1	0.0618	8.2	1.6
Total				1.00	527.0	100.0

Table 7 shows that 42.5%, 13.6% and 8.7% of the total area is very highly, highly and moderately suitable for landfill sites, respectively. While 33.6% and 1.6% is marginally suitable and unsuitable for their very flatness and steepness, respectively. Based on the weight assigned for each slope classes, slope map of the region were standardized and slope suitability map was prepared (Fig. 12).

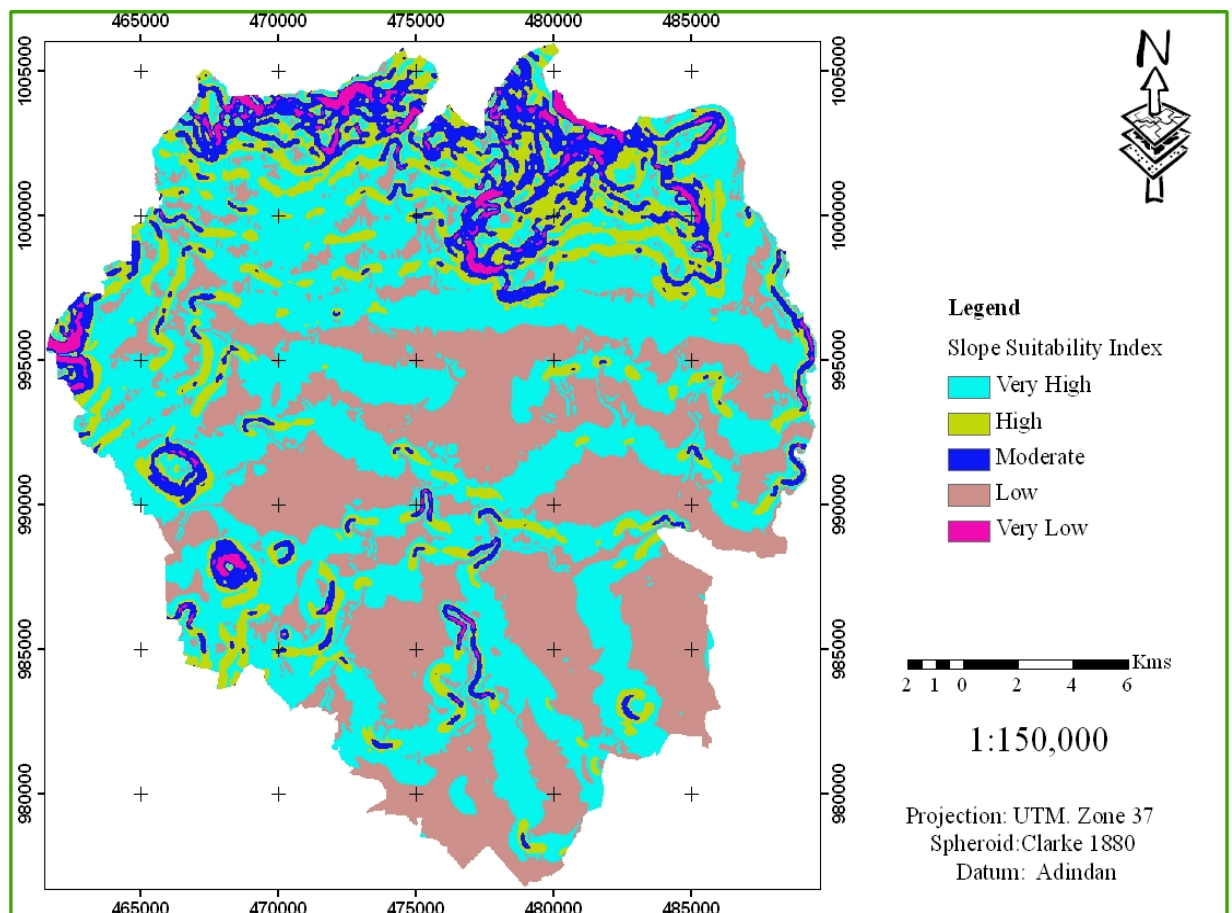


Fig. 12. Slope suitability map of the study area

3.2.4.3 Proximity from Rivers and Streams

Perennial and intermittent rivers and streams of the study area were generated from DEM in GIS environment using Spatial Analysis tools (Fig. 13). The necessary preprocessing operations like patching and filling were performed in GIS and 3dem respectively. The analysis was performed by assuming one stream per 500 cell size in order not to consider gullies and small depression as stream. The result of analysis was compared with the previous map river to assess their accuracy and it was found to overlap each other.

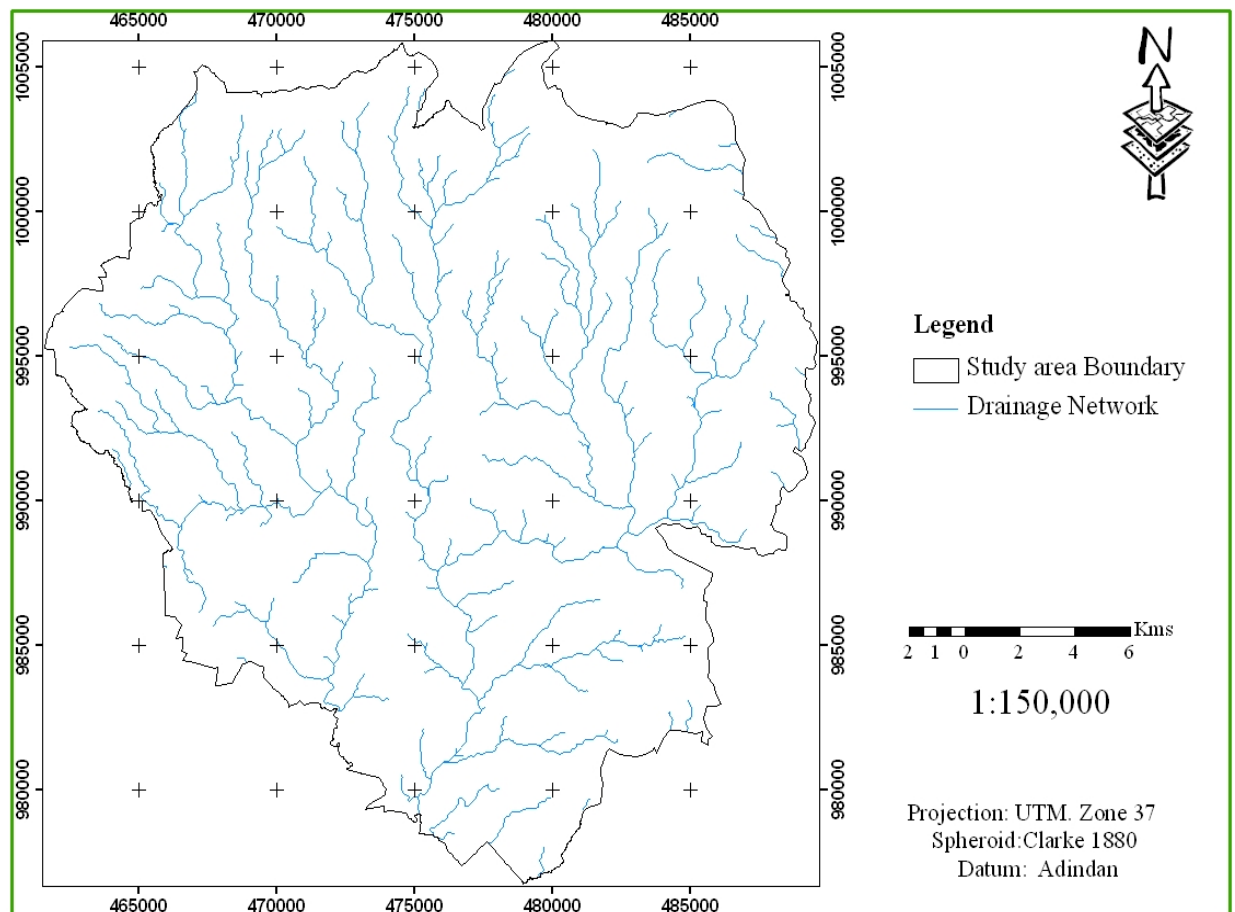


Fig. 13. Drainage network map of the study area

Fig. 13 shows that the northern parts of the study area are characterized by dense streams with dendritic and parallel drainage pattern. Drainage density decreases down to the southern part of the area while size of the streams increases from the north to south. This indicates that the northern part of Addis Ababa is the recharge area for the southern part.

To protect surface water from pollution, landfill should not be located near streams and rivers. The contaminated runoff from landfill will have an adverse effect on surface water. Therefore, to

minimize such pollution, different researchers set minimum buffer distance for landfill site selection. For example, Hasan et al. (2009) used 100 m buffer distance, UNEP (2005) & EPA (1995) used 300-500m as a minimum buffer distance while 300m minimum distance is set by Map Asia (2004), Ersoy and Bulut (2009) and Jamjan (2009). Furthermore, Akbari et al. (2008) use 200m buffer distance. The further the distance from rivers and streams the more preferable area for landfill site.

In particular research, 300 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: 0-300,300-500, 500-1000, >1000m. To minimize the effect of landfill leachate on surface water pollution, 0-300 m buffer area were 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 four classes.

Weights were calculated for the classes based on their preference using AHP modular in IDRISI software. Accordingly, more weight was assigned for more suitable areas (>1000m) while least weight (0.0954) was given to areas in the vicinity of the rivers and streams. Therefore, areas >1000m were given maximum weight (0.4673). Generally, weights and suitability level increases with distance from surface water. Summary of suitability level with their respective areas are shown in Table. 8.

Table 8. Rivers and streams proximity suitability

S.No.	Distance(m)	Suitability	Rank	Weight	Area(km ²)	Area (%)
1	0-300	Very Low	1	0.0954	234.7	44.5
2	300-500	Low	2	0.1601	121.5	23.1
3	500-1000	Moderate	4	0.2772	151.5	28.7
4	>1000	High	5	0.4673	19.3	3.7
Total				1.00	527.0	100.0

Accordingly, 44.5% of the study area was excluded from the siting processes due to the vicinity to the streams and rivers and hence unsuitable for landfill. An extent of 3.7% of the area was highly suitable for landfill siting because of the minimum effect on surface water. Moreover, 28.7% and 23.1% of the total areas were moderately and marginally suitable respectively.

Based on these suitability level and weights, standardized thematic map of rivers/streams suitability grid map were prepared (Fig.14).

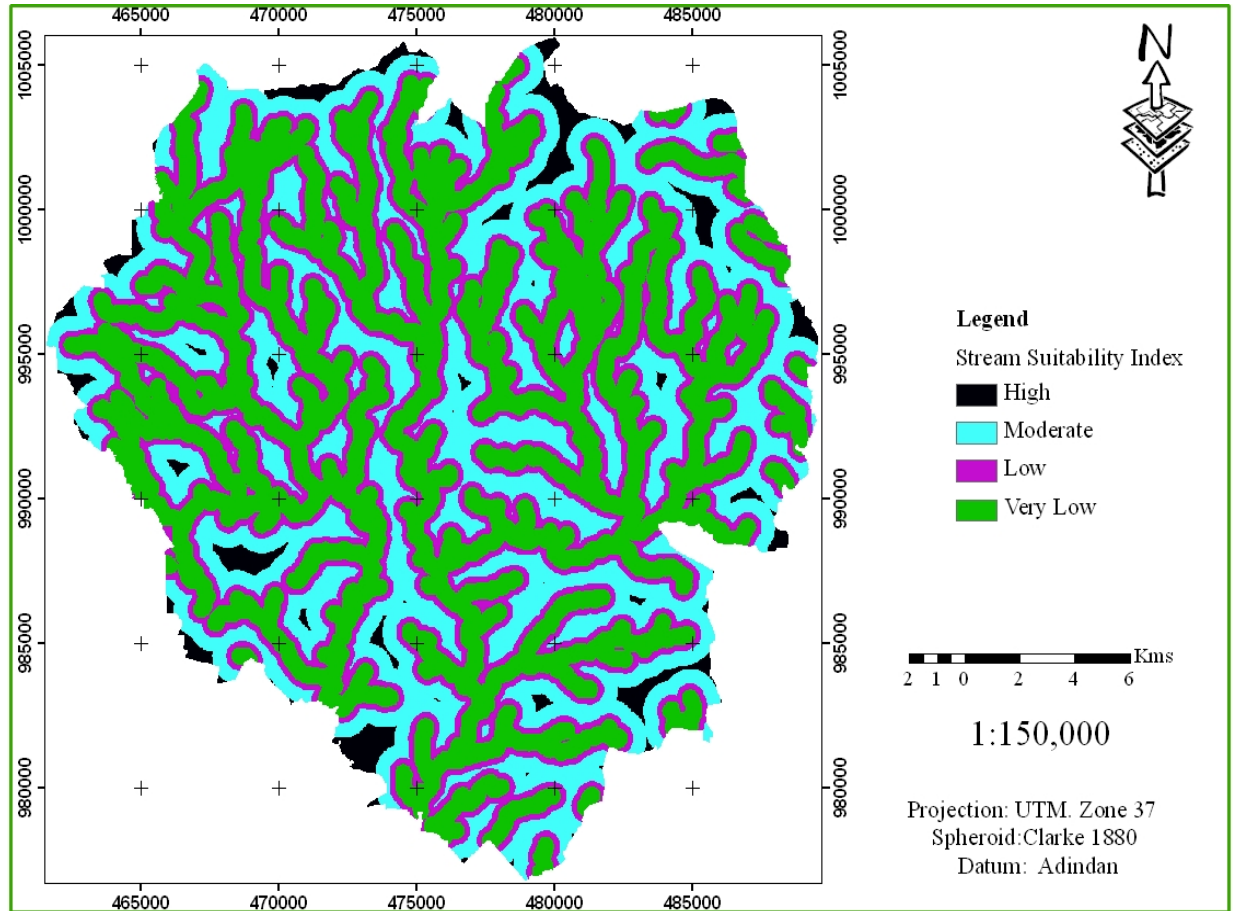


Fig. 14. Streams and rivers proximity suitability map.

Highly suitable areas were found in the marginal areas of the city in northern, south western, south eastern and north eastern parts of Addis Ababa.

3.2.4.4 Proximity from Faults

Proximity from faults is one of the determinant criteria that were considered for solid landfill site selection. The faults were digitized from geologic map of Addis Ababa. All the visible structures found on the map were carefully digitized. The major faults 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 in Tamiru Alemayehu et al. (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. Thus, all structures including minor faults were, digitized, buffered and mapped (Fig. 15).

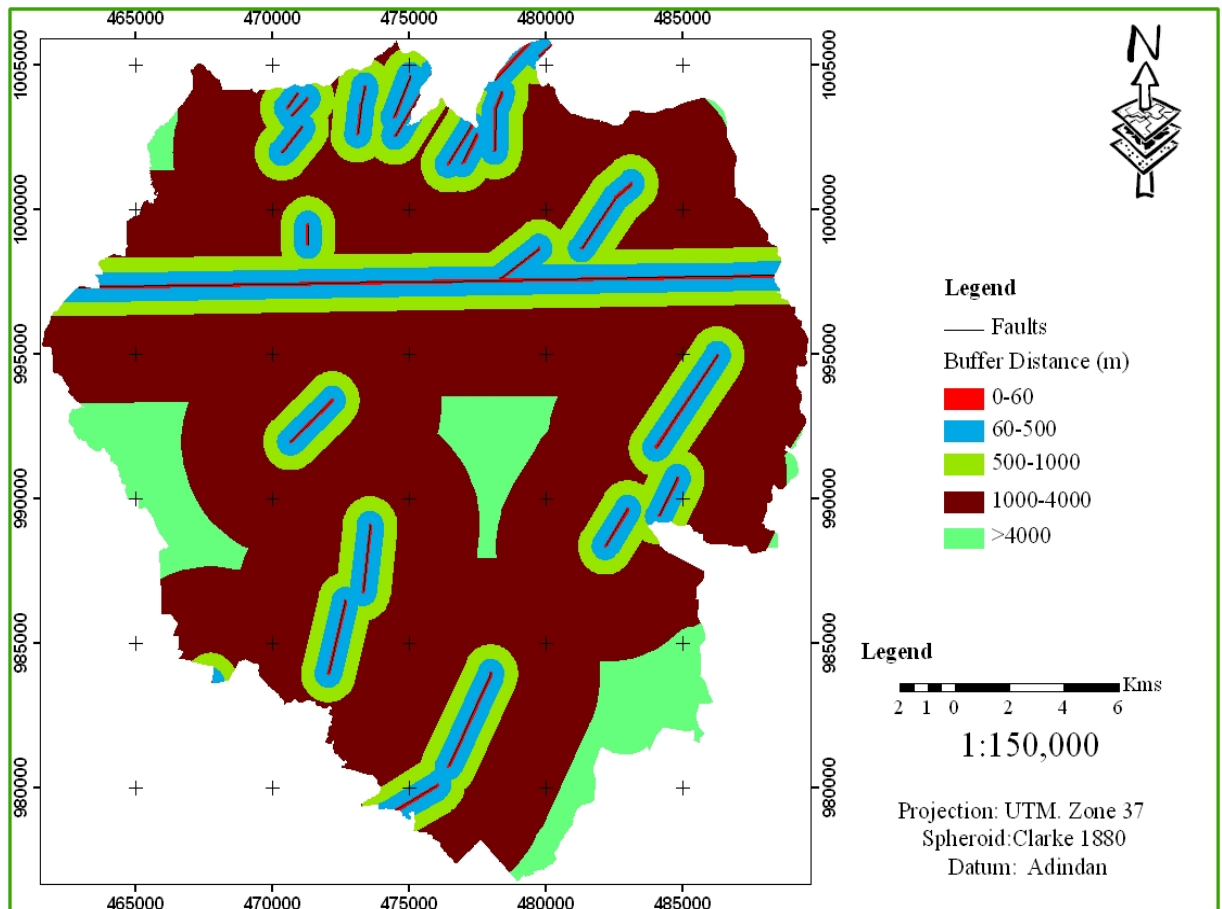


Fig. 15. Faults proximity map of the study area

Buffering around faults was to identify areas with no faults and at safest distance from faults, because faults increase permeability of rocks and hence increases the probability of groundwater pollution with leachate from landfill. Moreover, waste disposal areas should be away from faults. Otherwise in case of earthquake, the wastes can pollute the underground water or damage the nearby engineering structures. Therefore, for sustainable solid waste management and to protect environment from potential effects of landfill, solid waste should be deposited away from fault area. According to Ersoy and Bulut (2009) and Guam EPA (2004), areas within 60 m buffer distance should be excluded from landfill siting processes. However, Akbari et al. (2009) described 100 m as a minimum buffer distance for landfill siting.

In this thesis work, a minimum distance of 60 m was used for site selection processes. Accordingly, Multiple Ring Buffer tools were used to prepare a proximity map from each fault with 0-60m, 60-500m, 500-4000m, 4000-8000m and >8000m distance ranges. The principle behind this buffering was to identify the safest site for landfill. The more distance from fault, the

more suitable for siting landfill to minimize the negative effect of landfill on environment. Therefore, more weight was given to far distance from the faults as they are safest sites while least weight was given to near areas as they are unsuitable. Generally, weights and suitability level of the areas increases as the distance increases away from faults. The weight and suitability level of each buffer classes with their respective area coverage are shown in Table 9.

Table 9. Fault proximity suitability of the study area

S. No	Distance(m)	Suitability	Rank	Weight	Area(km ²)	Area (%)
1	0-60	Very Low	1	0.0618	7.8	1.5
2	60-500	Low	2	0.0973	64.9	12.3
3	500-4000	Moderate	3	0.1599	78.4	14.9
4	4000-8000	High	4	0.2625	327.5	62.1
5	>8000	Very High	5	0.4185	48.4	9.2
Total				1.00	527.0	100.0

Areas with >8000m away from faults were very highly suitable and hence given more weight (0.4185) such area covers about 9.2% of the total in the study area. Areas within 60m radius (1.5%) were not suitable for landfill site and thus least weight (0.0618) was assigned. Furthermore, 62.1%, 14.9% and 12.3% of the total areas were highly, moderately and marginally suitable, respectively, for landfill site.

Based on the weights and suitability level, standardized map of faults proximity suitability map was prepared (Fig. 16).

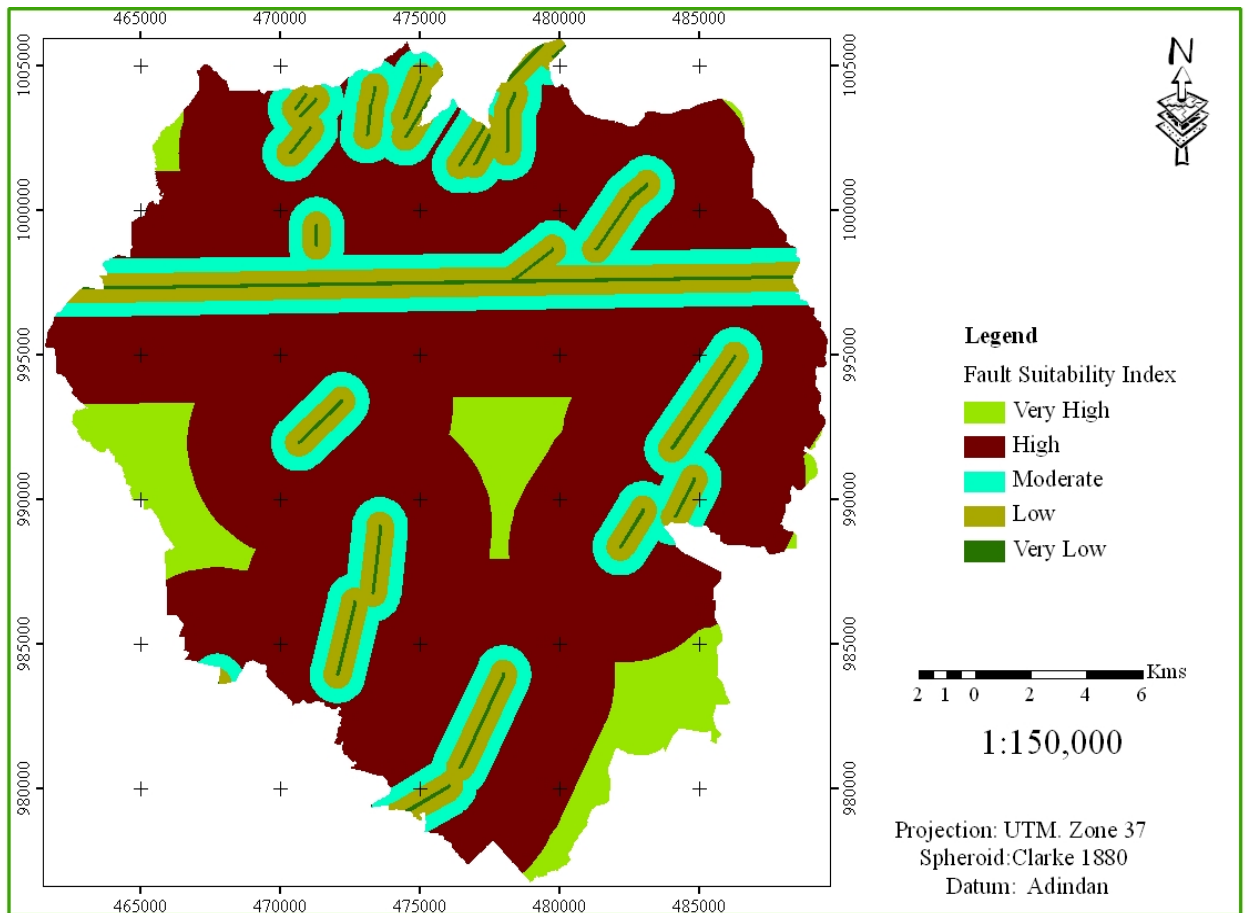


Fig. 16. Faults proximity suitability map

As shown in Fig. 16, very highly suitable site for landfill is found mainly in the central, south eastern and western part of the city.

3.2.4.5 Proximity from Airport

During solid waste landfill site selection, proximity from airport should be given due attention as solid waste disposal site attracts birds that pose hazards to aircrafts. The potential effect of landfill like odor and nuisance affect health of passengers and thus should also be avoided from airport area to protect public health. Hence, landfill site should be away from airport territory so as to minimize such hazards. According to Jamjan (2009), landfill must be 5000m away from airport. However, UNEP (2005) described as 3000m radius from airport should be excluded for landfill siting. The present study employs 3000m buffer distance as a minimum distance from airport for landfill site selection.

Therefore, compound of Bole International Airport was digitized from Addis Ababa master plan and Multiple Ring Buffers of 0-3000m, 3000-4000m, 4000-5000m, 5000-7000m and 7000-30000m were performed around the boundary (Fig. 17).

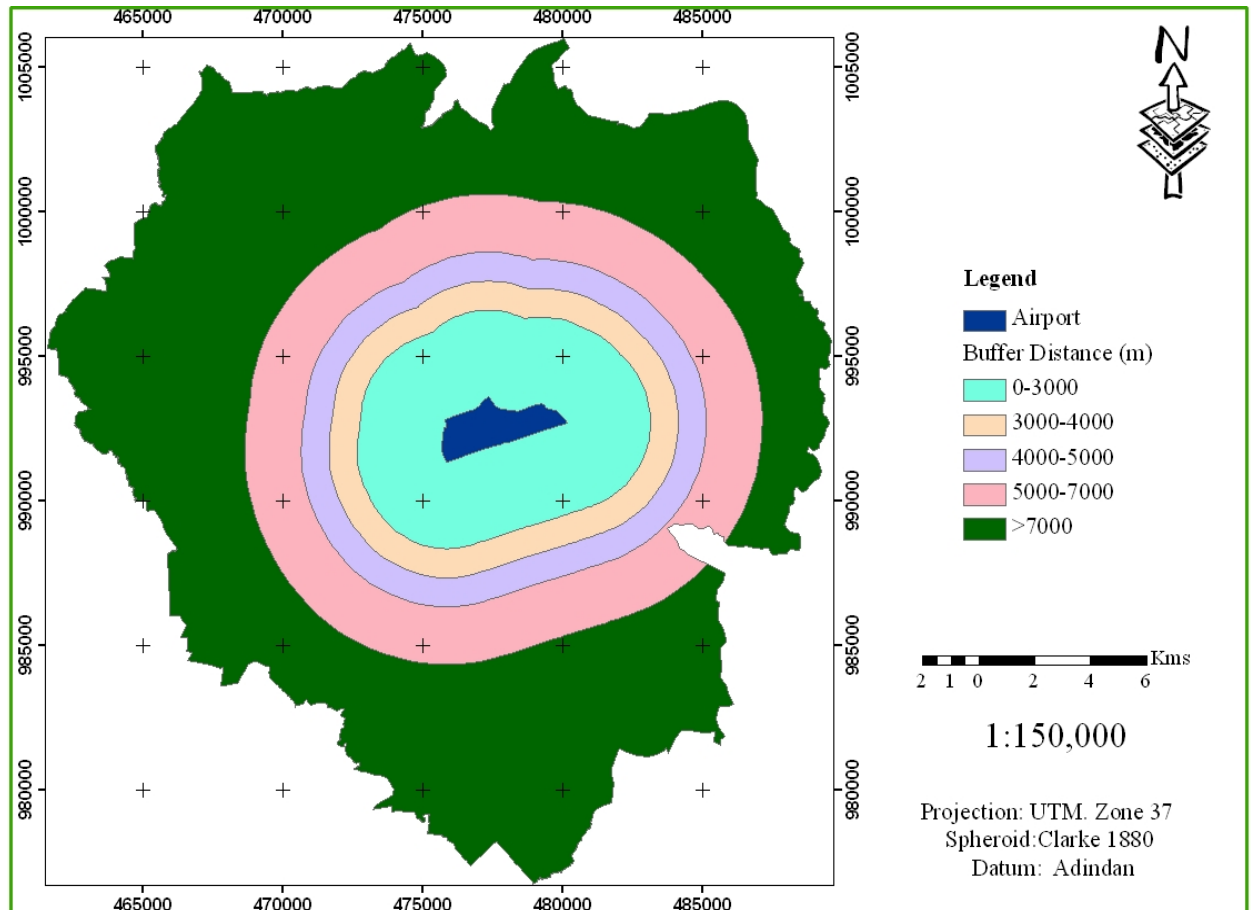


Fig. 17. Airport proximity map of the study area

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 are more preferred than near sites, more weight was given for far away site and vice versa. Accordingly, for areas greater than 7000m away from airport was given more weight (0.4185) as very highly suitable. The least weight (0.0618) was given for areas within 3000m radius and as unsuitable for landfill site. The suitability and weight assigned to each buffer classes are summarized by (Table. 10).

Table 10. Airport proximity suitability of the study

S.No	Distance(m)	Suitability	Rank	Weight	Area (km ²)	Area (%)
1	0-3000	Very Low	1	0.0618	66.3	12.6
2	3000-4000	Low	2	0.0973	32.8	6.2
3	4000-5000	Moderate	3	0.1599	39.1	7.4
4	5000-7000	High	4	0.2625	95.3	18.1
5	>7000	Very High	5	0.4185	293.5	55.7
Total				1.00	527.0	100.00

Table 10 shows that 55.7% of the total area is given more weight as very highly suitability for landfill site. However, 12.6% of the total area is unsuitable as near to airport and hence excluded from siting processes. Generally, suitability level and weights were increased as one move away from the airport site. As a result, 18.1%, 7.4% and 6.2% of the total area were highly, moderately and marginally suitable, respectively. According to their weight, airport proximity map of the study area was standardized and suitability map was prepared (Fig. 18).

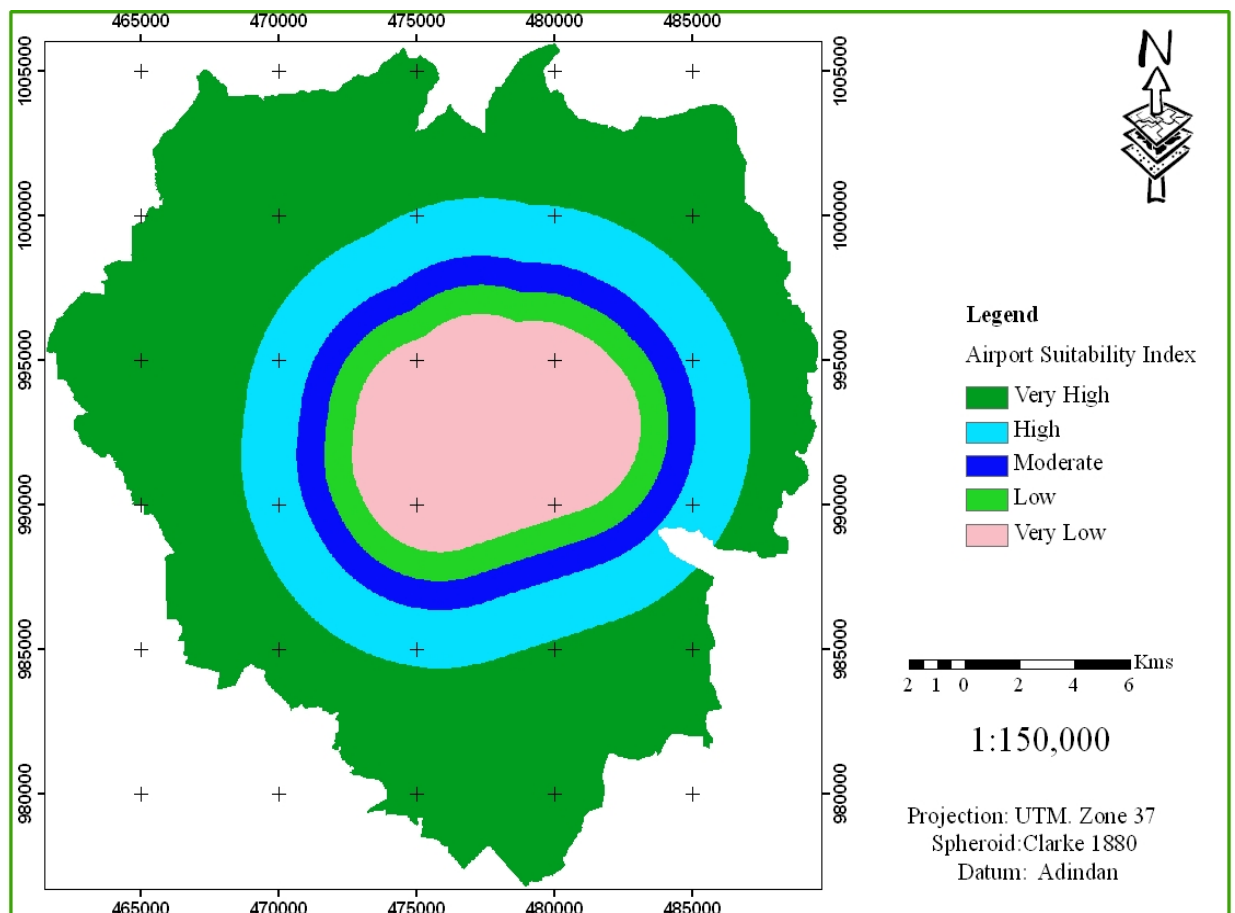


Fig. 18. Airport proximity suitability map of the study area

3.2.4.6 Proximity from Road

Proximity from roads is one of the criteria that should be considered from economic and social point of views during solid waste landfill site selection processes. This is because siting landfill very close to roads may have public health problem as landfill pose hazardous effect to health. Moreover, landfill site very far from road network is also not recommended due to high transportation cost. Therefore, to minimize such problems, it must not be sited very close to and far from roads. Minimum and maximum distance from road network of the study area was set after summarizing different literatures. Chang et al. (2007) set 75m buffer while Hasan et al. (2009) uses 50-100m buffer from road as a minimum distance within which landfill should not be located. However, 100m buffer distance is mentioned as the safest distance (Map Asia, 2004; Zain, 2009; Yahaya, 2010; Ersoy and Bulut, 2009; EPA, 1995). For this work, areas within 100-7000m away from roads were analyzed as best site for landfill. Therefore, Multiple Ring Buffer tools were used to create buffer classes around the roads with 0-100m, 100-700m, 700-1500m, 1500-4000m, 4000-7000m and >7000m distance ranges (Fig. 19). However, areas with >7000m buffer distance from roads was not used for this analysis as it is out of Addis Ababa boundary.

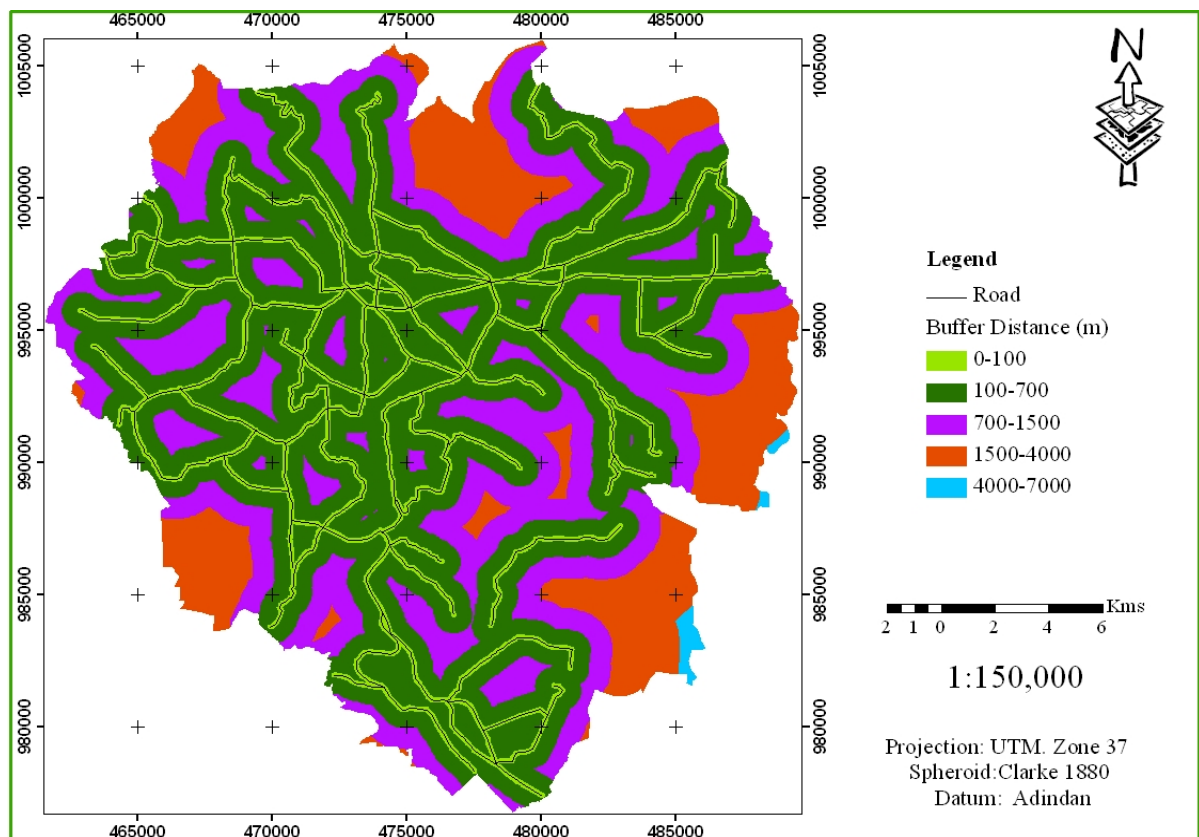


Fig. 19. Road proximity map of the study area

The road network proximity map was reclassified and standardized based on the fact that very close and far away sites are unsuitable for landfill and hence excluded from the analysis. Accordingly, 0-100m and >7000m buffer distances were excluded. However, >7000m area does not fall within the study area. Rests of the areas, from 100m to 7000m, were given a weight according to their preference. The more preferable site is 100-700m radius from the roads and thus more weight (0.4185) was assigned to it. While 4000-7000m radius is less preferred hence less weight (0.0618) was given. Generally, for areas between 100-7000m preference decreases with increasing distance. This is due to increased transportation cost and inaccessibility of the area. Table 11 summarizes weight assigned and suitability level with their area coverage.

Table 11. Road network suitability of the study area

S.No.	Distance(m)	Suitability	Rank	Weight	Area(km ²)	Area (%)
1	0-100, >7000	Very Low	1	0.0618	58.4	11.1
2	100-700	Very High	5	0.4185	254.5	48.3
3	700-1500	High	4	0.2625	134.4	25.5
4	1500-4000	Moderate	3	0.1599	77.6	14.7
5	4000-7000	Low	2	0.0973	2.1	0.4
Total				1.00	527.0	100.0

Table 11 shows 48.3% of the total areas is very highly suitable while, 11.1% is unsuitable for landfill. Furthermore, 25.5%, 14.73% and 0.4% are highly, moderately and marginally suitable for landfill siting. The spatial distribution of road proximity suitability map is shown in Fig. 20.

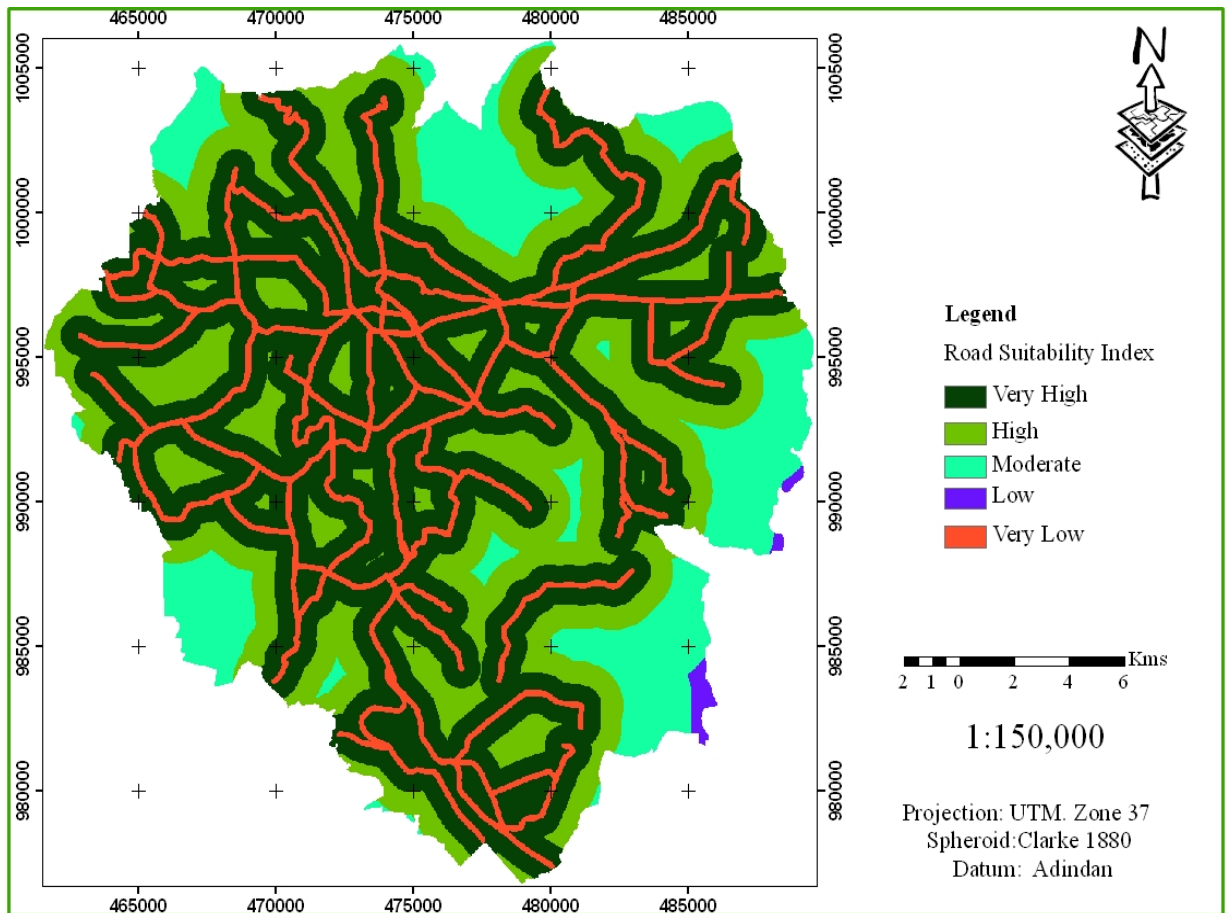


Fig. 20. Road proximity suitability map of the study area

3.3.4.7 Ground water Depth

To protect ground water from potential effects of landfill, depth to ground water is the main environmental criteria that should be considered during site selection processes. Leachate from landfill percolates deep in to the ground and hence pollutes ground water in the long run. Such effect can be minimized by avoiding to site landfill in shallow water table areas. Siting landfill in deeper ground water table areas will minimize the probability of groundwater pollution, because it takes long period of time for the leachate to reach groundwater table. According to Agustín (2008), the deeper the groundwater is, the lower the probability of groundwater contamination. Moreover, Mahini and Gholamalifard (2006) stated as areas with >50m ground water depth is most preferred for landfill site but least preferred in areas with <10m groundwater depth. For the purpose of this work, borehole data were procured from Addis Ababa Water and Sewage Authority (AAWSA) and the data were analyzed to map ground water depth of the area. Hence,

234 point data were interpolated by using Inverse Distance Weighted (IDW) techniques and then reclassified in to five classes (Fig.21).

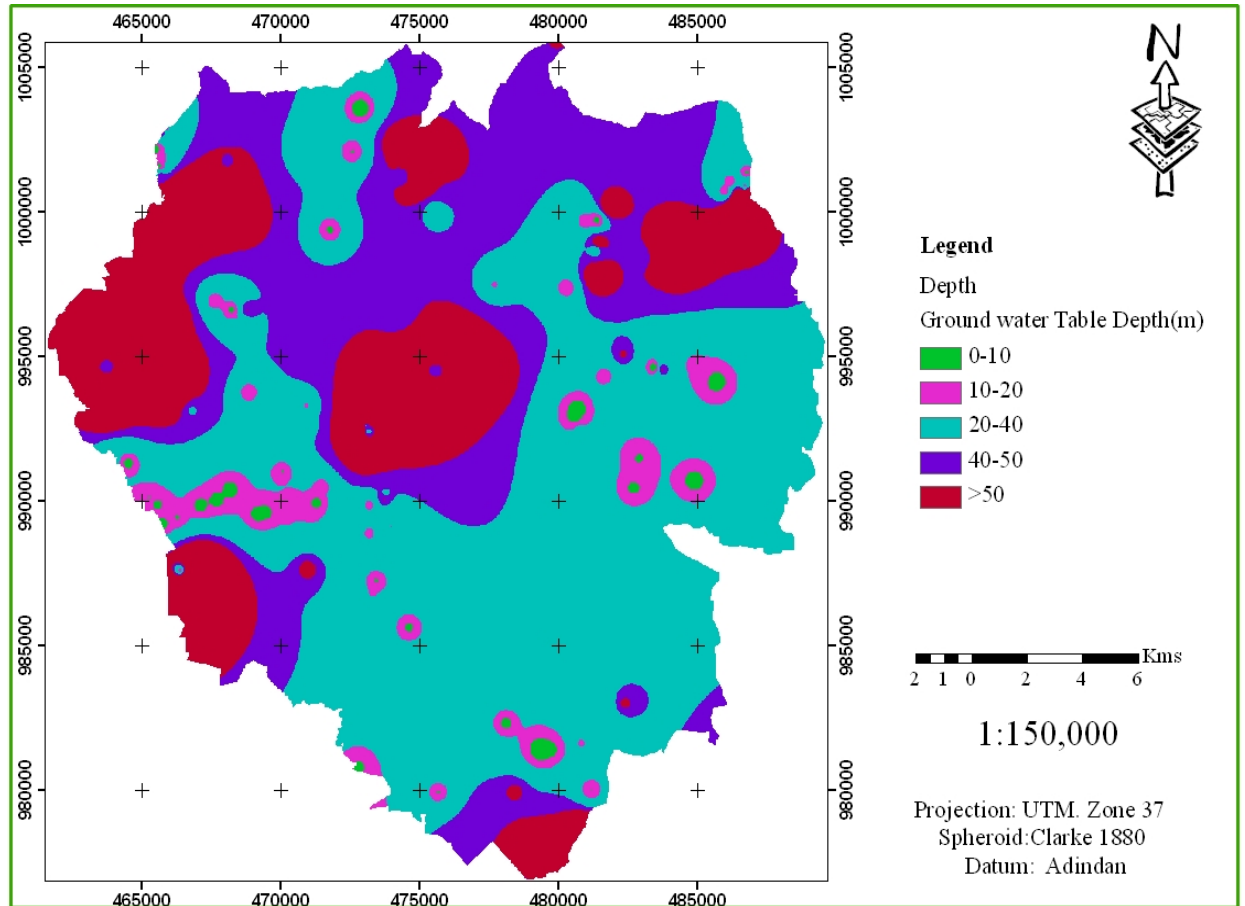


Fig. 21. Depth to ground water table of the study area

Based on the fact that deep ground water table is more preferable than shallow water table for landfill, the map was reclassified and standardized to prepare suitability map of depth to ground water. More weight (0.4185) was given to areas of deeper depth which is highly suitable for landfill siting while least weight (0.0618) was assigned to shallow water table class that is unsuitable. Generally, more weight and high suitability level were given to areas of deeper water table and the vice versa (Table. 12).

Table 12. Depth to ground water table suitability table of the study area

S.No.	Depth to Ground Water Table (m)	Suitability	Rank	Weight	Area(km ²)	Area (%)
1	0-10	Very Low	1	0.0618	4.0	0.8
2	10-20	Low	2	0.0973	24.5	4.6
3	20-40	Moderate	3	0.1599	255.0	48.4
4	40-50	High	4	0.2625	134.8	25.6
5	>50	Very High	5	0.4185	108.7	20.6
Total				1.00	527.0	100.0

Table 12 shows that 20.6% of the total areas is very highly suitable and hence higher rank (5) was given while 0.8% is not suitable and hence least rank (1) was assigned. Furthermore, 25.6%, 48.4% and 4.6% of the area is respectively highly, moderately and marginally suitable for landfill. 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. 22.

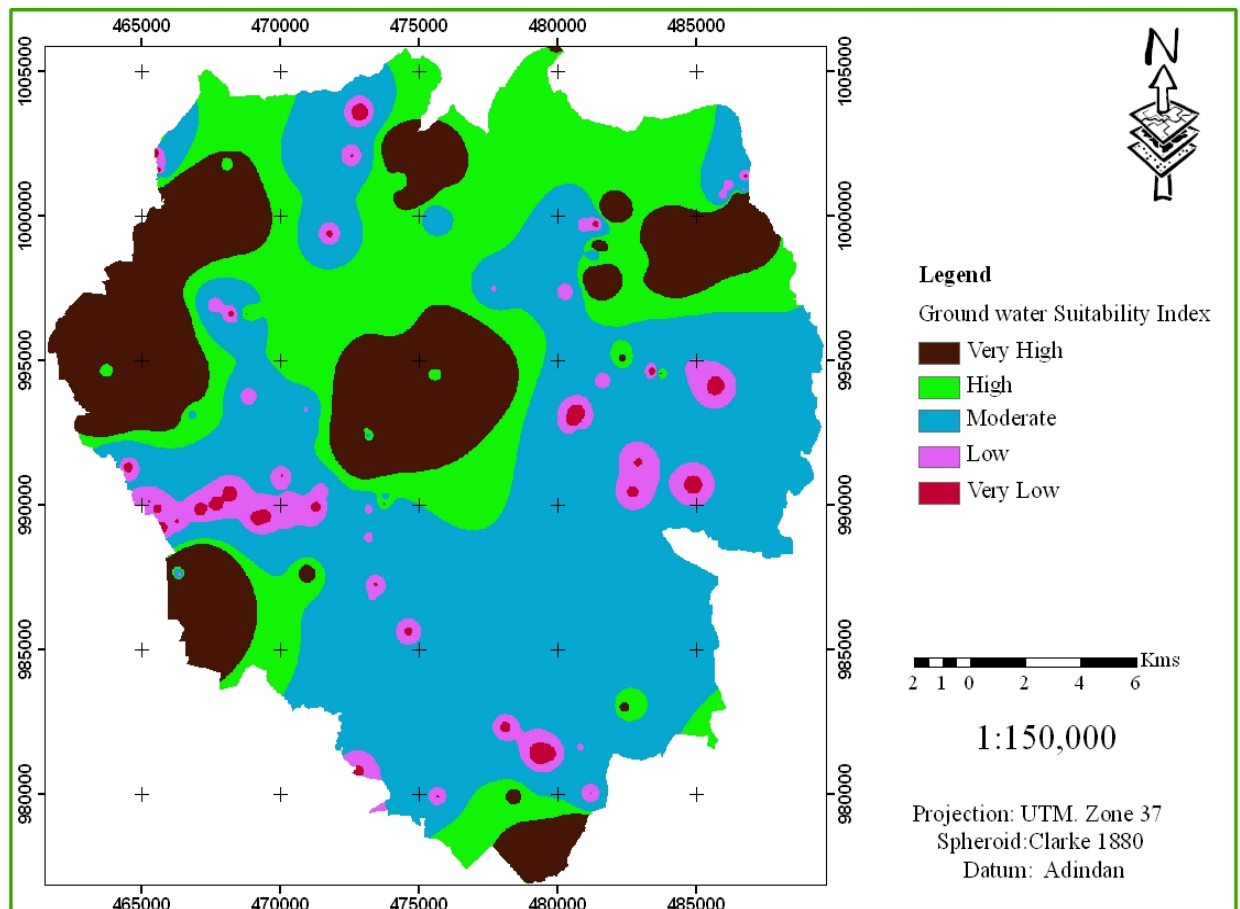


Fig. 22. Depth to ground water table suitability map of the study area

3.2.4.8 Proximity from Groundwater Well

Proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection so that wells may be protected from the runoff and leaching of the landfill. Hence, solid waste disposal should be placed away from water wells. Otherwise, it can have irretrievable human and environmental effects. As a result, proximity from groundwater well was considered as an important criterion for this research. Accordingly, 156 ground water well points that are currently functional and proposed were obtained from Addis Ababa Water and Sewerage Authority (AAWSA) and Multiple Ring Buffer tools were used to prepare buffer zones around each well. Chang et al. (2007) described as landfill should not be sited within 50m buffer distance from water wells. However, Hasan et al. (2009) used 500- 1000m and Jamjan (2009) used 700m as a minimum distance from which landfill can be safely sited. For this work, 500m buffer distance was used. Moreover, additional buffering was performed around the wells in order to identify the best site for landfill. Buffer distance of 0-500m, 500-800m, 800-1200, 1200-2000m and >2000m were prepared around each and every well points (Fig. 23).

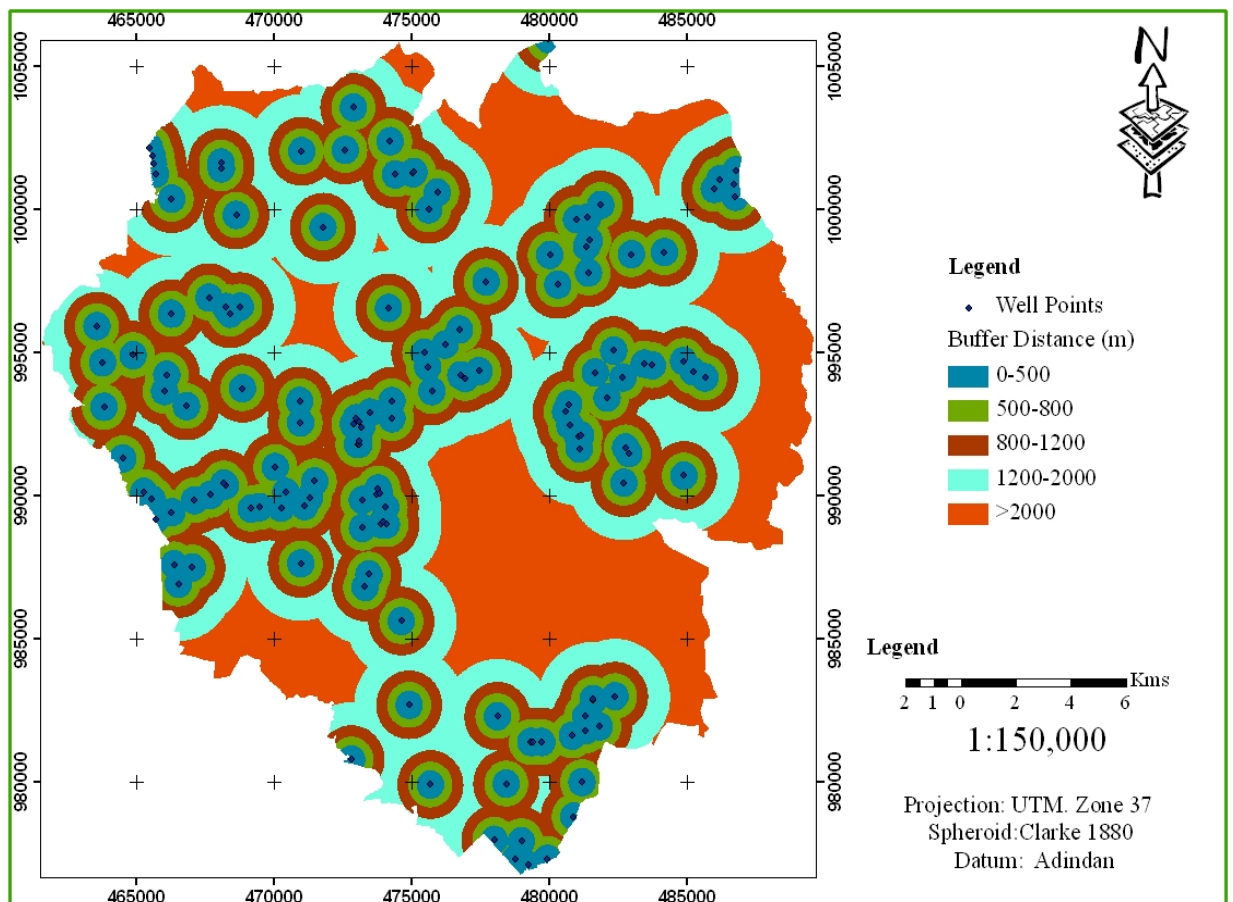


Fig. 23. Groundwater well proximity map of the study area

Different buffering was used to identify and rank areas according to their preference. Landfill very far from water well will have minimum effect and the vice versa. Generally, the more closely the landfill, the more probable for ground water to be contaminated. Areas with >2000m buffer distance were very highly suitable and areas with 0-500m is the least. Weights were calculated for each class based on the suitability level. More weight was assigned to more suitable areas, and vice versa. Hence, more weight (0.4185) was assigned to areas >2000m and least weight (0.0618) for areas within 500m radius from water wells (Table 13).

Table 13. Groundwater proximity suitability

S.No.	Distance(m)	Suitability	Rank	Weight	Area (km ²)	Area (%)
1	0-500	Very Low	1	0.0618	79.6	16.0
2	500-800	Low	2	0.0973	80.1	15.2
3	800-1200	Moderate	3	0.1599	104.1	19.8
4	1200-2000	High	4	0.2625	139.5	26.5
5	>2000	Very High	5	0.4185	123.6	23.5
Total				1.00	527.0	100.0

Table 13 shows that 23.5% of the total study area is very highly suitable from ground water proximity point of view and 16% is not suitable as they are in the vicinity of water wells. Moreover, 26.5%, 19.8% and 15.2% are highly, moderately and marginally suitable, respectively. Hence, the above proximity map was standardized so as to prepare suitability map of groundwater proximity (Fig. 24).

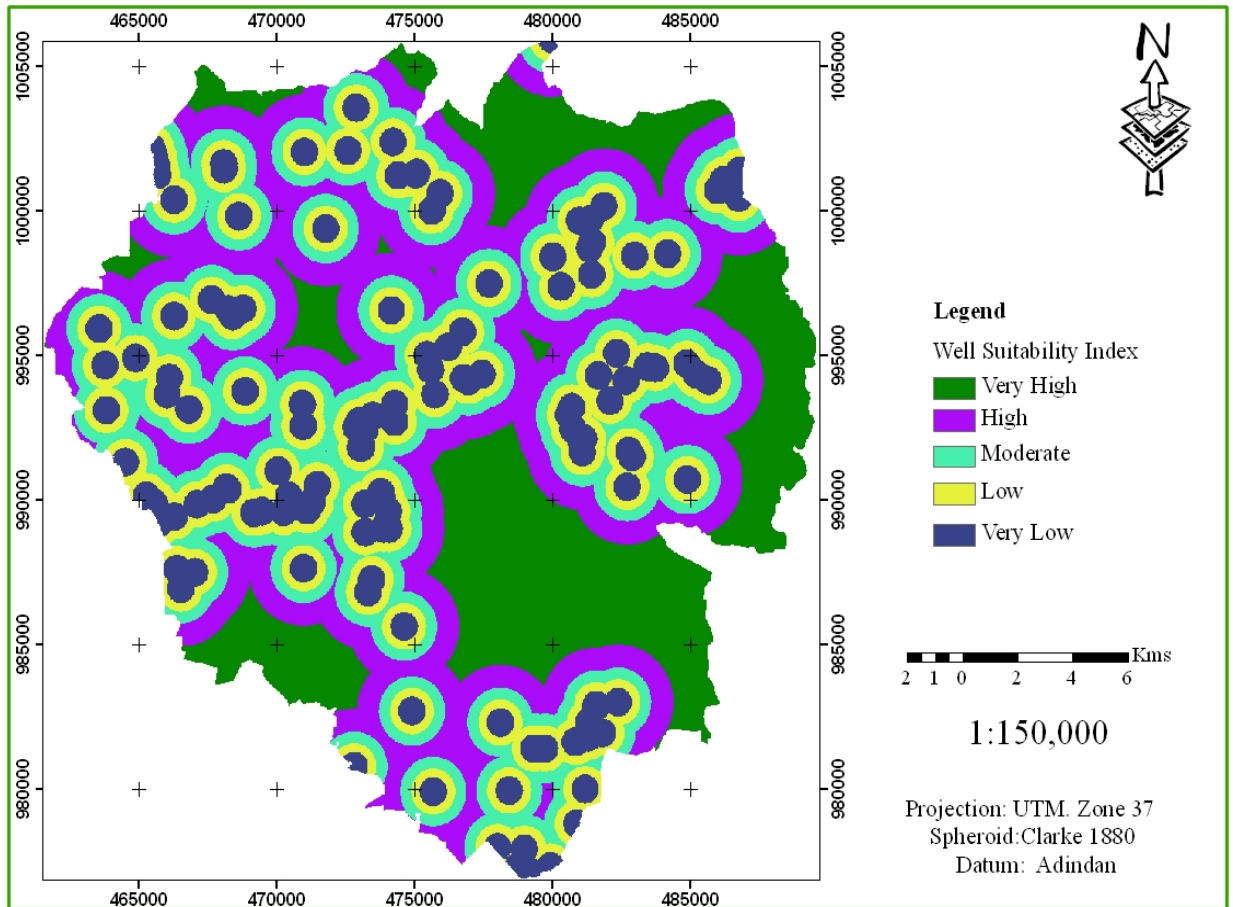


Fig. 24. Groundwater proximity suitability map of the study area

3.2.4.9 Permeability of strata

Permeability is one of the most environmental criteria that should be considered to protect ground water pollution from landfill effects. This is because permeability of geologic formation and soil not only determine the movement of leachate but also off-site migration of gas flow that results in environmental pollutions especially air and groundwater. Ideally, the permeability of geology and soil in landfill site should be very low in order to minimize such hazards. According to Themistoklis et al. (2005), the high permeability strata with hydraulic conductivity of 10^{-5} m/s such as karsts formations and sandy soils were considered as undesirable areas for landfills. The low-to-medium permeability strata with hydraulic conductivity between 10^{-5} to 10^{-7} m/s such as marl, flysch, ophiolite and granite were considered as moderately suitable. Moreover, the low permeability strata with hydraulic conductivity of less 10^{-7} m/s such as clayey soils, rocks and shale were considered as optimal for landfill site. The permeability of a soil should be about 10^{-5} m/s for safe landfill siting (Themistoklis et al., 2005).

For this study, soil texture and hydraulic conductivity of formation of the area were integrated to map permeability of the region. Borehole data were procured from AAWSA from which 143 hydraulic conductivity values were obtained. IDW was used to interpolate the values and map hydraulic conductivity of the whole study area. The map was reclassified in to five classes namely $<10^{-6}$ m/s, 10^{-6} - 10^{-4} m/s, 10^{-4} - 10^{-1} m/s, 10^{-1} -0.8 and >0.8 m/s. The classes were also standardized in to suitability index in order to prepare hydraulic conductivity suitability map for landfill. Accordingly, areas with lower values were considered very highly suitable and thus more weight (0.4185) was assigned. However, for highly permeable areas least weight (0.0618) was given as unsuitable for landfill sites (Table. 14).

Table 14. Hydraulic conductivity suitability

S.No	Hydraulic Conductivity(m/s)	Suitability	Rank	Weight	Area(km ²)	Area (%)
1	$<10^{-6}$ m/s	Very Highly	5	0.4185	0.01	0.002
2	10^{-6} - 10^{-4}	Highly	4	0.2625	0.03	0.01
3	10^{-4} - 10^{-1}	Moderate	3	0.1599	198.9	37.7
4	10^{-1} -0.8	Low	2	0.0973	299.6	56.8
5	>0.8	Very Low	1	0.0618	28.5	5.4
Total				1.00	527.0	100.0

As indicated in Table 14, very highly and highly suitable areas were very small only 0.002% and 0.01% of the total area, respectively. Most part of the study area (about 56.8%) was identified as marginally suitable for landfill site due to their high permeability. Moreover, about 37.7% and 5.4% were moderately and unsuitable suitable (due to very high permeability), respectively. Standardized thematic map of hydraulic conductivity of the area was prepared by using the above suitability table (Fig. 25).

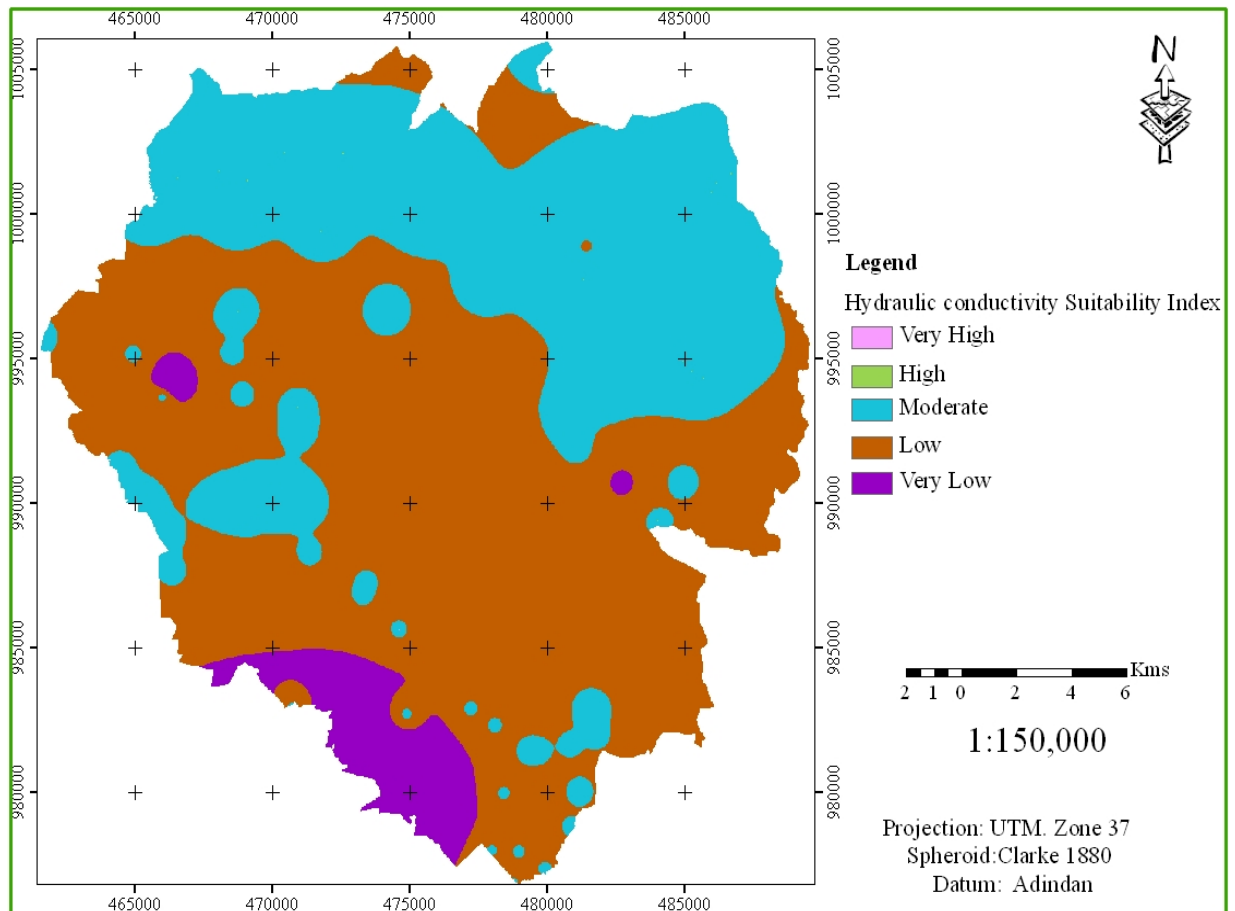


Fig. 25. Hydraulic conductivity suitability map of the study area

As shown in Fig. 25, most part of the study areas were not safe for landfill siting due to high permeability. Hence, lining the base of landfill will be required to protect ground water from leachate contamination. Soil characteristics of the study area like texture and depth should also be considered for landfill site selection within the study area. This is due to availability of lining material and permeability depends on depth and texture soil, respectively. Clay textured soil is more preferred for landfill as it is impermeable to leachate and also used for lining the base of sanitary landfill. Moreover, area with deep soil is preferred as it provides soil for covering solid waste after each disposal day to minimize air pollution from the landfill. In this study, Vertisols (both chromic and pellic) are identified as highly suitable soil for landfill due to its clay dominated (60%) and very deep soil. Calcic Xerosols and Leptosols were identified as unsuitable soil types for landfill due to their coarser texture and shallow soil depth. Other soil types of the study area fall in between these extremity due to their moderate depth and fine texture. Soils of the study area were classified in to five classes based their texture and depth (Table.15).

Table 15. Soil types of the study area

S.No.	Soil Type	Suitability	Rank	Weight	Area(km ²)	Area (%)
1	Pellic Vertisol & Chromic Vertisol	Very High	5	0.4185	321.7	61.0
2	Chromic Luvisols	High	4	0.2625	11.9	2.2
3	Eutric Nitisols	Moderate	3	0.1599	111.5	21.2
4	Orthic Solonchaks	Low	2	0.0973	39.2	7.5
5	Calcic Xerosols & Leptosols	Very Low	1	0.0618	42.7	8.1
Total				1.00	527.0	100.0

Out of the total area, 61.03% is covered by Vertisols, which are very fine textured and very deep soil, hence very highly suitable for solid waste disposal. The suitability of Vertisol was seen from two prospects, one is from its impermeability and the second is from its advantage to supply cover material for solid waste covering near the site. In such areas, potential effects of landfill will be minimized. However, 8.1% of the area is covered by shallow and coarser textured soil (Calcic Xerosols and Leptosols) and thus unsuitable for landfill. This is due to the risk of groundwater contamination and may be shortage of soil material for lining and covering. Moreover, 2.2%, 21.2% and 7.5% of the area are highly, moderately and marginally suitable, respectively. Accordingly, the southern and some of the north eastern parts of the study area were very highly suitable for landfill. Spatial distribution of soil suitability map of the study area was prepared in GIS environment (Fig. 26).

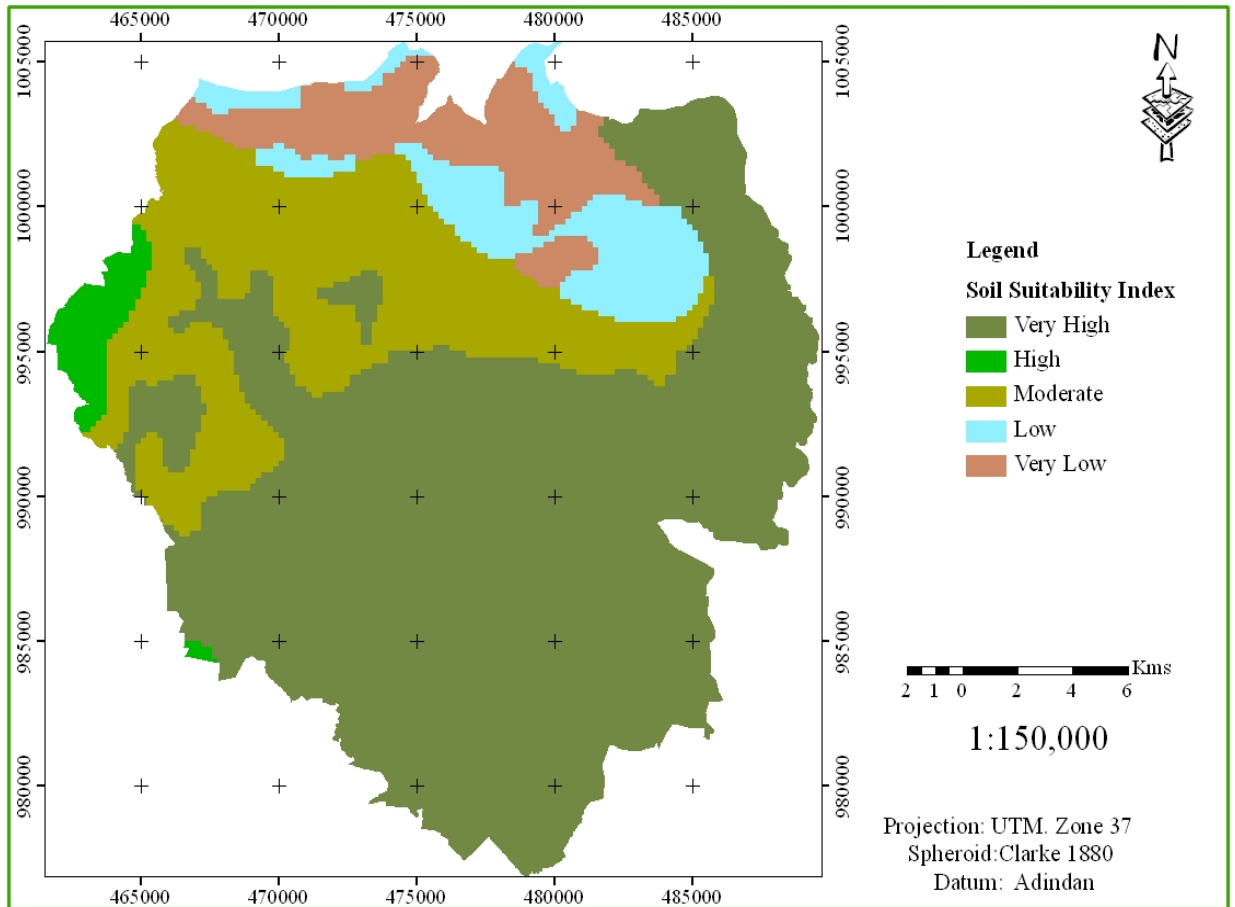


Fig. 26. Soil suitability map of the study area

Nevertheless, only considering soil texture and depth will not guarantee groundwater protection from landfill leachate. For example, the cracks that vertisol forms during dry season may make the soil permeable and allow the movement of leachate to groundwater. Therefore, measured hydraulic conductivity of geologic formation of the area should also be integrated with soil of the area in order to site landfill in the safest area.

For the purpose of this study, hydraulic conductivity and soil suitability maps were integrated in GIS environment using weighted overlay analysis. The overlay was performed by giving more weight (0.7) for hydraulic conductivity map and less weight (0.3) for soil map. These thematic maps were combined and permeability map of the area was prepared. Accordingly, most parts of the area are moderately suitable for landfill site. However, the very highly suitable areas were very small (0.001km^2). Table 16 summarizes the area coverage of landfill suitability site within the region.

Table 16. Area coverage of permeability suitability table

S.No.	Suitability	Rank	Weight	Area (km ²)	Area (%)
1	Very Highly	5	0.4673	0.001	0.0004
2	Highly	4	0.2772	71.7	13.5
3	Moderate	3	0.1601	326.5	62.0
4	Low	2	0.0954	128.8	24.5
Total				527.0	100.0

Very highly suitable areas are insignificant (0.0004%) for landfill siting as it is very small areas. However, 61.96% is moderately suitable. The spatial distribution of suitability map of the area is shown in Fig. 27.

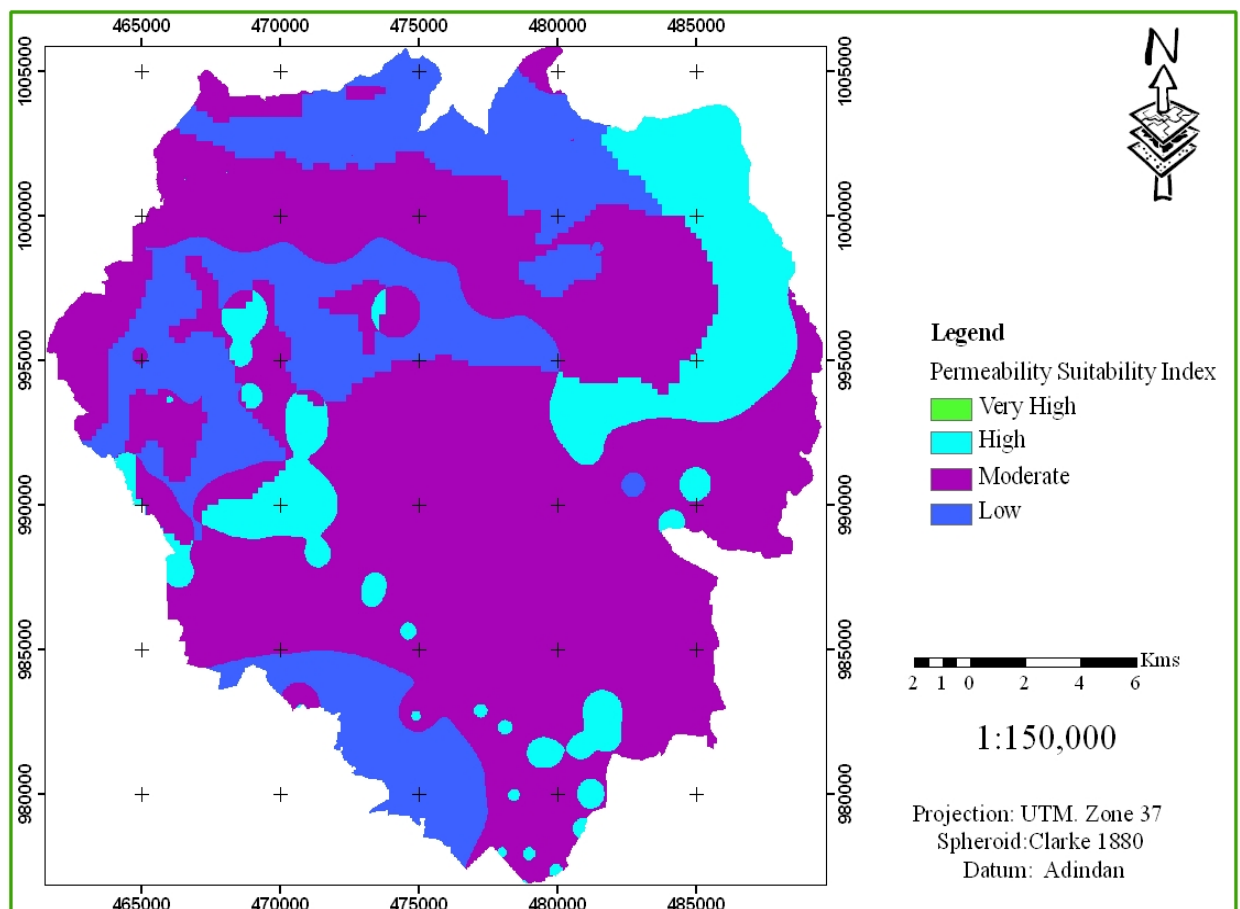


Fig. 27. Permeability suitability map of the study area

3.2.4.10 Land Use/ Land Cover

Land use/land cover of the study area was mapped from satellite images (ETM+ and SPOT of 2005). The two images were merged so as to extract maximum information. Master plan of Addis Ababa was also used as auxiliary information during image classification. Hence, resolution merge was followed by image classification to use remote sensing raw data as information.

Resolution Merge

Resolution merge is the technique used to combine remote sensing images covering the same area. Merging could be multi-sensor and multi-temporal. Hence, the images to be merged could be taken with the same or different sensor and with the same or different resolution. The general objective of this technique is to create a product useful for visual interpretation. For the purpose of this work, multi-spectral images and high spatial images of different sensor and resolution were merged to obtain the hybrids of the images (multi spectral with high spatial resolution images). Accordingly, ETM+ image with band 6 and spatial resolution of 30mx30m fused with SPOT of band 3 and spatial resolution of 5mx5m in IRDAS Imagine Software. The output image, with band 6 and spatial resolution of 5mx5m, was advantageous over both input images in having both high spatial and multispectral images. Therefore, the merged image was used for mapping land use/land cover of the study area.

Image Classification

The overall objective of image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand et al., 2004). Image classification is, thus required to convert remote sensing data in to thematic data. The present study used supervised classification techniques to categorize the images in to different land use/land cover categories. Supervised classification can be used to cluster pixels in data set into classes corresponding to user defined training classes. This classification method requires selecting training areas for use as the basis for classification.

Supervised classifications require a prior knowledge of the scene area in order to provide the computer with unique training classes. In this method, the user defines the original pixels that contain similar spectral classes representing certain land cover class. Accordingly, master plan of the study area was used as a guidance to identify representative land cover classes. This was used for solving the problems of identifying features of similar reflectance like green area with forest, open land and agricultural, open land with agricultural land. Moreover, representative points thought to represent the various land cover classes were marked using Garmin GPS during field visits in accessible places. Finally, supervised classification has been carried out using ERDAS Imagine software from the merged images of Landsat and SPOT of 2005. Accordingly, five land use/land cover types namely: built-up, agricultural land, open land, forest area and green area were identified (Table. 17).

Table 17. Land use/ land cover classes.

S.No.	Land Use/Land Cover Classes	Area (km ²)	Area (%)
1	Built Up area	287.0	54.5
2	Forest area	30.2	5.7
3	Open land	51.8	9.8
4	Green area	87.0	16.5
5	Agricultural land	71.0	13.5
Total		527.0	100.0

Large parts of the study area are covered by built up area which accounts about 54.46%. Agricultural land, green area, open land and forest account for 13.47%, 16.53%, 9.92% and 5.72% of the total study area, respectively. Land use/land cover of the study area is shown in Fig. 28.

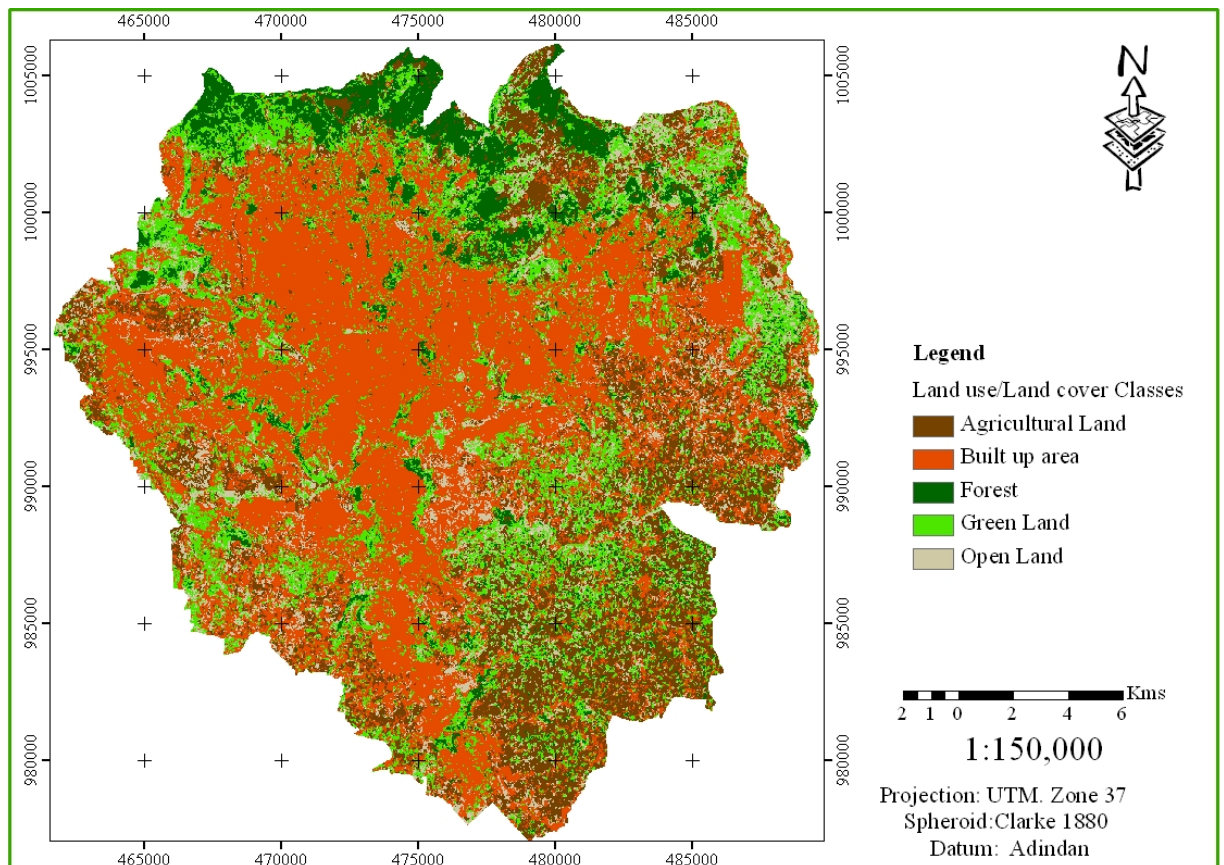


Fig. 28. Land use/ land cover map of the study area

Accuracy Assessment

Accuracy assessment should be done as image classification without accuracy assessment is incomplete (Lillesand et al., 2004). Land cover maps derived from remote sensing imagery always contain some sort of errors due to several factors which range from classification technique to method of satellite data capture. Therefore, accuracy assessment performed for image classification is used to tell how accurately the land use/land cover maps were classified. The present study used a total of 303 randomly selected pixels for the 2005 land use/land cover map, which were also checked with reference data (ground data) in the field to assess the accuracy of the classification.

The current study revealed an overall accuracy of 82.8% and a kappa index of agreement of 0.7715 (Table. 18). The kappa coefficient implies that the classification process is avoiding 77% of the errors that a completely random classification generates. Individual class accuracies ranged from 70.8% to 94.4% and from 76.9% to 90.0% for producer's and user's accuracy, respectively.

Table 18. Accuracy assessment of the classified land use/land cover map.

CD	Reference Data											
	AG	GA	OPL	FA	BUA	ROT	RT	CLT	NC	PA	UA	KC
AG	40	8	4	0	0	52	51	52	40	78.4%	76.9%	0.7225
GA	4	51	1	1	2	59	72	59	51	70.8%	86.4%	0.8221
OPL	2	0	36	0	2	40	48	40	36	75.0%	90.0%	0.8812
FA	2	0	0	23	2	27	25	27	23	92.0%	85.2%	0.8385
BUA	3	13	7	1	101	125	107	125	101	94.4%	80.8%	0.7032
CL	51	72	48	25	107	303	303	303	251			

CD = Classified Data

Overall Classification Accuracy= 82. 8%

Overall Kappa Statistics = 0.7715

Land covers categories: AG= Agricultural land, GA= Green area, OPL= Open area, FA= Forest area, BUA= Built up area.

Accuracies: Overall Classification Accuracy= 75.6%, Overall Kappa Statistics= 0.6782, PA= Producer's Accuracy, UA= User's Accuracy, KC=Kappa Coefficient.

Totals: ROT= Row Totals, RT= Reference Total, CT= Column Totals, CLT=Classified Total, NC=Number Correct.

RT=CT.

Land use land cover should also be considered as one of landfill site selection criteria. This is due to the fact that, adjacent landfill may affect land use land cover of the area and lower economic values of the land. Therefore, current land use/land cover of the study area should be studied and high value land must be excluded from landfill siting. According to Ekmekçiog̃lu et al. (2010), sites with potential for higher value uses such as nature conservation, agriculture and residential development should not be used for landfill. Hence, areas with low economic advantages for man should be considered for landfill (Moeinaddini et al., 2010).

For the purpose of this study, land use/land cover of the area was analyzed from landfill siting point of views. Accordingly, landfill should not be sited in built up areas and forest lands as they are high value lands and thus excluded from siting processes. Open lands in the study area were identified as best option for solid waste landfill site. The rest of the lands like agricultural and green areas were used as last option for landfill site. Therefore, land use/land cover of the study area was reclassified in to three classes of unsuitable, marginally suitable and highly suitable levels. Weight for each class was derived using AHP module (Fig. 29).

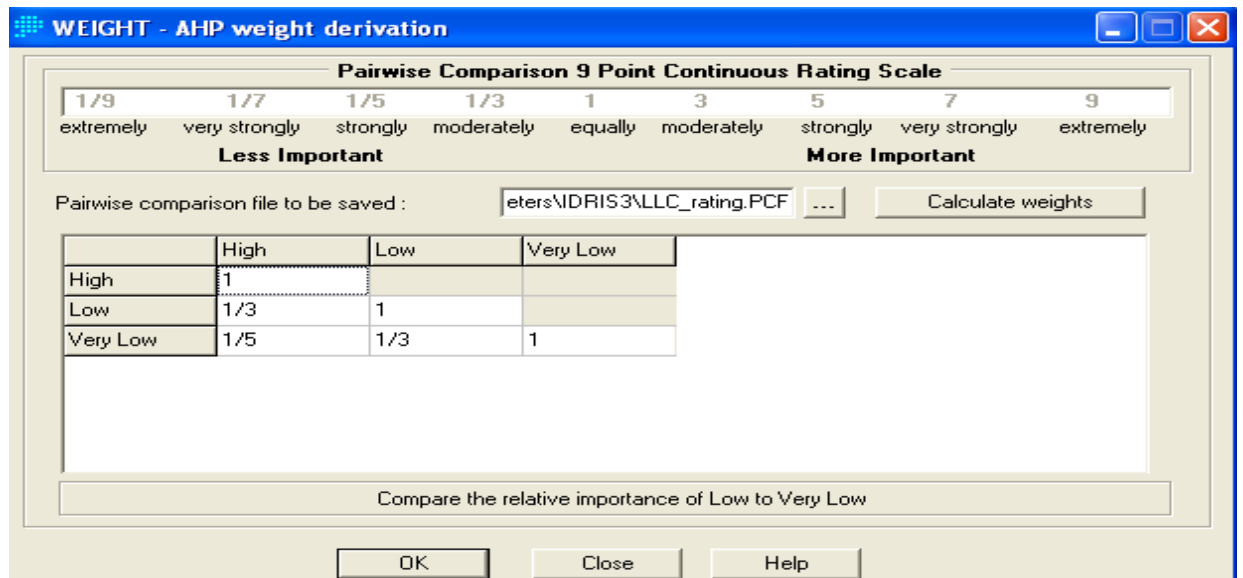


Fig. 29. AHP weight derivation methods for land use/land cover classes.

Accordingly, weight was calculated from this pair-wise comparison matrix. From suitability point of view open land was highly suitable hence more weight (0.6370) was assigned to it. However, built up and forest areas were unsuitable for landfill and were excluded from the analysis as a result least weight (0.1047) was given. Furthermore, agricultural and forest lands

were marginally suitable for landfill site and hence 0.2583 was assigned to it. Suitability level and their respective area coverage are indicated in Table 19.

Table 19. Land use/ land cover landfill suitability index with their respective area coverage.

S.No.	LU/LC	Suitability	Rank	Weight	Area (km ²)	Area (%)
1	Built up and Forest area	Very Low	1	0.1047	317.2	60.2
2	Agriculture and Green area	Low	2	0.2583	158.0	30.0
3	Open land	High	4	0.6370	51.8	9.8
Total				1.00	527.0	100.0

Table 19 shows that 60.2% of the total area are unsuitable for landfill site while 9.8% and 30% of the area are highly and marginally suitable, respectively. Land use/land cover of the study area was reclassified and standardized according to the above table and thus suitability map of landfill site was prepared (Fig. 30).

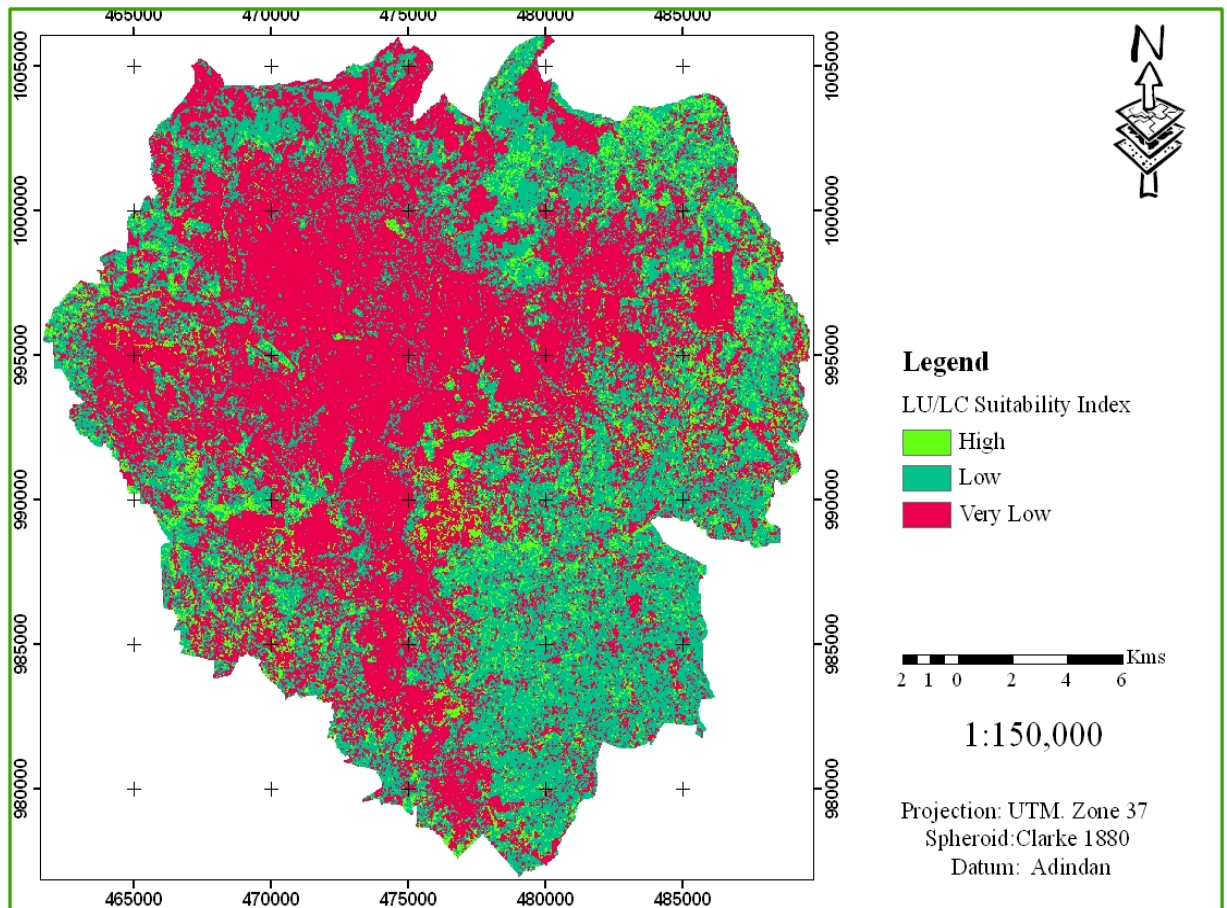


Fig. 30. Land use/land cover suitability map of the study area

3.2.5 Assigning Criteria Weights

One of the components of GIS-Based MCE methodology is assigning criteria weights for each factor maps. The purpose of weighting in landfill site selection process is to express the importance or preference of each factor relative to other factor effect on landfill siting. A number of criterion-weighting procedures based on the judgments of decision makers have been proposed in the multi-criteria decision literature. The procedures include ranking, rating, pair-wise comparison, and trade-off analysis. They differ in terms of their accuracy, degree of easiness to use and understanding on the part of the decision makers, and in the theoretical foundation (Hasan et al.2009). Accordingly, one of the most promising is pair-wise comparison developed in context of a decision making process is known as the AHP. In MCE using a weighted linear combination, it is necessary that the weights sum to 1. Accordingly, in IDRISI, the weight module utilizes the pair-wise comparison technique to help develop a set of factor weights that will sum to 1.0 (Table. 20). In AHP, weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved at a time, in determining suitability for the stated objective. Accordingly, all possible combinations of two factors were compared based on expert judgment to prepare a pair-wise comparison matrix from which the module calculates a set of weights and consistency ratio. This ratio is very import as it shows any inconsistencies that may have arisen during the pair-wise comparison process. Fig. 31 reveals the AHP weight derivation interface to derive the weights, with its consistency ratio, for solid waste landfill site selection.

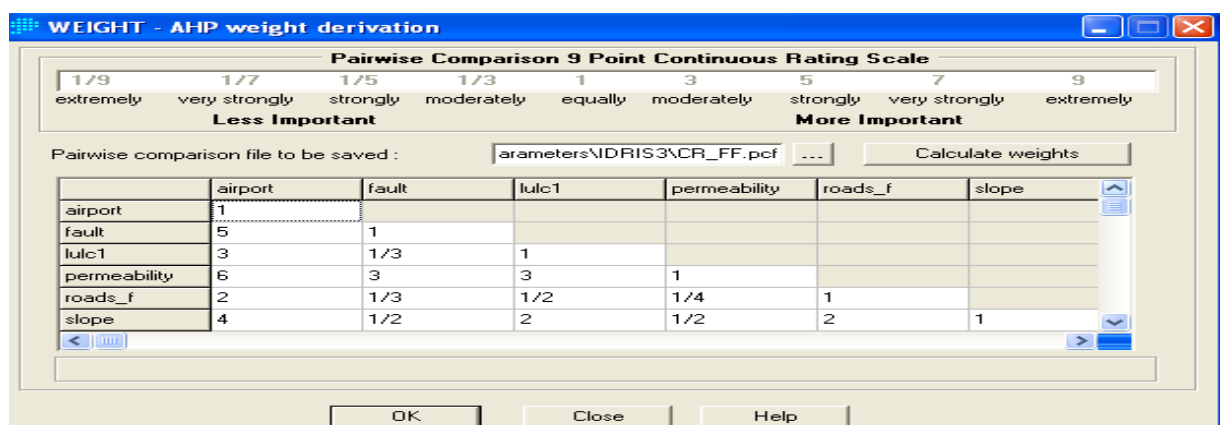


Fig. 31. AHP weight derivation method considering all factors for landfill site selection

Based on this AHP weight derivation module, the following eigenvectors of weights for all factors considered for landfill site selection are generated (Table 20).

Table 20. Factors and their eigenvectors weights for landfill siting

	PA	PF	LUC	Per	PR	S	PS	GWL	PW	G	Weight	Weight (%)
PA	1										0.0195	2.0
PF	5	1									0.0916	9.1
LUC	3	1/3	1								0.0438	4.3
Per	6	3	3	1							0.1318	13.2
PR	2	1/3	1/2	1/4	1						0.0315	3.2
S	4	1/2	2	1/2	2	1					0.0610	6.1
PS	7	2	4	2	5	3	1				0.1771	17.7
GWL	7	2	4	2	5	3	1	1			0.1771	17.7
PW	7	2	4	2	5	3	1	1	1		0.1771	17.7
G	5	1	2	1/2	3	2	1/2	1/2	1/2	1	0.0895	9.0
Total											1.00	100.0

Consistency Ratio = 0.02 << 0.1 ==> acceptable

(Note: PA= Proximity from Airport, PF= Proximity from Faults, LUC= Land use/Land cover, Per=Permeability, PR=Proximity from Roads, S=Slope, PS= Proximity from Streams/Rivers, GWL= Groundwater Level, PW= Proximity from Well and G=Geology).

Table 20 shows that proximity from streams/rivers, depth to ground water depth and proximity from ground water well are more important than other factors for landfill site selection. The main reason for this is to protect groundwater from leachate contamination from landfill. However, proximity from airport was taken as the least important factors in this work.

3.2.6 Aggregating the Criteria Weights and the Standardized Factor Maps

The distinguishing feature of GIS is its capacity for integration and spatial analysis of multisource datasets. The data are manipulated and analyzed to obtain information useful for a particular application such as suitability analysis (Malczewski, 2004). Landfill site selection by GIS is a MCE, which involves aggregation of factors in a systematic way. Once the factor maps are prepared, the last step in suitability analysis is to evaluate the criterion so as to combine the information from the various factors. The present study employs, MCE method to combine all the fact maps considered for landfill site selection. Among MCE procedures WLC is flexible, easy to use and frequently for factors aggregation (Malczewski, 2006). With a weighted linear combination, factors were combined by applying a weight to each followed by a summation and final landfill suitability map that shows suitable sites for landfill within the region. Suitable sites were evaluated against other criteria like size of the site and distance from the center to select the best suitable site/s for landfill. Therefore, area, distance from center and distance from nearby settlements were determined for each candidate landfill sites in GIS environment.

4. RESULTS AND DISCUSSION

4.1 Solid Waste Management System in Addis Ababa

Solid waste management system in Addis Ababa includes collection, transportation and disposal. Collection of solid wastes from the whole city is performed by the three collection systems namely: municipal containers, collection from different institutions and house-to-house collection that have been established by the municipality. In municipal container system, large plastic container (1.1 m³) and/or small open steel container (8 m³) are located on open spaces near the main roads in the city, where the households and other generators deliver their waste to the containers. House-to-house collection system service is available for those households that are located far from main roads. Hence, solid waste is collected from the households to container stations by the daily laborers and be ready for transportation. However, solid waste from institutions is collected by order via payment per container. The solid wastes collected by the three systems are transported to the final dumping site (“Koshe” or “Repi”) located at 13km to South-West part of the city center. It is the only disposal site available for the city to dump all types of solid waste generated for the city and it has been serving for the last 47 years, even though it was designed for only 25 years. The municipality of Addis Ababa city has been facing problems related to solid waste management. The problems start from the collection to final disposal due to the increased waste generation, unplanned city infrastructures and scarcity of dumping site. Moreover, the current open dumping system has been resulted in environmental and social problems.

Different researchers (Tamiru Alemayehu et al. (2003), Bjerkli (2005) and Tadesse Kuma (2004)) show that “Koshe” or “Repi” 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. The problems resulted due to not considering environmental and social factors during site selection. Landfill site suitability map (Fig. 33) of Addis Ababa done in this thesis showed that the current dumping site falls in unsuitable sites. The site is located near main road and surrounded by residential area (Plates 1 and 2) resulted in health and social problems like nuisance, health hazard stigma and hampering of societal activities practiced near the site due to large number of waste picker are continuously working daily. Moreover, the area is vulnerable to ground and surface water pollution as it is located at

very highly permeable area and near rivers/streams and faults. Moreover, all types of solid wastes from domestic, market, industry, commercial and hospitals, which may contain leachable toxic compounds, have been dumped without any treatment and separation. 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. Furthermore, open dumping is not acceptable from international and national environmental point of views (section 2.6). Therefore, the current solid waste disposal system is not environmentally friendly and socially acceptable.



Plate 1. “Koshe” Open Dumping Site near Settlement Area.

The picture shows that the dumping site is very close to the settlement area in almost all directions. The site is bounded by settlement in the Northern, Eastern, Western and North-Eastern. While the Southern and South-Western part of the site is bounded by the main (Ring) road to Akaki (Plate 2). Moreover, the site is with no fence and there is no covering material after each disposal of solid waste. 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.



Plate 2. “Koshe” Open Dumping Site near Main Road.

4.2 Landfill Suitability Analysis Results

The importance of environmental factors like geology, permeability, ground water table depth, and fault and socio-economic factors such as slope, proximity from groundwater well, airport and streams/rivers, for determining landfill sites are not the same. The analysis of the weight assignment shows that ground and surface water related factors like groundwater level, permeability, proximity from wells and streams/rivers are more influential than the other factors (Table 20), as they are very important to protect water pollution from landfill leachate. Weighted Linear Combination result showed four classes of suitability levels. These are unsuitable (restricted), marginally suitable, moderately suitable and highly suitable. As the overall suitability result shows there is no area that fulfills the very highly suitable criteria. This indicates that there is no parcel of land that is very highly suitable in all the ten criteria considered.

The area coverage of each suitability class was calculated in GIS environment after converting raster map to vector. The result showed 417.8km² (79.3%) of the study area is unsuitable (restricted) as the areas are environmentally unfriendly, socially unacceptable and/or economically unfeasible for landfill. The restricted area includes built up and forest area, steep slope (>30%), areas close to airport, road, groundwater well, rivers/streams and faults. The main purpose is to protect human health and environment from potential effects of landfill and as well to minimize the cost of construction and waste transportation. However, 40.5km²(7.7%) of the region satisfies the environmental, social and economical criteria set in the previous section and hence identified as highly suitable. These areas are more preferable land for landfill because of their minimum effect on environment and public health and cost effective than other parts of the area. Moreover, 68.7km²(13.0%) and 0.7km²(0.01%) of the area are moderately and marginally suitable. The moderately suitable areas may be used for landfill site with some careful management system such as lining the base of landfill and constructing leachate and gas collector so as to minimize their negative effects on the environment and public health. Landfill suitability index and their area coverage are shown in Table. 21.

Table 21. Suitability classes for landfill site with their respective area.

Suitability Classes	Area (km ²)	Area (%)
Unsuitable (Restricted)	417.8	79.3
Marginally Suitable	0.7	0.01
Moderately Suitable	68.7	13.0
Highly Suitable	40.5	7.7
Total	527.0	100.0

Most of the highly suitable landfill sites were identified in the eastern and north eastern part of the study area. Furthermore, highly suitable sites are also found in some parts of south east and south western parts of the city (Fig. 32). The northern part of the city, which is at high elevation, is excluded from siting landfill as it is the recharge area for the low-lying area. Moreover, the southern part of Addis Ababa city is believed to be the potential source of ground water for the city and the surrounding, hence not allowed for landfill site/s. Therefore, the northern and southern parts of the city are excluded for landfill site so as to protect water pollution.

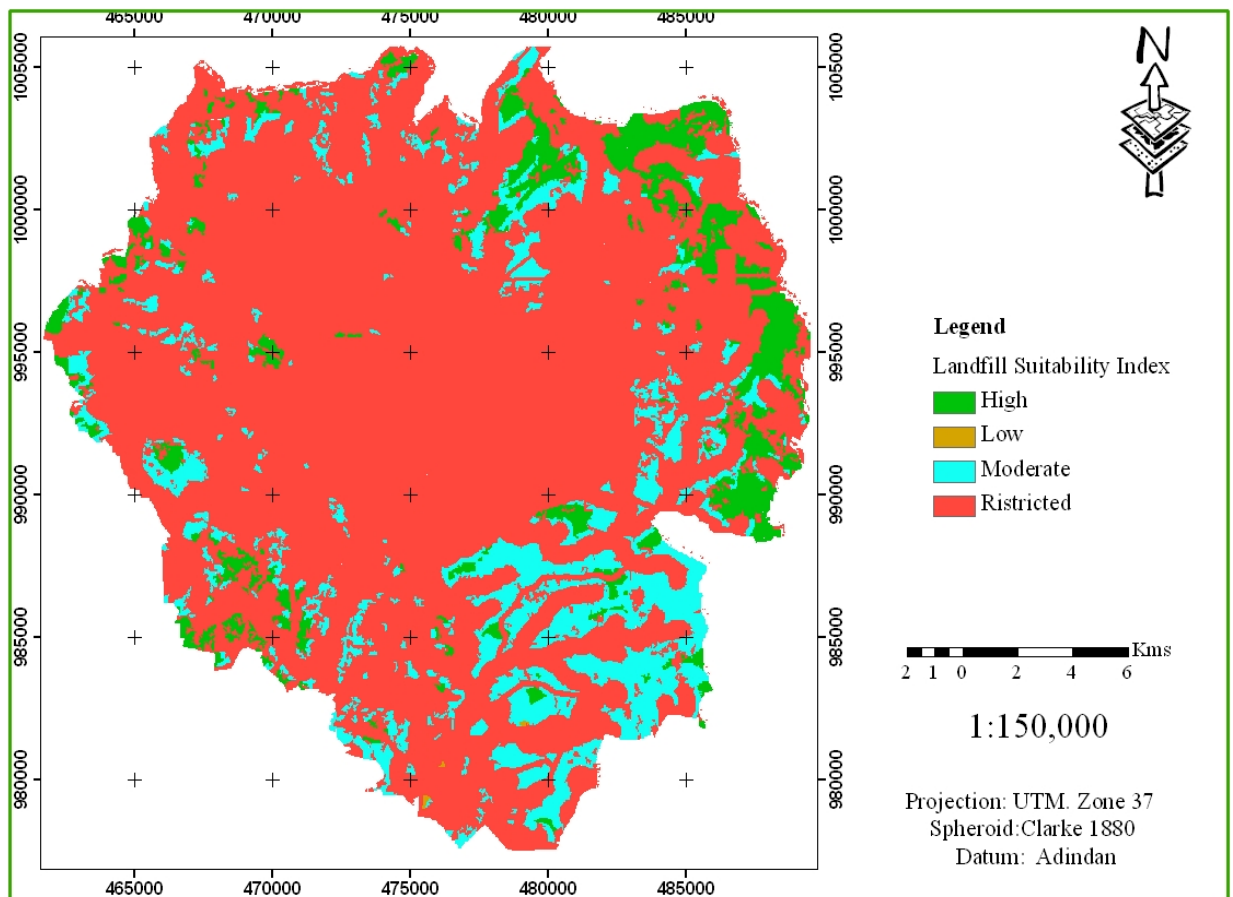


Fig. 32. Landfill sites suitability map of Addis Ababa

4.3 Evaluating Candidate Landfill Sites

Socio-economic criteria like size of the site, distance from nearby settlements and distance from the center of the city are the determinant criteria used to evaluate potential landfill site so as to choose the best suitable. Size of landfill is one of the determinant criteria for sustainable solid waste management as size of land selected for landfill determines the number of years for which the landfill will be used as waste disposal site. From sustainability and economical point of views, larger size of land that will serve for at least ten years are more preferable than small size. This is because selecting large sized landfill site can minimize the cost of site selection, design and closure (that will be performed at the end of its lifespan). Accordingly, the analysis of the potential landfill sites in GIS environment shows that, sites with area less than 0.5km^2 are economically not feasible and hence excluded from further analysis. The rest sites with area greater than 0.5km^2 are preferable and selected to be further evaluated with the previously set criteria. Accordingly, the result of the analysis shows 12 landfill sites are selected for further evaluation (Table 22).

Table 22. Analysis of candidate landfill sites with the previously used landfill siting criteria.

Criteria	Landfill Sites												Remark
	LF1	LF2	LF3	LF4	LF5	LF6	LF7	LF8	LF9	LF10	LF11	LF12	SI
PA(km)	>7	>7	5-7	>7	>7	>7	>7	>7	>7	3-4	>7	>7	H to V
PF(km)	4-8	4-8	4-8	4-8	0.5-4	0.5-4	4-8	4-8	>8	4-8	4-8	4-8	M to H
LUC	A, O	A, G,O	A, G	O, G	A,O, G	O,A	G, O	A, O	B,A,O	O,G, A	A, G	A,B, O	L to H
Per	H	L	M	M	L	M	L,M	M	M	M	M	M	L to H
PR(km)	0.1-0.7	0.1-0.7	1.5-4	0.1-0.7	0.1-0.7	0.1-0.7	0.1-0.7	1.5-4	0.7-1.5	0.1-0.7	0.7-1.5	0.7-1.5	M to V
S (%)	2-30	2-30	2-15	2-15	2-30	2-15	2-8	2-8	2-8	2-8	2-8	15-30	M to V
PS(km)	0.5-3	0.5-3	0.5-3	0.3-1	0.5-3	0.5-3	0.5-3	0.5-1	0.5-3	0.5-1	0.5-3	0.5-3	H to V
GWL(m)	40-50	40-50	40-50	>50	>50	>50	20-40	20-40	20-40	20-40	20-40	>40	M to V
PW(km)	>1.2	>1.2	>1.2	1.2-2	0.8-2	1.2-2	>1.2	>2	1.2-2	>1.2	>1.2	1.2-2	M to V
G	Ti1	Ti1	Qb	Tt2	Ti1	Tt2	Ti3	Ti3	Tb3	Ti2, Tb2	Ti3	Tt2	L to V

(Note: LF1=Landfill 1, LF2=Landfill 2, LF3=Landfill 3, LF4=Landfill 4, LF5=Landfill 5, LF6=Landfill 7, LF 8=Landfill 8, LF9=Landfill 9, LF10=Landfill 10, LF 11=Landfill 11, LF 12=Landfill 12, PA=Proximity from Airport, PF=Proximity from Fault, LUC=Land use/land cover, Per=Permeability, PR=Proximity from Road, S=Slope, PS=Proximity from Streams/Rivers, GWL=Ground Water Level, PW=Proximity from Well, G=Geology, A=Agriculture, O=Open Land, G=Green Land, B=Built up area, H=High, L=Low, M=Moderate, V=Very High, SI=Suitability Index, Ti1=Intoto Mixed Rocks, Qb=Quaternary Basalts, Tt2=Wechecha_Yerer_Furi Trachyte, Ti3=Wechecha_Yerer_Furi Ignimbrite, Tb3=Repi Basalt, Ti2=Lower Ignimbrite, Tb2=Chelekleka Basalt).

The analysis of candidate landfill sites with the previously used criteria like geology, ground water level, slope, land use/land cover, permeability, proximity from airport, fault, road, stream and well are shown in Table 22. The main reason to do so is to check whether the suitable landfill sites were in suitable area with respect to each criteria used. The results of the analysis showed that the suitability level for most of the landfill sites range from highly to very highly suitable for most landfill sites except that there is some part of landfill sites that fall in low and moderate suitability level. However, even most parts of these landfill sites are highly to very highly suitable from those criteria point of views.

Locations of the 12 selected landfill sites are shown in Fig. 33 and the analysis with each other in terms of their size, distance from the center and distance from nearby settlement areas are shown in Table 24.

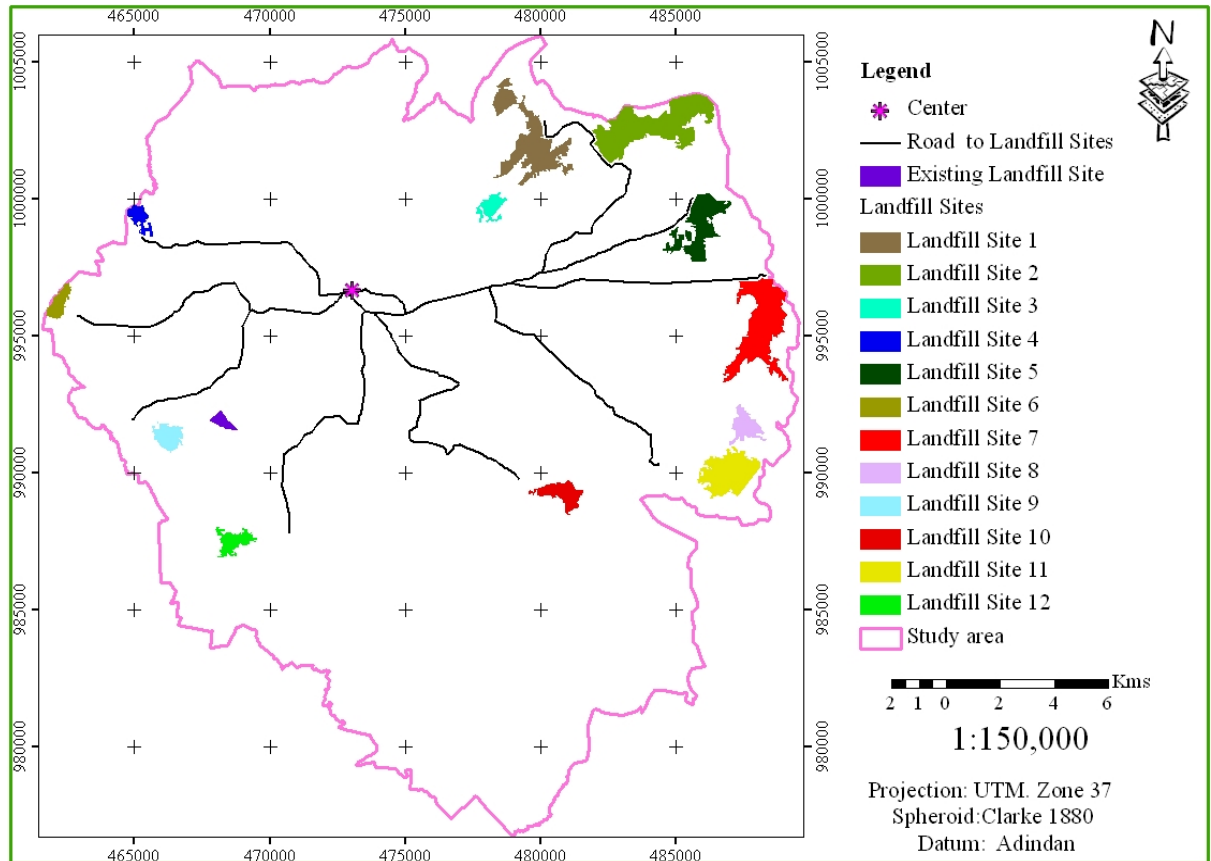


Fig. 33. Candidate Landfill sites Map

For evaluating landfill site, distance from the center of the city is also another very important criterion from economic point of view. Landfill far from the center of the region is not preferable due to high transportation cost that will be incurred during its life time. Therefore, site close to the center of the city is more preferable than far sites. The Analysis of all the candidate landfill sites with shortest path following the roads showed that, landfill site 4 is close (9km) to the center than other sites while landfill 1, 2 and 3 are far compared to the rest of the sites. They are 18km away from the center of the city. Hence, from transportation point of view landfill site 4 is the most suitable landfill of all candidate sites. However, landfill should not be located near settlement area as it poses negative impact on human health. Evaluation of candidate landfill sites with the distance from the nearby settlement area can minimize such effects. Accordingly, the analysis of the sites with distance from the nearby settlements in GIS environment shows that

landfill site 11 is the safest site as it is far (6km) from nearby settlement area. However, landfill site 5 is located near settlement (<1km) and thus unsuitable to be used for solid waste disposal. In addition, evaluation of candidate sites in relation to their size shows that landfill site 2, with area coverage of 5km², is the most suitable site as it will serve for longer years while site 4 is less preferred due to its smaller area (0.5km²). As described above, the criteria are conflicting to each other (Distance from city center and Distance from nearby settlement area). MCE solves such decision problems so as to choose the most suitable landfill site/s by considering all the three criteria at a time for the entire candidate landfill site.

AHP weight derivation method for other evaluation criteria such as volumetric capacity (size), distance from nearby settlement area and distance center is shown in Fig. 34. The result of weight assignment shows the importance of those criteria, size is more important for evaluating landfill sites (Table 23). The analysis of all the candidate landfill sites with respect to those evaluating criteria is shown in Table 24.

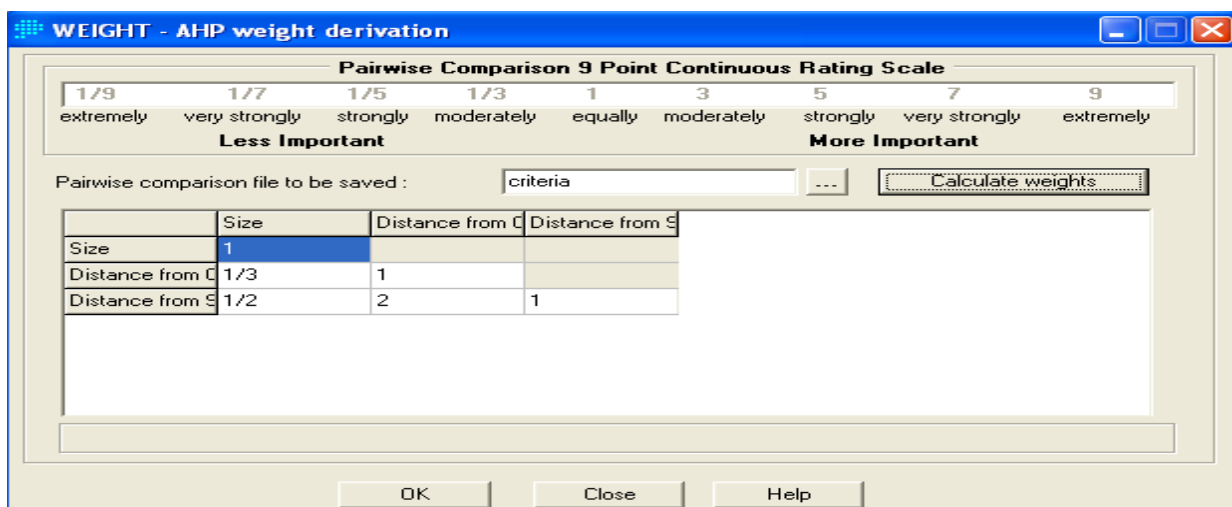


Fig. 34. AHP Weight Derivation Method for Evaluation Criteria.

Table 23. Calculated weight for the evaluating criteria.

Criteria	Weight	Weight (%)
Size of the Site	0.5396	54.0
Distance from Center	0.2970	29.7
Distance from nearby settlement	0.1634	16.3
Total	1.0	100.0

Consistency Ratio= 0.01<<0.1

Table 24. Comparison and weight calculation for each candidate landfill sites with each of the criteria

Size	LF1	LF2	LF3	LF4	LF5	LF6	LF7	LF8	LF9	LF10	LF11	LF12	Eigenvector of Weight
LF1	1												0.1252
LF2	2	1											0.2253
LF3	1/5	1/7	1										0.0245
LF4	1/6	1/8	1/2	1									0.0186
LF5	½	1/3	4	5	1								0.0891
LF6	1/6	1/8	1	1	1/5	1							0.0196
LF7	2	½	6	7	2	7	1						0.1738
LF8	1/3	1/5	2	3	½	3	1/4	1					0.0426
LF9	1/3	1/5	2	3	½	3	1/4	1	1				0.0472
LF10	½	¼	3	4	½	4	1/3	2	2	1			0.0679
LF11	1	½	5	6	2	6	1/2	3	3	2	1		0.1282
LF12	¼	1/6	2	2	1/3	2	1/5	2	1/2	1/2	1/5	1	0.0378
Distance from center(DFC)													
LF1	1												0.0391
LF2	1	1											0.0391
LF3	1	1	1										0.0391
LF4	4	4	4	1									0.1611
LF5	2	2	2	3	1								0.0997
LF6	2	2	2	½	3	1							0.1012
LF7	2	2	2	½	1	1/2	1						0.0680
LF8	2	2	2	½	1	1/2	1	1					0.0680
LF9	3	3	3	1/3	2	2	2	2	1				0.1351

DFC	LF1	LF2	LF3	LF4	LF5	LF6	LF7	LF8	LF9	LF10	LF11	LF12	Eigenvector of Weight
LF10	2	2	3	½	1	1/2	1	1	1/2	1			0.0680
LF11	2	2	2	½	1	1/2	1	1	1/2	1	1		0.0680
LF12	2	2	2	½	2	2	2	1	1/2	2	2	1	0.1137
Distance from Settlement													
LF1	1												0.0484
LF2	4	1											0.1451
LF3	1	¼	1										0.0484
LF4	½	1/5	1/2	1									0.0299
LF5	½	1/6	1/2	½	1								0.0205
LF6	½	1/5	1/2	1	2	1							0.0286
LF7	½	1/5	1/2	1	2	2	1						0.0323
LF8	5	2	5	6	7	6	6	1					0.1988
LF9	½	1/5	1/2	1	2	1	1	1/6	1				0.0299
LF10	4	1	4	5	6	5	5	1/2	5	1			0.1451
LF11	6	2	6	7	8	7	7	2	7	2	1		0.2418
LF12	½	1/5	1/2	1	2	1	1	1/6	1	1/5	1/5	1	0.0310

Consistency Ratio = 0.02, 0.04, 0.02<<0.1 respectively.

The values of the shaded part of the matrix table are the reciprocals of the opposite boxes.

(Note: LF1 = Landfill Site1, LF2 = Landfill Site3, LF3 = Landfill Site3, LF4 = Landfill Site4, LF5 = Landfill Site5, LF6 = Landfill Site7, LF8 = Landfill Site8, LF9 = Landfill Site9, LF10 = Landfill Site10, LF11 = Landfill Site11 and F12 = Landfill Site12).

Table 24 shows that landfill site 2 with weight of 0.2253 is the most suitable site while landfill 4 with weight of 0.0186 is the least preferred site from size point of view. From distance from the center point of view, landfill site 9 with weight of 0.1351 is most suitable while landfill 1, 2 and 3 with weight of 0.0391 are least suitable. Moreover, from distance from nearby settlement point of view, landfill 11 with weight of 0.2418 is most suitable while landfill 5 is the least preferred site with weight of 0.205. To solve the conflicting decision problems of choosing the most suitable landfill site, all the evaluating criteria were considered at a time in MCE methods. Hence, scores for all candidate landfill were derived from multiplying criteria weight and landfill site's weight that are derived in relation to that criteria and then summing the corresponding products (Table. 25).

Table 25. Mathematical matrix to calculate score of the candidate sites.

Weight percent of the criteria	Size of the sites	Distance from Center	Distance from nearby settlement	Score of Candidate Sites
	0.5396	0.2970	0.1634	
LF1	0.5396×0.1252	0.2970×0.0391	0.1634×0.0484	0.0870
LF2	0.5396×0.2253	0.2970×0.0391	0.1634×0.1451	0.1569
LF3	0.5396×0.0245	0.2970×0.0391	0.1634×0.0484	0.0327
LF4	0.5396×0.0186	0.2970×0.1611	0.1634×0.0299	0.0628
LF5	0.5396×0.0891	0.2970×0.0997	0.1634×0.0205	0.0810
LF6	0.5396×0.0196	0.2970×0.1012	0.1634×0.0286	0.0453
LF7	0.5396×0.1738	0.2970×0.0680	0.1634×0.0323	0.1193
LF8	0.5396×0.0426	0.2970×0.0680	0.1634×0.1988	0.0757
LF9	0.5396×0.0472	0.2970×0.1351	0.1634×0.0299	0.0705
LF10	0.5396×0.0679	0.2970×0.0680	0.1634×0.1451	0.0805
LF11	0.5396×0.1282	0.2970×0.0680	0.1634×0.2418	0.1289
LF12	0.5396×0.0378	0.2970×0.1137	0.1634×0.0310	0.0592

Table 25 shows that landfill site 2 is with the highest score (0.1569) compared to other sites. This shows that the site satisfies the criteria set in the previous section relative to the rest landfill sites. Landfill 3 is with the least score (0.0327) mainly due to their smaller size (0.52km²). Furthermore, landfill 11 and 7 are with the second and third highest score of 0.1289 and 0.1193, respectively. However, field verification revealed that some parts of landfill 7, 5 and 9 are occupied by new residential areas. The inconsistency of suitability map and field validation emanates from using 2005 satellite image for land use/land cover mapping. The residential area may be built after 2005 years of image acquisition. Therefore, re-evaluation of the ranking of the landfill sites were based on field check up is shown in Table 26.

Table 26. Summary of evaluating parameters and their score for all candidate landfill sites.

List of landfill sites	Area(km ²)	Distance from Center(km)	Distance from nearby settlement (km)	Score	Rank
LF 2	4.95	18	3	0.1569	1
LF 11	2.50	16	6	0.1289	2
LF 1	3.69	18	2	0.0870	3
LF 10	1.03	14	4	0.0805	4
LF 4	0.52	9	1	0.0628	5
LF 8	0.90	16	5	0.0757	6
LF 12	0.79	12	1	0.0592	7
LF 6	0.59	12	1	0.0453	8
LF 7	4.18	16	1	0.1193	9
LF 5	2.40	14	0	0.0810	10
LF 9	0.81	11	1	0.0705	11
LF 3	0.61	18	2	0.0327	12

Table 26 indicates that landfill site 2 is the most suitable site for landfill, because of its larger area and optimum distance from the center and nearby settlement than the rest of landfill sites. Moreover, site 11 and 1 are the second and third suitable site, respectively. Landfill 11 is more preferable than landfill 1 due to its location at safest distance from nearby settlement (6km). Landfill sites 2, 11 and 1 are also highly to very highly suitable for all parameters analyzed.

However, from accessibility point of view, landfill site 11 requires additional road construction as the existing road does not reach the site (Fig. 33). The Figure also shows that landfill 2 and 1 are accessible and they are at only 100m away from the road which make them more acceptable from economical and social health points of view. That means the site is at a location that requires minimum transportation cost and health effect. Generally, landfill 2, 11 and 1 are the first three most suitable sites to be used for landfill site.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Solid waste disposal system in Addis Ababa is open dumping. As a result there are environmental and social problems resulted from the dumping site. All types of solid wastes from hospitals, industries, domestic, market and commercial are dumped, which may contain leachable toxic compounds that are harmful to the environment and human health, at the site without any treatment and separation. Moreover, the disposal site is very close to the main road to Akaki and surrounded by residential houses and institutions hence resulted in societal problems like nuisance, hazard health and disturbances due to large number of waste pickers continuously working each day at the site. Furthermore, landfill suitability map shows that, the dumping site is located at environmentally and socially unsuitable area that does not satisfy the international and national environmental standards. Hence, it is environmentally unfriendly and socially unacceptable.

The present study considered ten factors namely: geology, slope, permeability of strata, ground water table depth, land use/land cover, and proximity from roads, ground water well, faults, streams/rivers and airports for proper landfill site selection. Integrating MCE with GIS for spatial decision making process is a worthwhile technique to handle large and conflicting criteria in landfill site selection processes. Accordingly, landfill suitability map for each of the factors were prepared in GIS environment. The factor maps were combined according to their importance, groundwater related factors were more importance to have overall suitability map. The result of the final suitability map showed that 7.7% of the study area is highly suitable for landfill. Moreover, 13.0%, 0.01% and 79.3% of the total area is moderately suitable, marginally suitable and unsuitable (restricted), respectively. Discontinuous and small area sites were masked. Accordingly, 12 candidate landfill sites each with an area greater than 0.5km² were selected.

These sites were compared to each other in relation to their size, distance from nearby settlement and distance from the center of the city. AHP pair-wise comparison method was applied again to select the most suitable landfill site among the candidate sites. Accordingly, weight was derived separately for each criteria and candidate landfill sites in relation to the criteria. The final score (rank) was computed from mathematical matrix and landfill 2 scored the highest score (0.1596)

while landfill site 3 scored the least score (0.0327). Hence, landfill site 2, which is found in the north eastern part of the city in Yeka sub-city north of the main road to Dessie, is the most suitable site among the 12 suggested sites due to its minimum environmental and social negative effects than other sites. Landfill site 11(found in south eastern in Bole sub-city) and 1 (found west of landfill 2 in Yeka sub-city) are the second and third most suitable site, respectively, due to their smaller area, closeness to settlement and /or farness from the center than landfill 2.

5.2 Recommendations

- ❖ The present study considers major environmental, social and economical factors for landfill site selection. However, other factors such as cost of construction, community preferences, landscape and aspect also influence landfill site selection and therefore, should be included as evaluating criteria. Therefore, the selected landfill sites (site 2, 11 and 1) should be evaluated with these factors especially with cost of construction.
- ❖ Detailed hydro-geological investigation for the selected landfill sites should be studied in order to further compare the landfill sites and predict the effects that will result from the landfill. Moreover, hydraulic conductivity of the sites should be studied so as to know whether the suitable site requires leachate and gas collector.
- ❖ 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 least for 10 years to reduce the cost of landfill site selection, construction and closure. Therefore, the rates 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 from industries, health institutions and from house-holds should be separated from non-hazardous solid waste before disposal. Hence, separate landfill should be selected for such hazardous solid waste as siting parameters and construction of landfill for hazardous solid waste is quite different from that of non-hazardous waste.

REFERENCES

- Addis Ababa City Municipality (2010). Overview of Addis Ababa City Solid Waste Management System, Addis Ababa, Ethiopia. P39.
- Agustín, B. G. (2008). Landfill Site Suitability Analysis for Non-toxic Solid Waste in Puerto Rico, A GIS Approach,
- Akar, I. (2009). How geographical information systems and remote sensing are used to determine morphometrical features of the drainage network of Kastro (Kasatura) Bay hydrological basin, *International Journal of Remote Sensing*, **30**:7,1737-1748.
- Al-Jarrah, O. and Abu-Qdais, H. (2006). Municipal solid waste landfill siting using intelligent system, *Waste Management*, **26**:299-306.
- Allen,A.(2001). Containment landfills: the myth of sustainability, *Engineering Geology*, **60**:3-19.
- Assefa Melesse, M., Weng,Q., Thenkabail,S.P. and Senay,B.G. (2007). Remote Sensing Sensors and Applications in Environmental Resources Mapping and Modelling, **7**:3209-3241.
- Babayemi, J.O. and Dauda, K.T. (2009). Evaluation of Solid Waste Generation, Categories and Disposal Options in Developing Countries: A Case Study of Nigeria, *Journal of Applied Environmental Management*, **13**: 3, 83-88.
- Biotto, G., Silvestri,S., Gobbo,L., Furlan, E., Valenti, S. and Rosselli,R.(2009). GIS, multi criteria and multi-factor spatial analysis for the probability assessment of the existence of illegal landfills, *International Journal of Geographic Information Science*, **23**: 10, 1233 -1244.
- Bjerkli, L.C. (2005). The cycle of plastic waste: An analysis on the informal plastic recovery system in Addis Ababa, Ethiopia. MSc thesis. Norwegian University of Science and Technology (NTNU), Norway, pp150.
- Brikci,D.H. and Trache,A.M. (2000). Combining geographical information system and multi criteria evaluation to deal with land use problem, *International Archives of Photogrammetry and Remote Sensing*. Vol. XXXIII, Part B7. Amsterdam. 306-312.
- Carver,S.J.(1991).Integrating multi-criteria evaluation with geographical information systems, *International Journal of Geographical Information Science*, **5**: 3, 321-339.
- CSA (2007). Central Statistical Agency of Ethiopia Population and Housing Census Report.
- Centre for Advanced Engineering (2000).Landfill Guidelines towards sustainable waste Management in New Zealand, University of Canterbury Christchurch New Zealand.
- Chakhar, S. and Mousseau, V. (2008). GIS-based multi criteria spatial modeling generic framework, *International Journal of Geographic Information Science*, **22**:11,1159-1196.Taylor & Francis.

- Chang, N.B, Parvathinathan, G, Breeden, B.J. (2007). Combining GIS with fuzzy multi criteria decision-making for landfill siting in a fast growing urban region, *Journal of Environmental Management*, **1**:11,1-15.
- Cheng, S.C., C.W. and Huang, G.H. (2002). Using Multiple Criteria Decision Analysis for Supporting Decisions of Solid Waste Management, *Journal of Environmental Science and Health, Part A*, **37**:6,975-990.
- Chenga, S., Chanb, C.W., Huang,G.H. (2003). An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management, *Engineering Applications of Artificial Intelligence*, **16**:543-554.
- Church, R.L. (2002). Geographical information systems and location science, *Computers & Operations Research*, **29**:54-562.
- Corrales, M. and Horton, N. (1995). Residential and Industrial (Solid) Waste Disposal Support Package pp43.
- Dadras, M., Ahmad, R. M., Farjad, B. (2010). Integration of GIS and multi-criteria decision analysis for urban solid waste management and site selection landfill in Bandar Abbas city, south of Iran, *International Geo-informatics Research and Development Journals*,**1**:2,14-27.
- Dai,C.F., Lee,F.C., Zhang, H.X. (2001). GIS-based geo-environmental evaluation for urban land use planning: A case study, *Engineering Geology*, **61**: 257-271.
- Department of the Army, the Navy and the Air Force (1990). Solid Waste Management, USA, pp282.
- Ekmekçiog˘lu, M., Kaya, T., Kahraman, C. (2010). Fuzzy multi criteria disposal method and site selection for municipal solid waste, *Waste Management*, **30**:1729-1736.
- Eldrandaly, K., Eldin,N., Sui,D., Shouman,M. and Nawara, G. (2005). Integrating GIS and MCDM Using COM Technology, *The International Arab Journal of Information Technology*, **2**: 2,162-168.
- Enger,.D.E. and Smith. F.B. (2008). Environmental Science, A study of Interrelationships, Eleventh edition, McGraw-Hill, USA, New York.
- EPA (1996). Landfill Manuals. Manual on Site Selection, 2nd Draft.
- EPA (1995). Decision Maker's Guide to Solid Waste Management, Volume II, pp58.
- EPA (2007). Environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste), EPA Guidelines.

- Ersoy,H. and Bulut,F. (2009). Spatial and multi-criteria decision analysis-based methodology for landfill site selection in growing urban regions, *Waste Management & Research* ,**00**:1-12.
- Fatta, D., Saravanos. P, and Loizidou, M.(1998). Industrial waste facility site selection using geographical information system techniques, *International Journal of Environmental Studies*, **56**:1,1-14.
- Federal Democratic Republic of Ethiopia (1997). Environmental Policy.
- Geologic Survey of Ethiopia (2010). Feasibility Study of the Chebi-Weregenu Sanitary Landfill Site for the City of Addis Ababa, Ethiopia.
- Girma Kebede. (2004). Living with Urban Environmental Health Risks. The case of Ethiopia.
- Guam Environmental Protection Agency (2004). Preliminary Landfill Site Suitability Report, pp18.
- Haile Sellasie Girmay and Getaneh Assefa. (1989).The Addis Ababa-Nazareth Volcanics: A Miocene-Pleistocene Volcanic Succession in Ethiopian Rift. SINET, *Ethiopian Journal of Science*, 12(1) Addis Ababa.
- Hasan,R.M., Tetsuo, K.and Islam,A.S. (2009). Landfill demand and allocation for municipal solid waste disposal in Dhaka city-an assessment in a GIS environment, *Journal of Civil Engineering (IEB)*, **37**:2,133-149.
- Henry,K.R., Yongsheng, Z., Jun,D. (2006). Municipal solid waste management challenges in developing countries-Kenyan case study, *Waste Management*, **26**:92-100.
- Higgs,G. (2006). Integrating multi-criteria techniques with geographical information systems in waste facility location to enhance public participation, *Waste Management and Research*, **24**:1-105.
- Idowu, I.A. and Ukoje. A. J. (2009). Application of Remote Sensing (RS) and Geographic Information Systems (GIS) to Environmental Impact Assessment (EIA) for Sustainable Development, *Research Journal of Environmental and Earth Sciences*, **1**:1,11-15.
- Jamjan, J. (2009). Selection of a potential solid waste landfill site in Nakhon Pathom province by using Geographic Information System (GIS). MSc Thesis, Mahidol University, Thailand, pp124.
- Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision making methods, *International Journal of Geographical Information Science*, **9**: 3,251-273.

- Jason,S., Donia.B, Rose,A, Gary.,L and Julie,C.(2005). Landfill Management, Leachate Generation, and Leach Testing of Solid Wastes in Australia and Overseas, *Critical Reviews in Environmental Science and Technology*, **35**:3,239-332.
- Kiker, A.G., Bridges, S.T., Varghese,A., Seager, P.T. and Linkov,I. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making, *Integrated Environmental Assessment and Management*, **1**:2,95-108.
- Laskar, A.(2003). Integrating GIS and Multi criteria Decision Making Techniques for Land Resource Planning, MSc Thesis, ITC, Netherlands, pp80.
- Leao, S., Bishop,I., Evans, D. (2010). Assessing the demand of solid waste disposal in urban region by urban dynamics modeling in a GIS environment, *Resources, Conservation and Recycling*, **33**:289-313.
- Mahini, S.A. and Gholamalifard,M. (2006). Siting MSW landfills with a weighted linear combination methodology in a GIS environment, *International Journal of Environmental Science Technology*, **3**: 4,435-445.
- Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview, *Progress in Planning*, **62**:3-65.
- Malczewski, J. (2006). Integrating multicriteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach, *International Journal of Environmental Technology and Management*, **6**:1/2,1-13.
- Map Asia (2004). GIS as Decision Support Tool for Landfills Siting, pp18.
- Map Asia (2010). Application of Geomatics in Determining of Suitability level of Integrated Waste Management Location in Megapolitan Jakarta, 1-14.
- Margherita di Pula,S., Cagliari. (2005). Environmental Sanitary Engineering Centre, Italy, 3-7 October, pp 11.
- Moienaddini, M., Khorasani,N., Ali,D.A., Darvishsefat, A., Zienalyan,M. (2010). Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj), *Waste Management*, **30**:912-920.
- Mulgeta H/Mariam, Asegid Getaneh and Kifle Mariam Gashaw. (2007). Geologic Mapping of Addis Ababa, Ethiopian Institute of Geologic Surveys, Addis Ababa, Ethiopia.
- New Landfill Site Selection Task Team (2009). Preliminary Site selection of new Sanitary Landfill for Addis Ababa City and Surrounding Towns, Addis Ababa, Ethiopia.
- Munier, N. (2005). Introduction to Sustainability; Road to a Better Future, Springer, the Netherlands.

- Nishanth,T., Prakash, M.N. and Vijith, H. (2010). Suitable site determination for urban solid waste disposal using GIS and Remote sensing techniques in Kottayam Municipality, India, *International Journal of Geomatics and Geosciences*, **1**:2,197-209.
- Nydick, L.R and Hill, P.R. (1992). Using the Analytic Hierarchy Process to Structure the Supplier Selection Process, *International Journal of Purchasing and Materials Management*, **28**:2, 31-36.
- Osei,J.A., Merem, C.E. and Twumasi,A.Y. (2006). Use of GIS and Remote Sensing Technology as a Decision Support Tool in Land Administration- The Case of Lagos, Nigeria, 5th FIG Regional Conference Accra, Ghana, March 8-11.
- Oštir, K., Veljanovski. T., Podobnikar.T. and Stančič, Z.(2003).Application of satellite remote sensing in natural hazard management: the Mount Mangart landslide case study, *International Journal of Remote Sensing*, **24**: 20,3983-4002.
- Rahman, A. and Netzband, M. (2007). An assessment of urban environmental issues using remote sensing and GIS techniques an integrated approach: A case study: Delhi, India, paper presented on workshop on urban population, Development and Environmental Dynamics in developing countries, 11-13 June, pp25.
- Sanitation, Beautification and Parks Development Agency (2003). Solid Waste Management Status of Addis Ababa: The way forward, City Government of Addis Ababa.
- Sardinia (2005). Proceedings, Tenth International Waste Management and Landfill Symposium.
- Satapathy, D. R., Katpatal, Y. B. and Wate, S. R. (2008) .Application of geospatial technologies for environmental impact assessment: An Indian Scenario, *International Journal of Remote Sensing*, **29**:2,355-386.
- Sharifi, M.,Hadidi, M., Vessali,E., Mosstafakhani, P.,Taheri, K.,Shahoie, S., Khodamoradpour,M. (2009). Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill siting in Kurdistan Province, western Iran, *Waste Management*, **29**:2740-27580.
- Soto, A.S. (2001). Solving a locational distribution problem of non-toxic Solid waste on the island of Puerto Rico, MSc thesis, 1-144.
- Steininger,M., Horning, N. (2007). The Basics of Remote Sensing. Sourcebook on Remote Sensing and Biodiversity Indicators, CBD Technical Series N0.32, pp205.
- Sumathi, R.V., Natesan, U., Sarkar, C. (2008). GIS-based approach for optimized siting of municipal solid waste landfill, *Waste Management*, **28**: 2146-2160.
- Sumiani,Y., Onn,C.C., Mohd Din, A.M. & Wan Jaafar, Z.W. (2009). Environmental Planning Strategies for Optimum Solid Waste Landfill Siting, *Sains Malaysiana* **38**:4,457-462.

- Tamiru Alemayehu, Tenalem Ayenew, Dagnachew Legesse, Yirga Tadesse, Solomon Waltenigus, Nuri Mohammed. (2003). Groundwater vulnerability mapping of the Addis Ababa water supply aquifers, Scientific Report, p.80.
- Themistoklis, D. K., Dimitrios, P. K., Constantinos, P. H. (2005). Siting MSW landfills with a spatial multiple criteria analysis methodology, *Waste Management*, **4**:2,1- 15.
- UNEP (2005). Guidelines for Hazardous Waste Landfill Site Selection and Environmental Impact Assessment in Hyper Arid Areas, Regional Center for Training and Technology Transfer for the Arab States in Egypt (BCRC-Egypt), First Edition, pp 52.
- UNEP (2005). Selection, Design and Implementation of Economic Instruments in the Solid Waste Management Sector in Kenya. USA, New York, pp80.
- UNEP (2005). Solid Waste Management, Volume II: Regional Overviews and Information Sources. USA, New York, pp334.
- UNEP (2005). Training Module. Closing an open Dumpsite and shifting from open dumping to controlled dumping and to sanitary land filling. USA, New York, pp92.
- UNEP (2009). Developing integrated solid waste management plan, Training manual, volume1 Waste characterization and quantification with projections for future, Pp 77.
- UNEP (2005). Solid Waste Management, 1: 1-223
- WHO (1996). Guides for Municipal solid waste Management in Pacific island countries, Healthy cities - healthy islands, Document series, no. 6, pp132.
- Yahaya, S. (2010). Land Fill Site Selection for Municipal Solid Waste Management using Geographic Information System and Multi criteria Evaluation, *American Journal of Scientific Research*, **10**:34-49.
- Zafar, M. and Alappat, B. J. (2005) Landfill Surface Runoff and Its Effect on Water Quality on River Yamuna, *Journal of Environmental Science and Health, Part A*, **39**:2,375-384.
- Zain, T.(2009). Some aspects of solid waste disposal site selection: the case of Wadi Madoneh, Jordan, *International Journal of Environmental Studies*, **66**: 2, 207-219.
- Zamorano, M., Molero, E., Hurtado, A., Grindlay, A., Ramos, A. (2008). Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology, *Journal of Hazardous Materials*, **160**:473-481.