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SOLID WASTE DISPOSAL SITE SELECTION USING GIS AND REMOTE SENSING: FOR MOJO TOWN, ETHIOPIA

BY

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MA THESIS SUBMITTED TO THE DEPARTMENT OF GEOGRPHY AND ENVIRONMENTAL STUDIES, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS IN GEOGRAPHY AND ENVIRONMENTAL STUDIES SPECIALIZATION GIS AND REOMTE SENSING

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Lists of Abbreviations and Acronyms

AHP:	Analytic Hierarchy Process
a.m.s.l:	above mean sea level
CAD:	Computer Assisted Drafting
CSA:	Central Statics Authority
DEM:	Digital Elevation Model
EGSSAA ;	Environmental Guidelines for Small-Scale Activities in Africa
EMA:	Ethiopian Mapping Agency
ERDAS:	Earth Resource Data Analysis System
ETM+:	Enhanced Thematic Mapper+
GIS:	Geographic Information System
GLCF:	Global Land Cover Facilities
GPS:	Global Positioning System
GSE:	Geological Survey of Ethiopia
ha:	hectar
ISWM:	Integrated Solid Waste Management
m:	meter
LU :	Land Use
MCDA:	Multi Criteria Decision Analysis
MCE:	Multi Criteria Evaluation
MOA:	Ministry of Agriculture
MUDC:	Ministry of Urban Development and Construction
UTM:	Universal Transverse Mercator
3D:	Three Dimensional

Abstract

Identifying and managing solid waste dumping sites in an environmentally acceptable manner is one of the major issues facing municipal planners. Land filling is now becoming a common method of waste disposal in Ethiopia even though solid waste dumping is a serious problem in the urban areas because most solid wastes are not dumped in the suitable areas. Mojo Town has the problem of solid waste dumping site identification. The existing solid waste dumpping site for Mojo town is damaging the environment, especially the river called 'Mojo River' due to its location. This study was conducted to assess the existing solid waste management system of Mojo town and to select potential areas for suitable solid waste dumping sites using GIS and Remote Sensing, which are environmentally suitable. The main data used for this study were digital elevation model (DEM), ground control point (GCP) collected by ground point survey (GPS), Landsat image as well as interviews and some observations. The maps were prepared and overlayed as well as suitability analysis were done geographic information system (GIS) and multi criteria analysis methods. The final suitability map was prepared by overlay analyses on Arc map and leveled as highly suitable, moderately suitable, less suitable, and unsuitable areas of the study area were determined. The results indicate that 45.4% of the study area is unsuitable for solid waste dumping; 26.6% less suitable; 22% suitable; and 6% highly suitable. The suggested highly suitable areas for solid waste dumping sites fall on south west and west part of the town where there are least environmental and health risks. The GIS and remote sensing techniques are important tools for solid waste site selection. Hence, the capacity to use GIS and remote sensing technology for the effective identification of suitable solid waste dumping site will minimize the environmental risk and human health problems.

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Waste is a material discharged from each daily human life activities, which leads to adverse impacts on human health and the environment. Solid wastes can be defined as non-liquid and non-gaseous useless products of human activities, like from households, municipal, construction and industries. The generation of solid waste has become a global environmental and health problem in the contemporary world both in developing and developed countries. Increasing population, rapid economic growth, the rise in living standards, expansion of urban and industrial activities accelerates solid waste generation (Tirusew and Amare, 2013).

Urban solid waste management is considered as one of the most immediate and serious environmental problems confronting municipal authorities in developing countries. The most common problems associated with lack of proper management of solid waste include diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses (Mujior, 2008).

As high population growth and high urbanization rates combined with ineffective and under-funded governments to prevent efficient management of wastes municipal solid waste disposal has been an enormous concern in developing countries. Waste management issues should be confronted in a more generalized manner, which means that new strategies need to be designed considering diverse and variable urban models. This demonstrates the necessity of developing integrated, computerized systems for obtaining more generalized and optimal solutions for the management of urban solid waste (Mohammedshum, 2014).

Solid waste disposing is an important part of waste management system, which requires much attention to avoid environmental pollution and health problems. The current global trends of waste management problems are the results of unsustainable methods of waste disposal, which is ultimately a result of inadequate planning and implementation (Abbas, et al., 2011).

In Ethiopia people are using unsafe solid waste disposal practices, such as open damping, burning and burying. As a result, many households practice uncontrolled open dumping and others employ various households solid waste disposal practices such as burning. However, all self-managed waste disposal practices do not guarantee cleanness and safety. For example, burning one's trash can give rise to significant albeit localized, negative externalities, like air pollution depending on how it is burned, local hydrology, and so on.

In city and towns, most solid waste disposal sites in Ethiopia are found on the outskirts of the urban areas where there are water bodies, crop fields, settlements, around roads, and so on. Such inappropriate disposal of solid waste leads to serious environmental pollution and health-related problems, contamination of surface and ground water, soil contamination through direct waste contact, create greenhouse gas emissions and other air pollutants, damage ecosystems, injure people and property, discourages tourism and other business (EGSSAA, 2009). Therefore, locating proper sites for solid waste disposal far from residential areas, environmental resources and settlement is the main issue for the management of solid waste.

Geographic Information System and Remote Sensing are computerized systems that can be integrated to get optimal solutions for efficient and effective solid waste management planning. On the one hand, GIS is a system that helps to capture, store, analyze, manage, and present data that are linked to location(s). It is the merging of computer aided design/drafting (CAD) systems, statistical analysis tools, and database technology that help informed decision making. It is a tool that allows users to analyze spatial information, edit data, maps, and present the results of any spatial and non-spatial based analysis (Mohammedshum, 2014).

1.2 Statement of the Problem

Waste management is a major issue of the global environmental agenda, as population and consumption growth result in increasing quantities of waste. In developing countries, the population of towns is increasing due to both natural increase and migration from rural areas. This high population growth and the activities of development result in the generation of large amount of solid waste which faces problem of their disposal and have potential effect to pollute the environment like water, soil and air. The pollution of these and other resources of the environment affects public health. In Ethiopia, most of the diseases are related to poor environmental sanitation and water contamination (Kumel, 2014).

The solid waste disposal system should be environmentally and socially acceptable to protect the environment and the safety of public health. But selecting appropriate site and managing solid waste dumping in countries like Ethiopia with limited finance and rapid population growth rate is more severe. Degnet (2008) stated that, like in many other developing countries, the majority of inhabitants in most towns of Ethiopia often use unsafe solid waste disposal practices, such as open dumping and burning. Similarly in Mojo town, the study area, there is a problem of solid waste disposal. The problem in the study area is even more severe since the solid waste is disposed in the nearby water body, called Mojo River. This landfill is also very close to agricultural fields as well as it distances less than 100 meter from the main road, which is the Mojo-Shashemene highway.

(a) (b)

Figure 1.1: Open field solid waste disposal along a) Mojo River b) agricultural field (Field survey, 2015).

The above figures (Fig1 a and b) shows that the municipality of Mojo town is not providing proper solid waste management. As Figure 1a shows there is solid waste disposal in the nearby river and Figure 1b shows the landfill is very close to the agricultural field, which is not safe environmentally and economically.

In Ethiopia, for some towns, researchers have conducted studies on land fill sites selection using GIS and remote sensing. For example, Tirusew Ayisheshim and Amare Sewnet by 2013, Kumel Beshir by 2014 and Tsegaye Mekuria by 2006 have conducted studies on land fill sites selection using GIS and remote sensing for Bahir Dar, Wolkite and Addis Ababa respectively. In the study area, there were some studies about how industrial wastes are polluting water resources. But no GIS based study has been conducted on land fill sites selection for the study area. The municipality of Mojo town has selected an open dump site, which is very close to Mojo river, as shown by the above Figure. That is why this project is planned to use the integrated GIS and remote sensing techniques to select solid waste disposal sites. Recently the number of industries and commercial centers in Mojo town are increasing, in which these are the major sources of solid waste in addition to hotels, as well as house-holds in the town. Due to the inappropriate location of the landfill site the river has become almost useless and people working in the nearby agricultural fields and those using the road are suffering from the air pollution. In order to alleviate these problems, integrating GIS and remote sensing techniques, to select the best solid wastes dumping site that is environmentally and socially acceptable, is important. The selection of solid waste disposal sites using GIS and remote sensing requires many factors that should be integrated into one system for proper analysis. This is because remote sensing can provide information about the various spatial criteria such as land use/land cover, drainage density, slope, etc, where as GIS aids utilizing and creating the digital geo-database as a spatial clustering process and easily understood ways for solid waste dumping site selection process. The selection criteria will consider and combine surface water, soil type, slope, settlement, protected areas, land use/cover and road networks.

1.3 Objective of the Study

The main objective of this project was to identify suitable solid waste disposal sites considering environmental, economical and social factors in Mojo town by applying Geographic Information System and Remote Sensing technology. The specific objectives were,

1. To asses existing solid waste disposal system in the study area.
2. To asses factors necessary for selecting suitable landfill sites.
3. To produce map showing suitable solid waste disposal sites.
4. To evaluate the final selected landfill sites.

1.4 Research Questions

1. What does the present solid waste disposal system of the study area looks like?
2. What are the necessary factors shall be considered to select suitable solid waste disposal site?
3. How can the suitable waste disposal sites be identified and mapped?
4. How would the final selected landfill site be evaluated?

1.5 Significance of the Study

This study is expected to select and map suitable solid waste disposal sites to protect the environmental safety of Mojo town. Since unsuitable solid waste disposal sites affect the social and economic activities of communities as well as the health of resources of the study area, like water, the final result of this project will help the town to solve the problems. In addition, the study is also expected to give an insight about the application of GIS and Remote Sensing technologies for the selection of suitable solid waste disposal sites.

1.6 Scope of the Study

The study will be limited in technical aspects for selecting suitable solid waste disposal site in Mojo town. It focuses only in the study of solid waste. The time for the study will be until May 2016.

1.7 Limitations of the Study

In the study area there a plan to construct airport, but the location of this anticipated airport is not identified. Due to this, the paper does not incorporate it as a factor for landfill site selection.

1.8 Organization of the Thesis

This thesis is divided into five chapters. The first chapter provides the introduction to the study including background of the study, statement of the problem, objectives of the study, project questions, scope, significance and limitation of the study. The second chapter presents review of related literatures, mainly including, the concept and types of solid waste management systems, the concept and process of landfill sitting, applications of GIS and RS in landfill sitting and different criteria for landfill sitting. The third chapter deals with the description of the study area as well as the materials and methods employed in the study. The fourth chapter presents the analysis and the final suitable site selected for the study area. Chapter five presents conclusions and recommendations.

CHAPTER TWO

2. Review of Related Literature

2.1 Solid Waste

Waste is generated universally and it is a direct consequence of all human activities. Wastes are generally classified into solid, liquid and gaseous. Solid wastes, the subject of this study, are mainly disposed of to landfill, because landfill is the simplest, cheapest and most cost-effective method of disposing of waste. These wastes can be generated by the full extent of human activities that range from relatively innocuous substances such as food and paper waste to toxic substances such as paint, batteries, asbestos, healthcare waste, sewage sludge derived from wastewater treatment and as an extreme example, high-level (radioactive) waste in the form of spent nuclear fuel rods. Numerous classifications of solid wastes have been proposed and the following represents a simple classification of waste into broad categories according to its origin and risk to human and environmental health (Taylor et al., no date). These includes: household waste, municipal waste, commercial and non-hazardous industrial wastes, hazardous (toxic) industrial wastes, construction and demolition waste, health care wastes – generated in health care facilities e.g. hospitals, medical research facilities);, human and animal wastes and Incinerator wastes.

Household waste represents waste generated at home and collected by municipal waste collection services. Municipal solid waste includes this plus shop and office waste, food waste from restaurants, etc., also collected by municipal waste collection systems, plus waste derived from street cleaning, and green (organic) waste generated in parks and gardens.

2.2 Solid Waste Management System

Solid waste management is the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations, and that is also responsive to public attitudes.

Management of solid waste reduces adverse impacts on the environment and human health and supports economic development and improved quality of life. Descriptions of the main types of solid waste management systems are given in the table below. Poor waste management systems coupled with hot climatic conditions results in increasing environmental problems with significant local as well as global dimension. In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by land filling remains the most commonly employed methods (Debishiree, 2014).

2.2.1. Reduce, Reuse, Recycle

Methods of waste reduction, waste reuse and recycling are the preferred options when managing solid waste. There are many environmental benefits that can be derived from the use of these methods. They reduce or prevent green house gas emissions, reduce the release of pollutants, conserve resources, save energy and reduce the demand for waste treatment technology and landfill space. Therefore, it is advisable that these methods be adopted and incorporated as part of the solid waste management plan.

Waste reduction and reuse of products are both methods of waste prevention. They eliminate the production of waste at the source of usual generation and reduce the demands for large scale treatment and disposal facilities. Methods of waste reduction include manufacturing products with less packaging, encouraging the public to choose reusable products such as cloth napkins and reusable plastic and glass containers, backyard composting and sharing and donating any unwanted items rather than discarding them (Lars,1999).

Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus, from this definition recycling occurs in three phases: first the waste is sorted and recyclables collected, the recyclables are used to create raw materials (Lars, 1999).

2.2.2 Treatment and Disposal

Waste treatment techniques seek to transform the waste into a form that is more manageable, reduce the volume or reduce the toxicity of the waste thus making the waste easier to dispose off. Treatment methods are selected based on the composition, quantity, and form of the waste material. Some waste treatment methods being used today include subjecting the waste to extremely high temperatures, dumping on land or land filling and use of biological processes to treat the waste. It should be noted that treatment and disposal options are chosen as a last resort to the previously mentioned management strategies of reducing, reusing and recycling of waste because these are best method economically as well as in terms of preserving the environment. Lars,(1999), recommended the following solid waste treatment and disposal methods.

Open burning: is the burning of unwanted materials in a manner that causes smoke and other emissions to be released directly into the air without passing through a chimney or stack. Open burning has been practiced by a number of urban centers because it reduces the volume of refuse received at the dump and therefore extends the life of their dumpsite. Garbage may be burnt because of the ease and convenience of the method or because of the cheapness of the method. In countries where house holders are required to pay for garbage disposal, burning of waste in the backyard allows the householder to avoid paying the costs associated with collecting, hauling and dumping the waste Lars,(1999).

Open burning has many negative effects on both human health and the environment. This uncontrolled burning of garbage releases many pollutants into the atmosphere. The particulate matter can be harmful to persons with respiratory problems such as asthma or bronchitis and carbon monoxide can cause neurological symptoms.

The harmful effects of open burning are also felt by the environment. This process releases acidic gases as well as the oxides of nitrogen and carbon. Nitrogen oxides contribute to acid rain, ozone depletion, smog and global warming. In addition to being a green house gas carbon monoxide reacts with sunlight to produce ozone which can be harmful. The particulate matter creates smoke and haze which contribute to air pollution Lars,(1999).

Open Dump: The open dump approach is the primitive stage of landfill development and remains the predominant waste disposal option in most of the African countries. A default strategy for municipal solid waste management, open dumps involve indiscriminate disposal of waste and limited measures to control operations, including those related to the environmental effects of landfills Lars,(1999)**.**

Controlled dumps: Controlled dumps are disposal sites which comply with most of the requirements for a sanitary landfill but usually have one deficiency. They may have a planned capacity but no cell planning, there may be partial leachate management, partial or no gas management, regular cover, compaction in some cases, basic record keeping and they are fenced or enclosed. These dumps have a reduced risk of environmental contamination, the initial costs are low and the operational costs are moderate Lars,(1999).

Operated or Semi-controlled Landfill

Operated dumps implement only limited measures to mitigate other environmental impacts. Operated dumps still practice unmanaged contaminant release and do not take into account environmental cautionary measures such as leachate and landfill gas management. This is especially relevant where leachate is produced and is unconstrained by permeable underlying rock or fissured geology. This issue may be less critical in semi-arid and arid climates, where dumps do not generate leachate in measurable quantities Lars,(1999).

Sanitary landfills: Sanitary landfills are designed to greatly reduce or eliminate the risks that waste disposal may pose to the public health and environmental quality. They are usually placed in areas where land features act as natural buffers between the landfill and the environment Lars,(1999).

In addition to the strategic placement of the landfill other protective measures are incorporated into its design. The bottom and sides of landfills are lined with layers of clay or plastic to keep the liquid waste, known as leachate, from escaping into the soil. The leachate is collected and pumped to the surface for treatment. Boreholes or monitoring wells are dug in the vicinity of the landfill to monitor groundwater quality Lars,(1999).

Bioreactor Landfills: Recent technological advances have lead to the introduction of the Bioreactor Landfill. The Bioreactor landfills use enhanced microbiological processes to accelerate the decomposition of waste. The main controlling factor is the constant addition of liquid to maintain optimum moisture for microbial digestion. This liquid is usually added by re- circulating the landfill leachate. In cases where leachate in not enough, water or other liquid waste such as sewage sludge can be used. These enhanced microbial processes having the advantage of rapidly reducing the volume of the waste creating more space for additional waste, they also maximize the production and capture of methane for energy recovery systems and they reduce the costs associated with leachate management. For Bioreactor landfills to be successful the waste should be comprised predominantly of organic matter and should be produced in large volumes Lars,(1999).

Biological waste treatment

Composting: This is the controlled aerobic decomposition of organic matter by the action of micro organisms and small invertebrates. The process is controlled by making the environmental conditions optimum for the waste decomposers to thrive. The rate of compost formation is controlled by the composition and constituents of the materials i.e. their Carbon/Nitrogen ratio, the temperature, the moisture content and the amount of air Lars,(1999).

Anaerobic Digestion*:* Anaerobic digestion like composting uses biological processes to decompose organic waste. However, where composting can use a variety of microbes and must have air, anaerobic digestion uses bacteria and an oxygen free environment to decompose the waste. Aerobic respiration, typical of composting, results in the formation of Carbon dioxide and water. While the anaerobic respiration results in the formation of Carbon Dioxide and methane. In addition to generating the humus which is used as a soil enhancer, Anaerobic Digestion is also used as a method of producing biogas which can be used to generate electricity Lars,(1999).

2.2.3 Integrated Solid Waste Management

Integrated Solid Waste Management (ISWM) takes an overall approach to creating sustainable systems that are economically affordable, socially acceptable and environmental friendly. An integrated solid waste management system involves the use of a range of different treatment methods, and key to the functioning of such a system is the collection and sorting of the waste. It is important to note that no one single treatment method can manage all the waste materials in an environmentally effective way. Thus all of the available treatment and disposal options must be evaluated equally and the best combination of the available options suited to the particular community chosen. Effective management schemes therefore need to operate in ways which best meet current social, economic, and environmental conditions of the municipality Lars,(1999).

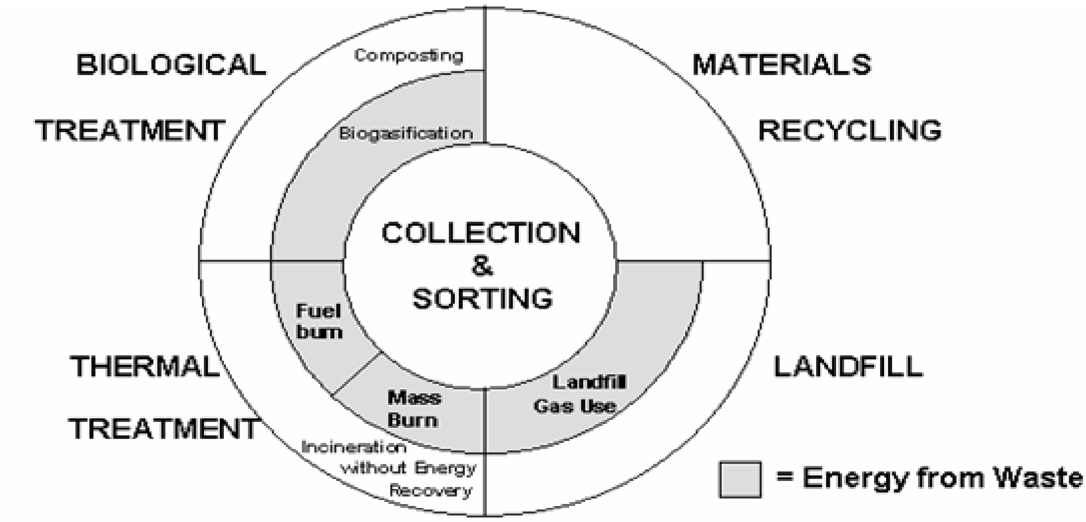

Figure 2.1 Integrated Solid Waste Management

2.3 Solid Waste Management System in Low Income Countries

The open dump approach is the primitive stage of landfill development and remains the predominant waste disposal option in most of Africa countries including Ethiopia. It is a strategy for municipal solid waste management which involve indiscriminate disposal of waste and limited measures to control operations, including those related to the environmental effects of landfills. An operated or semi-controlled dump is often the first stage in a country's efforts to upgrade landfills. Controlled dumps operate with some form of inspection and recording of incoming wastes, practice extensive compaction of waste, and control the tipping front and the application of soil cover. Operated dumps, however, implement only limited measures to mitigate other environmental impacts. Operated dumps still practice unmanaged contaminant release and do not take into account environmental cautionary measures such as leachate and landfill gas management (Lars et al., 1999). But as cities grow and produce more waste and their solid waste collection systems become more efficient, the environmental impact from open dumps becomes increasingly intolerable. The conversion of open or operated dumps to engineered landfills and sanitary landfills is an essential step to avoid future costs from present mismanagement. The first step and challenge in upgrading open dumps to sanitary landfills involves reducing nuisances such as bad smells, dust, vermin, and birds. The term sanitary landfill is generally used for landfills that engage in waste compaction and apply daily soil cover to reduce nuisances.

Generally, in most countries of Africa, the environmental impacts and economic damages of poor solid waste management practices on groundwater and receiving surface waters are becoming a serious issue. This study is also because of the environmental impacts of poor solid waste management practices on surface waters and other resources like crops of the study area.

In low income countries, municipal solid waste management system is either not efficient or as such solid waste generated has become a threat to the environment. The growth in population, urbanization, industrialization and waste generation in the developing countries calls for proper solid waste management as it has become a necessity for environmental conservation and sustainability. For a sustainable solid waste management system policies and techniques such as waste recycling, reuse, waste reduction, thermal treatment, land filling and biological treatment must be in place. The landfill method has been widely recognized as the most used of all waste management techniques (Ayo et al., 2011).

Sitting and designing engineered landfills in low-income countries is a difficult task. Often, affordability of environmental control measures is a key issue. Ideally, objectives for land filling in low-income countries should match corresponding objectives in high-income countries and objectives for landfills serving large towns and cities should be the same as those for landfills serving small villages (Laura, 2003 in Tsegaye, 2006). However, the communities of small towns and villages in low-income countries usually cannot afford landfill design, construction and operation standards equal to those applied in large cities, and in many cases, large cities cannot afford to apply standards equal to those of high-income countries. Perhaps the first question to be addressed when sitting a landfill is: What constitutes an appropriate level of environmental protection for the community? This will differ from community to community and will depend on the climate in the area as well as the available resources for construction and operation of the landfill. Often, construction and operation resources are limited and this must be reflected in the sitting process.

2.4 Landfill

A landfill site, also known as a tip, dump, rubbish dump, garbage dump or dumping ground and historically as a midden, is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common method of organized waste disposal and remain so in many places around the world.

Landfill is an environmentally acceptable disposal of waste on the ground. As Kumel, (2014) notes, many developing countries do not have criteria for landfill site selections and some have regulations of developed countries without modifying to their local conditions. But taking regulations of developed countries without considering local conditions is a problem because the development of engineered landfills involves complex engineering design and construction techniques. These sophisticated engineered landfills can occur where the local economy can afford the high level of expenditure required for construction and operation of the landfill and where the technical resources to achieve high standards of construction and operation are made available. It is therefore important to ensure that when new landfills are sited, the construction and operational capabilities of the local communities are considered in developing sitting criteria so that environmental protection objectives can be met. As Laura, (2003) noted, in addition to available financial and human resources, the composition of the waste differs, and the climate of the area should be considered.

Landfill has been recognized as the cheapest form for the final disposal of municipal solid waste and as such has been the most used method in the world. However, sitting landfill is an extremely complex task mainly due to the fact that the identification and selection process involves many factors and strict regulations. For proper identification and selection of appropriate sites for landfills careful and systematic procedures need to be adopted and followed. Wrong sitting of landfill many result in environmental degradation and often time public opposition.

The sitting of a solid waste landfill must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them (Sumathi, 2007). GIS has been found to play a significant role in the domain of sitting of waste disposal sites. Many factors must be incorporated into landfill sitting decisions and GIS is ideal for this kind of studies due to its ability to manage large volumes of spatial data from a variety of sources (Debishree., 2014).

Land filling is a common solution for the final disposal of wastes in lower-income countries and a large majority of community's practice subsistence land filling or open dumping as their main method of waste disposal. Recently, due to the growing urgency of urban environmental problems, solid waste management in lower income countries has attracted much attention and there is now a movement toward landfills designed to increase environmental protection (Tsegaye, 2006).

Some landfills are used to recover energy. The natural anaerobic decomposition of the waste in the landfill produces landfill gases which include Carbon Dioxide, methane and traces of other gases. Methane can be used as an energy source to produce heat or electricity. These landfills present the least environmental and health risk and the records kept can be a good source of information for future use in waste management, however, the cost of establishing these sanitary landfills are high when compared to the other land disposal methods.

2.4.1 Landfill Sitting

Landfill sitting is difficult task to accomplish because the site selection process depends on different factors and regulations and also because it requires data from diverse social and environmental fields such as water supply sources, land use, sensitive sites and road network. These data often involve processing of a significant amount of spatial information which can be used by GIS as an important tool for land use suitability analysis (Zeinhom El et al., 2010).

Landfill sitting is becoming increasingly difficult due to growing environmental awareness, decreased amount of governmental and municipal funding with extreme political and social opposition. The increasing of population, public health concerns, and less land available for landfill construction adds more difficulties to the problem to overcome. Environmental factors are very important to be considered in such work due to the fact that landfill might affect the biophysical environment and the ecology of the surrounding area. Several techniques can be found for site selection of solid waste disposal. Such sitting techniques combine multiple criteria decision analysis (MCDA) and GIS. The result of these techniques is the evaluation of the suitability for the entire study region based on suitability index, which is useful in order to make an initial ranking of the most suitable areas (Mohammad et al., 2014).

Landfill site selection in an urban area is a critical issue because of its enormous impact on the economy and the environmental health of the region and many sitting factors and criteria should be carefully organized and analyzed.

One of the complicated steps is locating of waste landfill sites have precise steps including site selecting and preparation of waste landfill site. If these landfill sites are near the individual's work place or living places, it is considered as a negative outcome and it may cause irreparable consequences to human life (Seiied, 2015).

Sitting a sanitary landfill requires an extensive evaluation process in order to identify the optimum available disposal location. Therefore, the sitting of a solid waste landfill must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them. GIS has been found to play a significant role in the domain of sitting of solid waste disposal sites. Many factors must be incorporated into landfill sitting decisions and GIS is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. The integration of GIS and Analytical Hierarchy Process (AHP) is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and AHP supplies consistent ranking of the potential landfill areas based on a variety of criteria (Debishree et al., 2014).

2.5 Application of Remote Sensing and GIS for Landfill Site Selection

2.5.1 Application of Remote Sensing for Landfill Site Selection

Remote sensing is the science and art of obtaining information about an object or area without physical contact. Remote sensing is one of the incomparable tools for sensing the earth surface to make the interface of object property and measurement analysis as well as inventory of environment and its resources, and has a unique ability of providing the synoptic view of a large area with the capacity of repetitive coverage (Shweta . 2013). Using remote sensing images like satellite images or aerial photographs we can have information about the resources of the environment. From the application of remote sensing, landfill sitting is the one that satellite images are used for extracting the criteria used for landfill sitting such as land use land cover identification.

Its multispectral capability provides appropriate contrast between various natural features where as its repetitive coverage provides information on the dynamic changes taking place over the earth surface and the natural environment. When remotely sensed data are combined with other landscape variables organized with in a GIS environment provides an excellent frame work for data capture, storage, synthesis, measurement and analysis. For assessing a site as a possible location for solid waste disposal, several environmental and political factors and legislations should be considered (Subhrajyoti et al., 2012).

One of the most applications of remote sensing in solid waste landfill sitting is where remote sensing data like satellite images are used for extracting landfill sitting criteria (example; land use land cover, geology and surface water with saving time and cost.

2.5.2 Application of GIS for Landfill Site Selection

GIS is a digital database management system designed to manage large volumes of spatially distributed data from a variety of sources. It is ideal for preliminary site- selection studies because it efficiently stores, retrieves, analyzes and displays information according to user-defined spec-ifications. Once a GIS database is developed it can provide an efficient and cost effective means of analyzing potential landfill site attributes (Mohhamed . et al., 2015).

GIS is a powerful tool that can integrate different types of spatial data and perform a variety of spatial analysis. This evolution has been driven by significant advances in computer technology and the availability and quantity of data. GIS and environmental models functioning with a board spectrum of geospatial data are usually used for divers applications and spatial analyses at different scales (Mohammad et al., 2014).

GIS plays a significant role in the domain of sitting of waste disposal sites. Many factors must be incorporated into landfill sitting decisions and GIS is ideal for this kind of studies due to its ability to manage large volumes of spatial data from a variety of sources. GIS is a powerful tool to solve the landfill site selection problem, because GIS provides efficient tools for the manipulation and presentation of the data (Debishree, 2014). People can evaluate the locations of different things in order to ascertain there relation in terms of spatial attributes and its planning and operations are de-pendent on spatial data. GIS is useful to reduce the time and cost of the site selection and also pro-vide spatial data related to positions from different things so people can more easily find out the crite-ria for site suitability (Shewta ,. 2013). Even though landfill sitting is time taking process, GIS reduc-es time and cost as well as provides digital data for future monitoring program, using the effective capturing, storage, management, retrieval, analysis and display capabilities.

The Geographic Information Systems in solid waste management enables people to evaluate the locations of different things in order to ascertain there relation in terms of spatial attribute and its planning and operations are dependent on spatial data. GIS techniques provide spatial data related to positions from different things so people can more easily find out the criteria for site suitability (Shweta ,. 2013).

Application of GIS technique in the field of waste management using a multi-criteria decision making technique provides the organized approach for assessing and integrating the impact of various factors as indicators of suitability (Shweta . 2013).

Generally, GIS in solid waste management not only save time and cost of design and spatial analysis of site selection, but also provides a digital data bank for future monitoring of the sanitary landfill site. (Zeinhom et al.,2010).

2.6 Multi-Criteria Decision Analysis (MCDA)

Multi criteria analysis is a set of mathematical tools and methods, like weighing, to compare different alternatives according to the criteria. Multi-criteria decision analysis (MCDA) helps to rank potential landfill sites using different criteria -such as soil suitability, habitat effect, flood resistance, property costs, distance from population center, and others by measuring the relative importance weight for individual evaluation criteria (Zeinhom El et al,.2010). The MCDA methods were developed in the 1960s to address problems and assist decision makers in decision-making with various options. Multi-criteria approaches have the potential to reduce the cost and time involved in sitting landfills by narrowing down the potential choice based on defined criteria and weights.

Analytical Hierarchy Process (AHP), one of the methods of MCDA, is a conventional land suitability analysis method that provides right decision-making approach for site selection. AHP has been integrated with GIS for land suitability modeling when selecting the best alternatives from a pool of various possibilities in the presence of multiple criteria. This technique provides a means of decomposing the problem into a hierarchy of sub-problems that can be more easily comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values that are ranked on a numerical scale (Debishree et al., 2014).

Combination of GIS and multi criteria evaluation (MCE) has been routinely adopted as an approach to assess the suitability of an area to host a landfill. Taking into account both technical elements and people's values and perceptions is essential to build consensus around a decision, to reduce conflicts, and consequently to pave the way to successful landfill sitting interventions. Spatial MCE is commonly applied to land suitability analysis and specifically to landfill site selection (Tayyebia et al., 2010).

2.7 The Site Selection Process

According to Taylor et al.,(2003), site selection using GIS technology process requires a two stages. The first is the GIS stage, which involves two primary screening steps leading to the identification of target areas for the location of landfills, and a secondary screening step in order to identify suitable individual sites, utilizing output from the previous steps, and involving more detailed local information and site-specific analysis. Secondly, geotechnical evaluation stage, involving a rigorous geological/ hydro-geological assessment of individual sites identified within the target areas, employing a combination of site investigation and laboratory techniques.

2.7.1 Landfill Site Selection Process

Landfill site selection is an important step in implementing a waste management program. Proper sitting can contribute to a reduction in design, construction, and operating costs, as well as help to minimize environmental impacts. Lawrence (1996) in Tsegaye, (2006) identified three major sitting approaches: the environmental suitability approach, the social equity approach and the community control approach. Each of these approaches can be applied in a variety of ways since they influence the success of landfill sitting. These three approaches are described as follows:

Environmental Suitability Approach: The goal of this approach is to minimize the negative and maximize the positive environmental effects of projects like landfill sitting. There are typically three major stages in this approach namely: area screening and identification; site screening and identification and finally site comparison. There are many different qualitative and/or quantitative evaluation methods that can be used for screening and comparing site alternatives. (Tsegaye, 2006).

Social Equity Approach: This approach focuses on fairness in the planning process, and a fair distribution of facilities, costs and benefits among stakeholders. Direct involvement of all interested and affected parties is considered essential. Equity concerns have only recently been incorporated into landfill sitting processes (Tsegaye, 2006).

Community Control Approach: Proponents of the landfill and community groups work together to make decisions. There are various ways in which the community can have control over the process: procedural control on the structure and implementation of the sitting process; location control, or the freedom to choose whether or not to accept a site; and facility control, the control over the need for, size and operation of a facility (Tsegaye, 2006).

2.8 Steps in Landfill Sitting

The following flow chart provides an overview of the steps in the landfill sitting process.

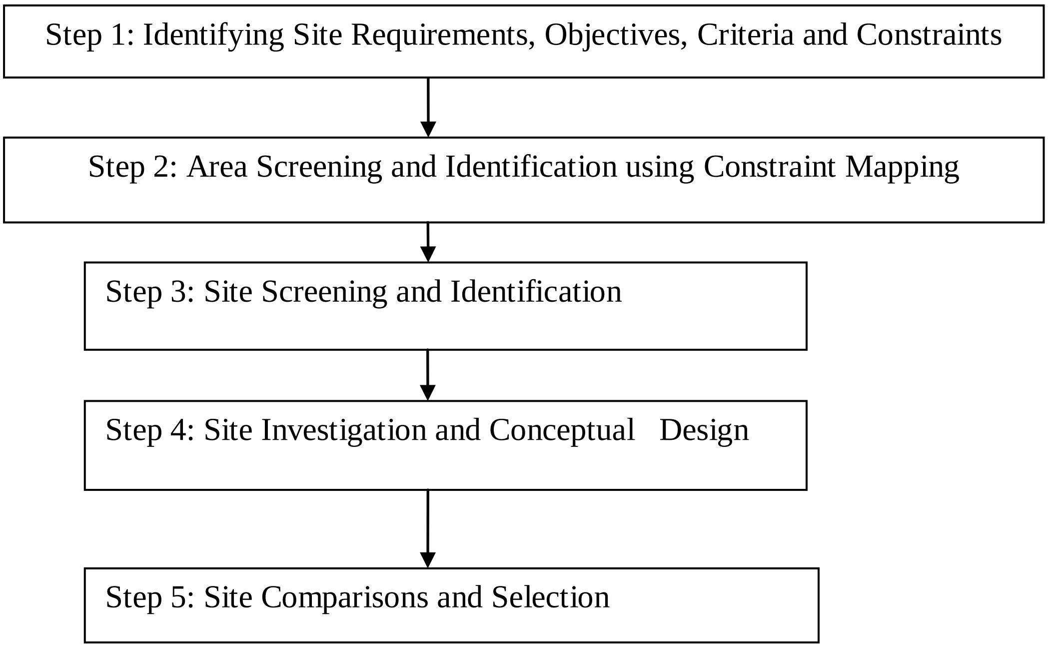

Figure2.2; Steps in Landfill Sitting (Tsegaye, 2006)

Step 1: Identify Site Requirements, Objectives, Criteria and Constraints

The first step in the process is to identify landfill site and size, which are requirements and determine the objectives, constraints and criteria to be used in the process. Objectives like to minimize the risk of groundwater contamination, to maximize the depth to the water table with a constraint that the water table must be, for example, 1.5 m below the base of the landfill. Once the criteria and constraints are established, the data requirements can be determined. These are for giving insight, but there are also additional necessary criteria for this study.

Step 2: Area Screening and Identification Using Constraint Mapping

Constraint mapping is a commonly used technique that involves creating a series of maps to show the areas identified as unsuitable for land filling based on each of the constraints. When the maps are overlaid, the potential candidate sites can be easily identified. An important element of a successful landfill sitting process is evaluating the basic suitability of all available land for land filling to aid in the selection of a limited number of potential sites for more detailed evaluations. The resources and constraints of the government agencies involved in the process should be taken into consideration. The following are some of examples of typical constraints relating to water resource protection, as the current open field solid waste disposal site is affecting water resource the study area.

• Water bodies (lakes, streams) are not suitable for landfill development.

•Areas with complex geology are not suitable as it will be difficult to monitor and remediate in the event of groundwater contamination.

• Landfills should not be sited in protected areas such as forests and endangered species habitats.

. Landfills should not be close to urban landscapes.

• Landfill should not be constructed in the floodplain of a river or other areas susceptible to frequent flooding.

Step 3: Site Screening and Identification

In this step, the areas identified from the constraint analysis are evaluated and compared in order to identify potential sites suitable for land filling. The objective is to reduce the number of sites to an appropriate number for detailed comparison in the next step. Reducing the number of an appropriate sites important for the next step, in which each site will require detailed data collection, which is time consuming and expensive. The data used to compare and evaluate the sites in this step is usually based on published data from concerned offices and walk over or field surveys are required. Walkover surveys may not be required if published sources provide enough data for site comparison.

Step 4: Site Investigation and Conceptual Design

In this step, detailed data are collected for each candidate site and basic designs are completed. Site investigations should be designed to confirm published data, and collect data required measuring how well each site meets the criteria. To fully understand how each site may affect water resources, subsurface exploration and topographic surveys are carried out at the candidate sites. Designs are then completed to the point where approximate cost estimates can be made for comparative purposes.

Step 5: Site Comparisons and Selection

This step involves a detailed evaluation and comparison of the candidate sites. This requires comparing data collected from site investigations and published sources, and conceptual designs to determine which site best meets the criteria. Often, this is achieved by weighting and rating criteria. The weight of each criterion is determined according to its relative importance and each site is rated for each criterion. The method used for rating does not necessarily need to be the same for all criteria. Numerical ranking such as a scale of 1 to 9, or a qualitative ranking such as high, medium or low can be used.

2.9 Criteria used for waste disposal site selection

Selection of site is a very important process for a successful operation of waste disposal using landfill method. Landfill involves an extensive evaluation process in order to identify the optimal available disposal location. This location must satisfy basic government regulations, and also take into recognizance how to minimize factors on health, economic, environmental and social cost. In fact, different researchers have used varying criteria for site selection purposes due mainly to the fact that different criteria applies to different region and all facilities (Ayo et al., 2011).
The following criteria are often used for solid waste disposal site selection

i. Distance from Settlement: The landfill site should not be placed near a residential or an urban area, to avoid adversely affecting land value and future development and to protect the general public from possible environmental hazards released from landfill sites. In the same time, it should not be located too far to avoid extra transportation costs and environmental pollution. The safe distance from settlements is determined as 1500 m (MUDC, 2012).

ii. Land slope: landfill site should have a gentle incline to avoid soil erosion and limit expenditure on cleaning and maintaining drainage system components. The land with a slope less than 10% is highly suitable for solid waste dumping (MUDC, 2012 and Tirusew et al., 2013).

iii. Proximity to Water bodies: to maintain the environmental health of water sources at least 500 m buffered distance should be ringed through straight line calculation (MUDC, 2012).

iv. Distance from roads network: landfills shall not be located within 400 m of any major highways and city streets and also should not be placed too far from existing road networks, to avoid the expensive cost of constructing connecting roads (Issa, 2012 and MUDC, 2012).

v. Protected areas: the landfill should not be located within 1000m distance of sensitive areas like churches, mosques, parks, schools and memorial sites (MUDC, 2012).

vi. Land use and land cover type: The land cover and use is the natural and human landscape that exposed by the threats imposed because of landfill adjacency and it is advisable to select land, which is occupied by bare and grass lands for solid waste disposal(MUDC,2012 and Tirusew et al., 2013).

vii. Soil Type: It is recommendable that the soil of the selected site has good natural impermeability in order to reduce the possibility of aquifer contamination. The soil of the selected site should be clayey (MUDC, 2012).

CHAPTER THREE

3. Description of the Study Area and the Research Methods

3.1 Description of the Study Area

3.1.1 Geographic Location

Mojo town is an administration center of Lome Woreda and industry town of East-Shewa zone, which is part of Oromia region. It is found to south east of Addis Ababa at a distance of 70km. The total area of the town is 4532 hectar. Geographically the study area lies within the coordinates between 08°39'00"- 08°65'00"North and 39°5'00"- 39°83'00" East with a range of altitude from 1751 to 1805 meter amsl. Mojo town is located to the south east of Bishoftu town, North West of Adama town, north east of Liben woreda and south of Ejere town. It is located along Addis Ababa-Adama and Addis Ababa Shashemene highway.

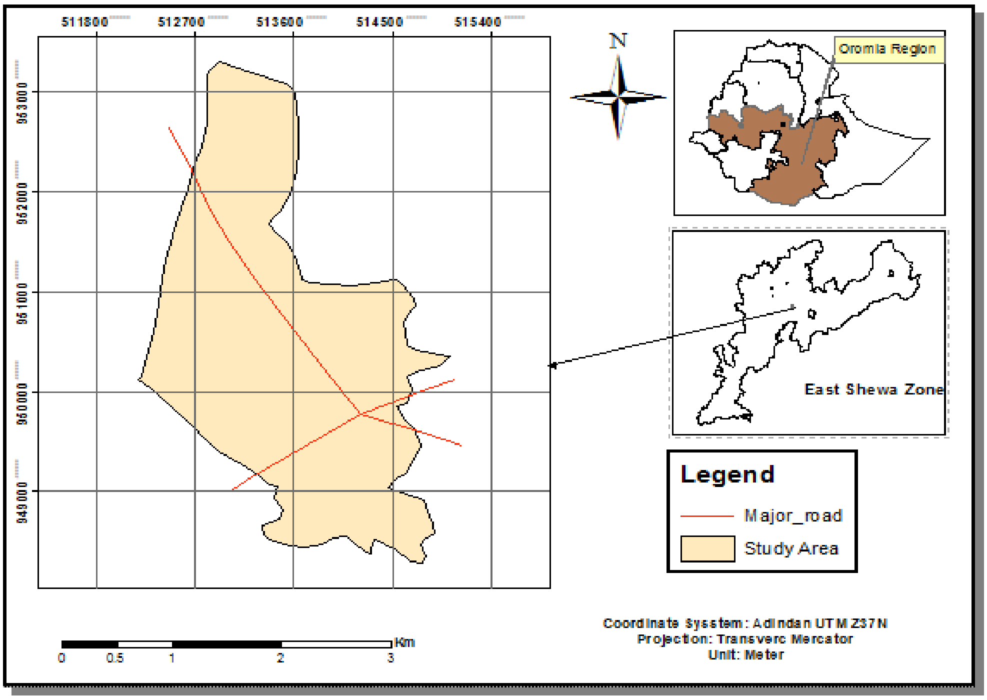

Figure 3.1: Location map of the study area, 2016

3.1.2 Climate

The study area is mainly arid and semi-arid with hot temperature for most of the year. The climate of Mojo town is characterized by four distinct seasons. The main wet season extends from June to August, short rainy season locally known as tsedey extends from September to November, Dry season locally known as bega extends from December to February and a little rainy season locally known as belg extends from March to May. Generally, according to the traditional climate zone classification Mojo town is grouped under Woina dega climatic zone. According to the meteorological data, the mean monthly temperature of the town for the last three years (i.e 2013- 2015) was 20.2 ^{o}c. The minimum and maximum temprature was 6.8 ^{o}c and 31.8 ^{o}c respectivelly.

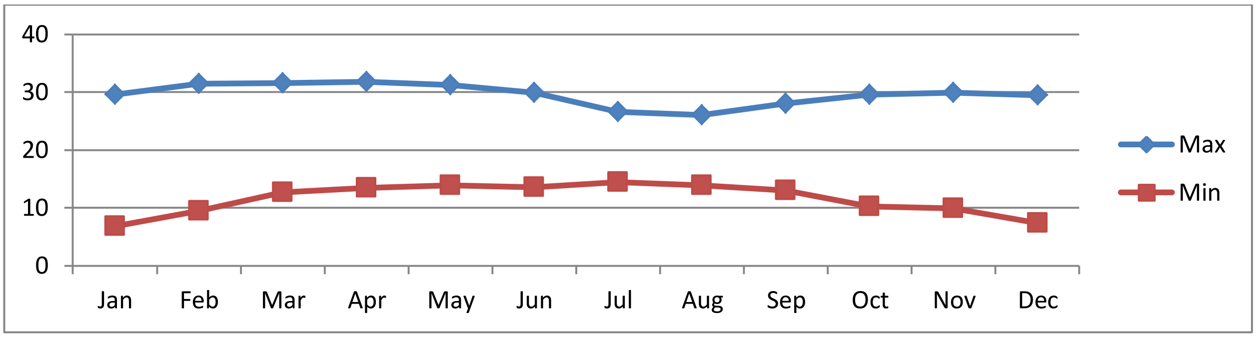

Figure 3.2: Average monthly maximum and minimum temperature of Mojo town (Ethiopian Meteorological Authority, 2016)

According to the meteorological data, the mean monthly rain fall of the town for the last three years was 79 mm, the highest record of precipitation was 420 mm and the lowest was 5.9 mm. As the data shows December and January are driest months while July, August and September are the wettest months.

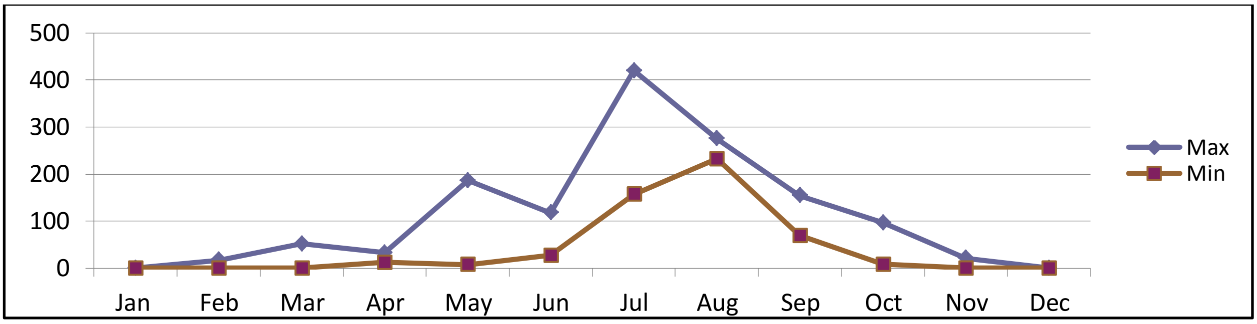

Figure 3.3 Average monthly maximum and minimum rainfall distribution of Mojo town (Ethiopian Meteorological Authority, 2016).

3.1.3 Topography and Water Resources

Topography shows the patterns of land features of the area. The topography of Mojo town is characterized by plain surface with an elevation ranging from 1750m to 1803m amsl. Mojo town has an elongated shape that extends from north to south. Elevation is the criteria that show topography of the area. The elevation of Mojo town in this study was generated from DEM of the town, using Spatial Analyst tool of Surface extension.

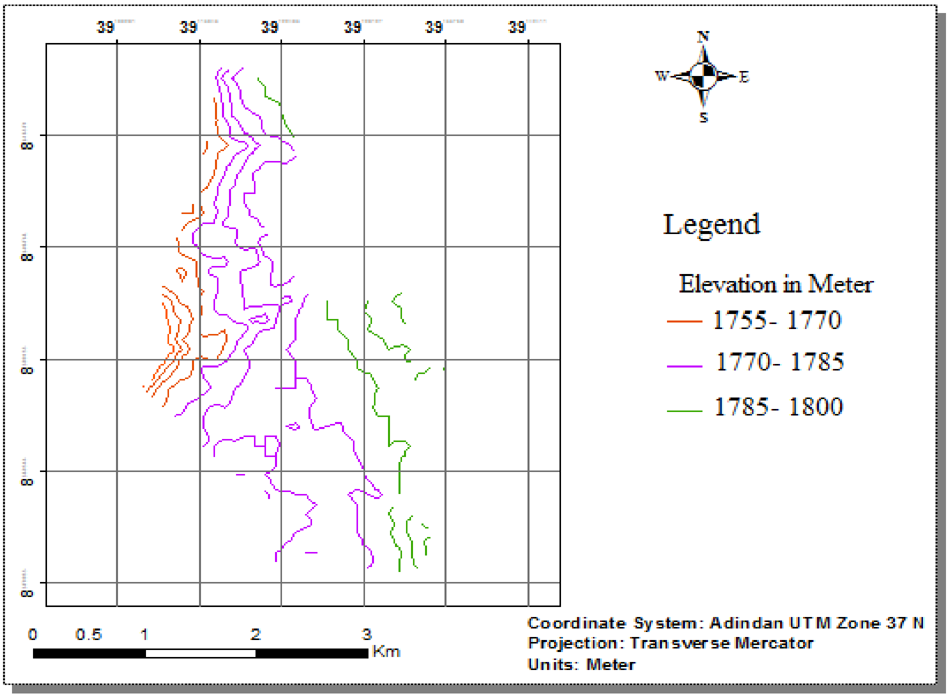

Figure 3.4 Elevation Map

Slope: Slope refers to the slants of downward or upward of ground. It is an important criterion to select suitable landfill sites. The more the steep slope the most unsuitable and gentler slope the more suitable. An area with steeper slope contributes to erosion and increases construction costs.

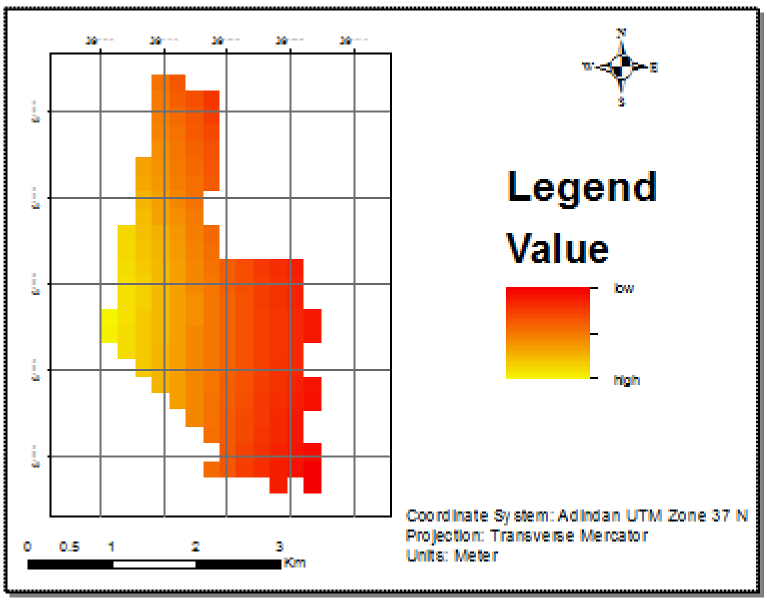

Figure 3.5 Map of Slope

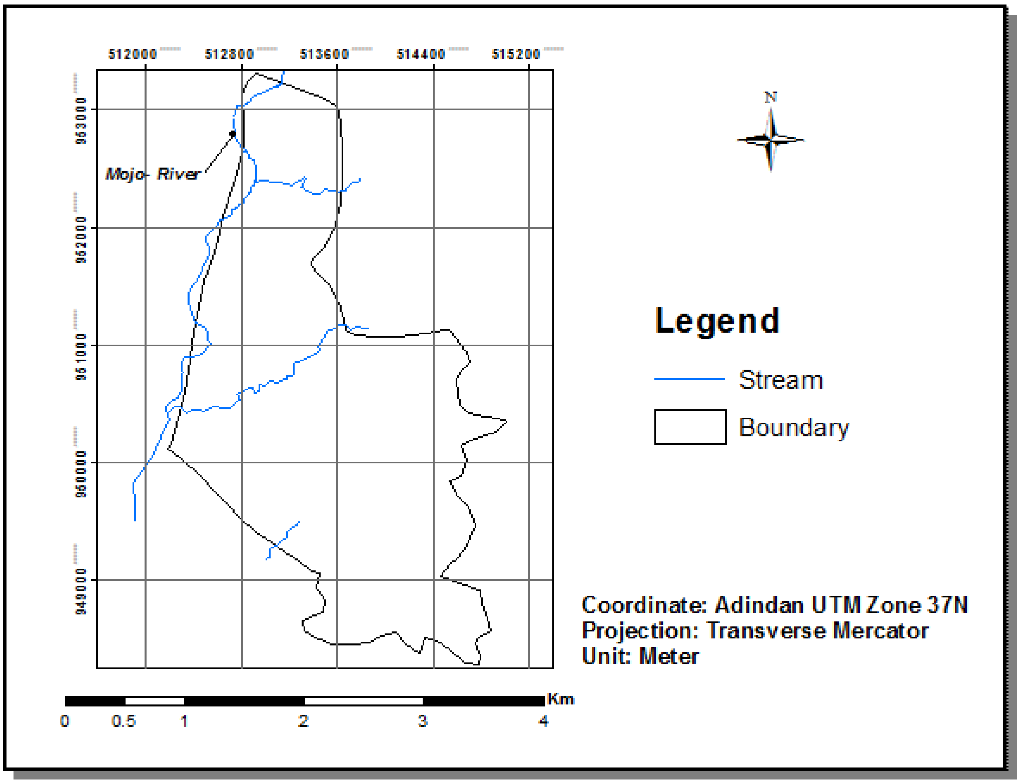

Figure 3.6 Stream Map of the Study Area

Surface water in the study area are streams, and there is one major and permanent river called Mojo River, originated from the northern highlands of North Shewa zone, like Gango, Ruketi and Titti. This river flows from North to south west and there are also some tributary streams flows from east to west.

3.1.4 Socio-economic Characteristics

Population: According to CSA, 2007, total population of the town was 28,064; of which 15,119 (53.8%) were male and 12, 945 (46.2%) were females. The current population size (2015) of the town is expected to be 41,360, of which 22,291 male and 19,069 female.

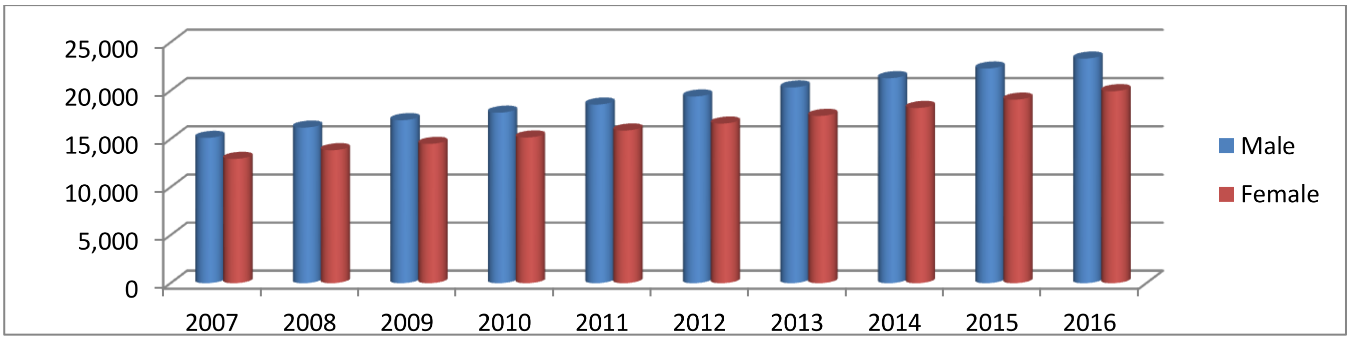

Figure 3.7 Population distributions Graph

Economic Characteristics: Economically most of the residents in Mojo town are engaged in trade activities and as employees of industries. Agriculture and handcrafting are also economic sources for some residents.

Mojo town is accessible with different infrastructures like road, water and electricity supply, education, bank, health services and telephone services. Transportation service in the town is highly accessible for neighbouring towns. The major highway networks connect the town with Addis Ababa city, Adama town and Shashemene town. The town was also accessible with the first Addis Ababa-Djibouti rail road, in which these days it is not functioning.

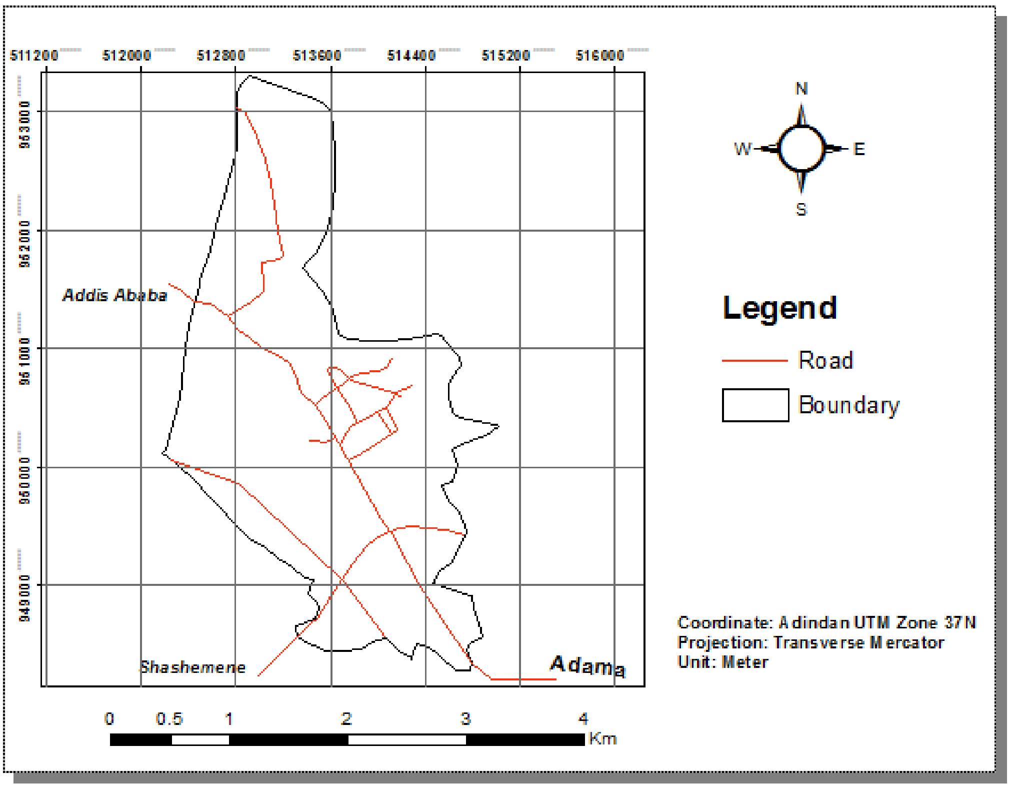

Figure 3.8 Road Network Map

3.2 Sources of Data

This study used both primary and secondary data types. Accordingly, necessary data were collected from primary and secondary data sources.

3.2.1 Primary Data

Ground control points are from the primary data types that were used in this study. During field survey points to identify public facilities like schools and health centers as well as protected areas like churches and mosques were collected using GPS. In addition some sample points from different land use/ cover types were also collected to update the current land use/ cover type of the study area. Photographs and field observations were also used to show the existing land fill site. Satellite images were also some of the primary data types used to show the character of LU in this study. Interviews with experts of environmental protection officers and residents who are near to the existing landfill were made to get more information. The results from interviews were used to identify the problem of existing landfill in the study area.

3.2.2 Secondary Data

Different factor maps that help to select suitable landfill site were used. These includes: road network map of Mojo town, soil map of the study area, land use land cover type of the study area, DEM of Mojo also helped to derive the slope, counters and drainage and topographic maps of the study area, which are very important for further analysis to select suitable landfill.

Table3.1. Source and type of Secondary data

No_	Type of Data	Source of Data	Soft ware Used
1	Road network map	Landsat ETM+ 1999	ArcGIS 10.1
2	Soil map	Ministry of Agriculture	ArcGIS 10.1
3	Land use /land cover type	Landsat ETM+ 1999	ERDAS Imagine 2013
4	Slope and Elevation	SRTM	ArcGIS 10.1
5	Topographic map	Ethiopian Mapping Agency	ArcGIS 10.1
6	Stream network	DEM	ArcGIS 10.1
7	Meteorological Data	Ethiopian Meteorological Agency	Microsoft Excel

3.3 Methods

There are different methods of GIS operation for suitability analysis. Methods like buffering, overlay, digitizing, spatial analysis and AHP were the major ones used in this study to select suitable landfill sites.

3.3.1 Buffering

Buffer operation refers the creation of a zone of a specified width around a point, a line or a polygon area. It is also referred to as a zone of specified distance around coverage features. Buffering is one method of spatial analysis called proximity analysis. It is used to produce areas of a given distance around specific criteria that used to select suitable solid waste disposal site. The features that were buffered in this project include: road, dry port, settlement, surface waters, schools, health centers, churches and mosques.

3.3.2 Overlay

Overlay analysis often requires the analysis of many different factors that are necessary for landfill sitting. In overlay analysis, it is desirable to establish the relationship of all the input factors together to identify the desirable locations for landfill. For this study, all the weighted factor maps were overlaid using weighted overlay extension of spatial analyst tool. In this combination approach, it is assumed that the more favourable the factors, the more desirable the location will be. Thus, the higher the value on the resulting output raster, the more desirable the location will be.

3.3.3 Multi-criteria Decision Making (MCDM)

Multi criteria analysis is a process that transforms geographical data into decision. MCDM is a set of mathematical tools and methods, like weighing, to compare different alternatives according to the criteria. The main components for MCDM are human value judgment and assessment of criteria, to rank potential landfill sites using different criteria (Zeinhom et al,. 2010).

3.3.4 Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Saaty (1977). AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives among which the best decision is to be made. AHP generates a weight for each evaluation criterion according to the decision maker's pair wise comparisons of the criteria. The comparison is about whether the row criterion is equal, greater or lower importance that the column criterion and the higher the weight, the more important the corresponding criterion. The reciprocal values (1/3, 1/5, 1/7, 1/9) have been used when the row criterion is less important than the column criterion. AHP also provides measure to determine inconsistency of judgments, in which the CR should be less than one.

3.4 Conceptual Framework of the Analysis

The general workflow of this study includes four major steps. The first was identifying factors to be used to identify best location for solid waste landfill and producing maps for each. Secondly, assigning weight for the selected factors. The third was overlaying and generating landfill suitability map and finally, determining suitable areas for landfill. The detail of conceptual framework is shown in figure 3.9.

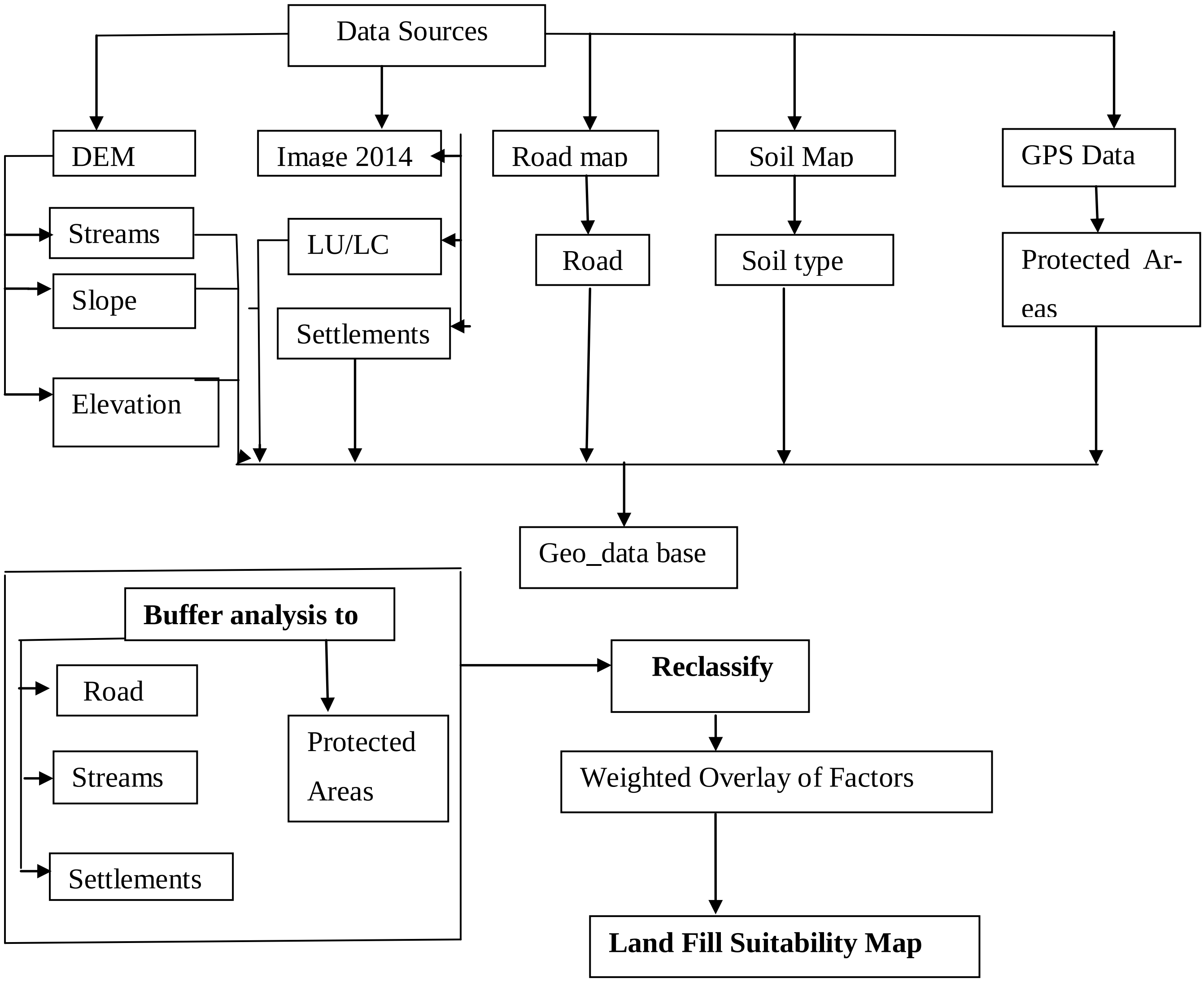

Figure 3.9 General work flow of the study

CHAPTER FOUR

4. Data Analysis, Result and Discussion

This part discusses the analysis and presentation of different data sets that were used to select suitable solid waste disposal sites. In this study, suitable sites were determined for Mojo town's solid waste landfill by using the GIS capability and weighting product of AHP method.Landfill must be situated and designed so as to meet the necessary conditions for preventing pollution of the groundwater or surface water and other resources. Similarly, a landfill site should be kept as far away as possible from population density, for reducing impact on public health. On the other hand, the landfill site should be placed not much far from existing roads for saving road development, transportation, and collection costs. Furthermore, difficult or steep terrains are not appropriate for hosting landfills.

For this study nine suitability criteria (distance from settlement, protected areas, roads network, surface water, ground water, soil type, geology, urban land use type and land slope) were used based on the relevant Ethiopian Environmental Protection Regulations, in addition to international practices that account for environmental, economic and social factors. Maps were created for each suitability criterion and the final composite map was finally produced by simple overlaying of the individual maps. The layers, buffer zones used, rankings and layer's weights were summarized using tables. The weights were assessed by taking into account the possibility of modifying the natural conditions of the sites so as to increase their suitability**.**

4.1 Solid Waste Management System in Mojo Town

The first objective of the research was to assess the present waste management strategies in Mojo town. This objective was achieved through field observation and interview with experts of Environmental Protection department of Mojo town. The result showed that the municipal of the town together with the land administration office selected and prepared the existing open dumping site based on the criteria only distance from center of the town. According to the observation and interview, the existing solid waste disposal system is not satisfactory, because the existing site does not consider major environmental and health factors, like distance from water bodies, agricultural fields and settlement. The residents near to the existing open dump site are suffering from air pollution and due to pollution of the river they cannot use for animal feeding and irrigation too.

For collecting and transporting the solid wastes the environmental protection department gave contract to one association. The collectors gather the waste from houses and other institutions twice per week and transport it to dumping site using trucks. In many towns of Ethiopia, there are temporary garbage’s (Gedna’s) at different distances, serving to put solid wastes after collecting from different sources. Since many of these are near to the settlement, this is a serious problem on human health. But in the study area, Mojo town, solid wastes are dumped in the existing site immediately after collected from sources.

As the town is becoming an industry zone, the municipality did not give medal attention to sustainable solid waste disposal and management system. Solid waste management is currently receiving wide attention in many towns of Ethiopia, especially in the study area where solid wastes are from abattoir, from industries like leather, textile; this is mainly because solid wastes that are generated in most towns of Ethiopia are not appropriately handled and managed. However, it is possible to minimize and solve these problems through planning and implementing different municipal solid waste management components. Unsuitable and not manageable site of landfill lead to serious contamination to the environment, for instance surface water and air pollution, which have negative effect and considered as threat to residents. In the study area, surface water and air pollution are the main problems. However, the negative impacts from landfill can be minimized through selecting an appropriate site, which minimize potential environmental impact and GIS and RS techniques are effective for the purpose.

Open solid waste disposal at the study area

In the town 90% of solid waste collected from residences, institutions and asphalt roads, abattoir as well as industries is disposed in open field which is very close to the main river, crop field major road. Solid waste that disposed in the open field close to the river contaminates the river highly because runoff and wind since the slope towards the river is steep.

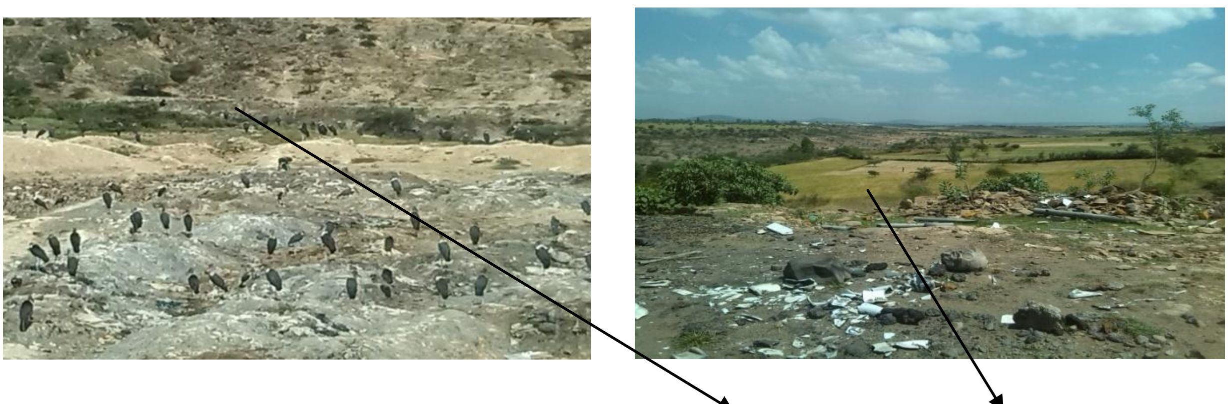

Figure 4.1: Open field solid waste disposal along a) Mojo river b) agricultural field (Field survey, 2015).

Illegal solid waste disposal in the study area

About 10% of generated solid wastes in the town are disposed illegally in any open spaces.

Figure 4.2 Illegal Solid Waste Disposals

The above figure revealed that the inefficient solid waste management at Mojo town. Even though the municipality of Mojo town attempted more in planning and implementing, there is failure in lack of commitment from contractors. Sometimes they may not collect solid wastes from all sources due to this most of the dwellers drop the waste anywhere illegally.

4.2 Land Fill Site Selection Criteria

As stated in chapter two, the first step landfill sitting process is identifying site requirements or criteria. Since the main objective of this study is selecting suitable landfill site, criteria used should minimize surrounding environmental, economic and social impacts. The following criteria were used to meet the above objectives.

Table 4.1 Landfill Site Selection Criteria

N_o	Spatial Data	Layer Name	Criteria
1	Surface water	Stream	1000 meter away
2	Road Network	Road	between 1000- 2000 meter
3	Slope	Slope	less than 10 %
4	LULC Type	LULC	barren land and area covered by grass lands
5	Settlement	Settlement	1000 meter away
6	Soil type	Soil	Clayey soil
7	Protected areas	Protected Areas	1000 meter away

Source: Ministry of Urban Development and Construction, (2012)

4.3 Topographical Factor

Topography shows the patterns of land features of the area. Slope is topographical factors in determining the suitability of landfill sites.

Slope: slope is an important factor in suitable site selection process, because slope determines the amount of runoff in the site. In this study, slope of the study area was generated from DEM using Arc-GIS spatial analyst extension of surface tool. Then the slope raster was reclassified into four classes of slope percent. The reclassified slope was ranked from 1 to 4, as 4 is highly suitable and 1 is for the least suitable for site selection.

Table 4.2 Slops Suitability Class

Suitability Class	**Level of Suitability**	**Rank**	**Area (ha)**	**Percentage of total area**
<10%	Highly suitable	4	4047.08	89.3
10-13%	Moderately suitable	3	217.54	4.8
13- 16%	Less Suitable	2	145.01	3.2
>16%	Unsuitable	1	122.37	2.7
Total			4532	100

This study considered the lower slope more highly suitable than the land with higher slope. Different research shows that areas with high slopes will have high risk of pollution and potentially not a good site for dumping.

As the slope becomes steeper the area should be considered as least suitable. According to Tirusew et al., (2013); the type of slope for landfill site should be gently, less than 10%. The majority of the study area falls under the slope class of 0-10%, covering 89.3% of the total study area, which is highly suitable for solid waste dumping. Depending on this, most of the land is suitable for solid waste disposal site. Whereas 4.8%, 3.2% and 2.7% of the study area was covered by slope classes 10-13, 13-16 and >16% respectively. This shows that slope is not a significant problem for solid waste dumping site selection in Mojo town. This means that the town is more or less flat in its topography.

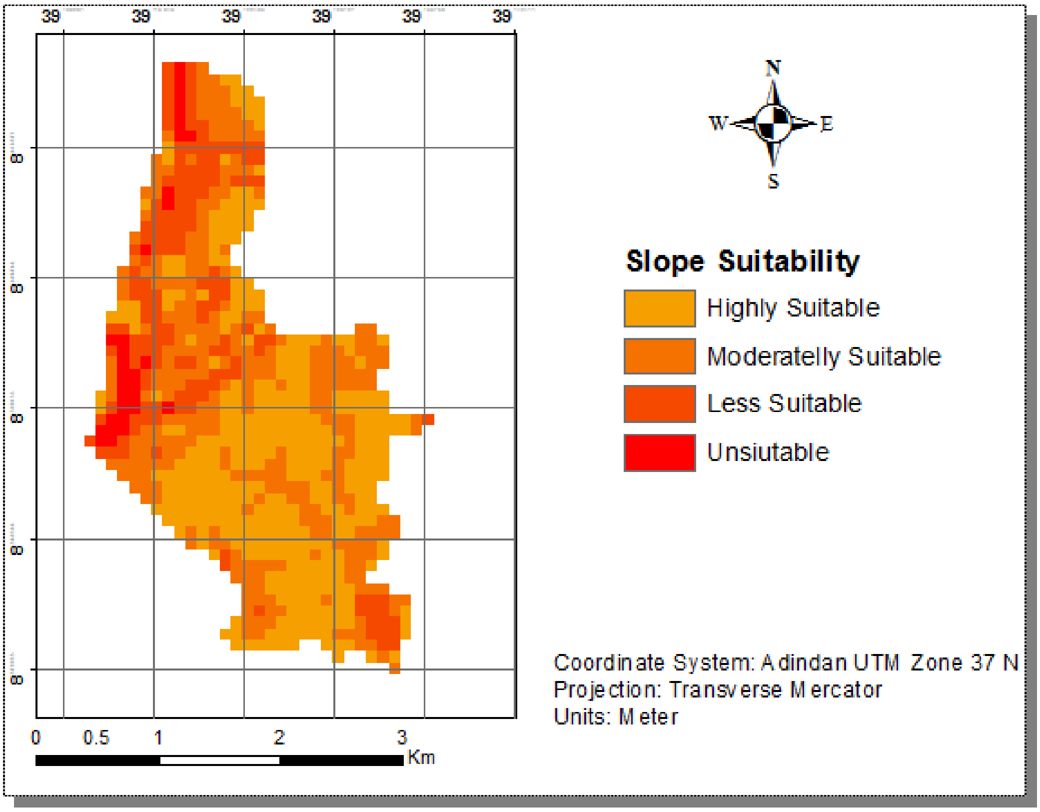

Figure 4.3 Slope Suitability Map

4.4 Accessibility

Road is one of the criteria that should be considered in suitability analysis. Landfill sites should not be very close to roads, this is because as landfills close to roads may result public health problem. As the general concept, the landfills shall not be located within 400 meter of any major highways, city streets or other transportation routes. Solid waste dumping site must be located at suitable distance from roads network in order to facilitate transportation and it is preferred to locate landfills away 400 meter distance from roads (MUDC, 2012).

Table 4.3 Road Suitability class

Suitability Class	Level of Suitability	Rank	Area (ha)	% of total area
0- 400 meter	Unsuitable	1	679.80	15
400- 1000 meter	Less suitable	2	906.41	20
1000- 1600 meter	Suitable	3	1042.35	23
>1600 meter	Highly Suitable	4	1903.44	42
Total			4532	100

In this study existing roads were digitized from topographic map of the town, which was accessed from EMA. To locate landfills as suitable to the existing roads, buffer zones were categorized into four levels and standardized as very close. Very far places from roads are not suitable for landfills, because additional transport and construction cost may be needed. Even though this is the criteria Mojo town is networked with roads and no places are within the town away 1900meter from main roads. Accordingly, 0-400 meter buffer was assigned as unsuitable.

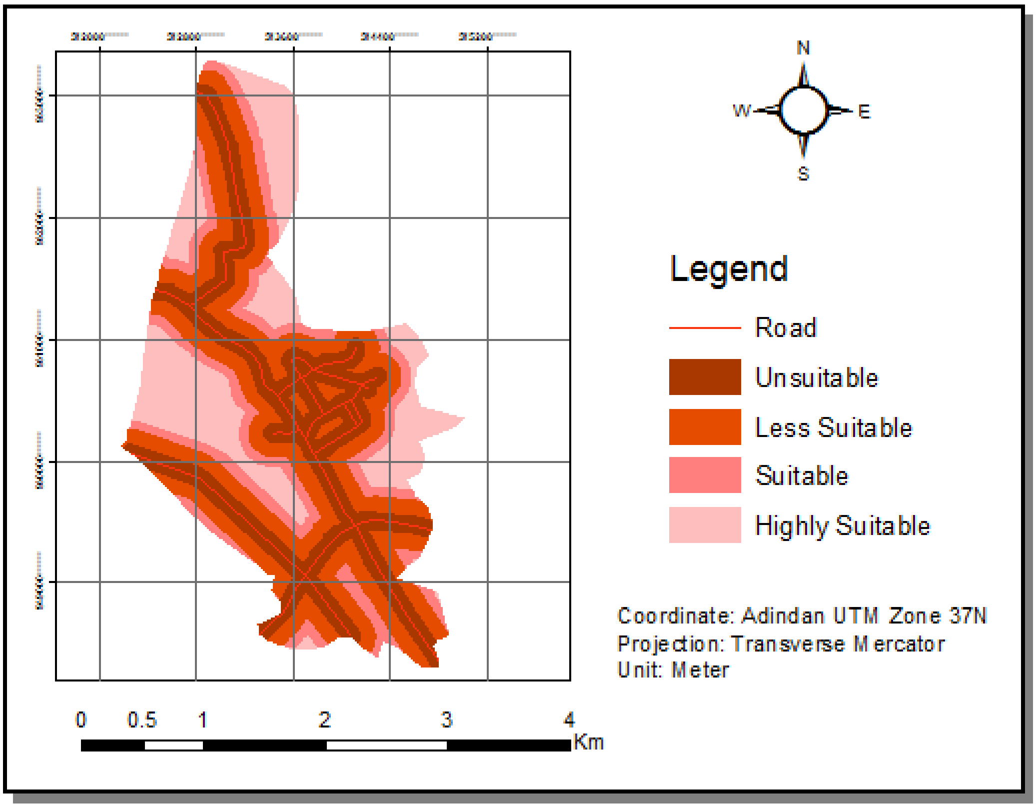

Figure 4.4 Road Suitability Map

4.5 Surface Water

Most of the surface waters in the study area are streams. The landfill site must not be close to surface water bodies like streams, rivers and lakes. This is because as the distance between the landfill and water bodies narrows, the probability of polluting the water becomes high. The pollution in water resources causes saviour problems in environment, public health as well as economy.

In this study the streams/ rivers were generated from DEM of the Mojo, using spatial analyst hydrology extension. Then it was buffered using the standards of MUDC, 2012, to locate suitable sites for landfills. Accordingly, four different zones were specified: in which far buffers from streams are more suitable while buffers near to streams are less suitable for landfill sitting.

Table 4.4 Stream suitability class

Suitability Class	Level of Suitability	Rank	Area (ha)	% of Total Area
<500 m	Unsuitable	1	1133.01	25
500m- 1000 m	Less suitable	2	815.75	18
1000m- 1500 m	Suitable	3	997.03	22
>1500 m	Highly Suitable	4	1586.21	35
Total			4532	100

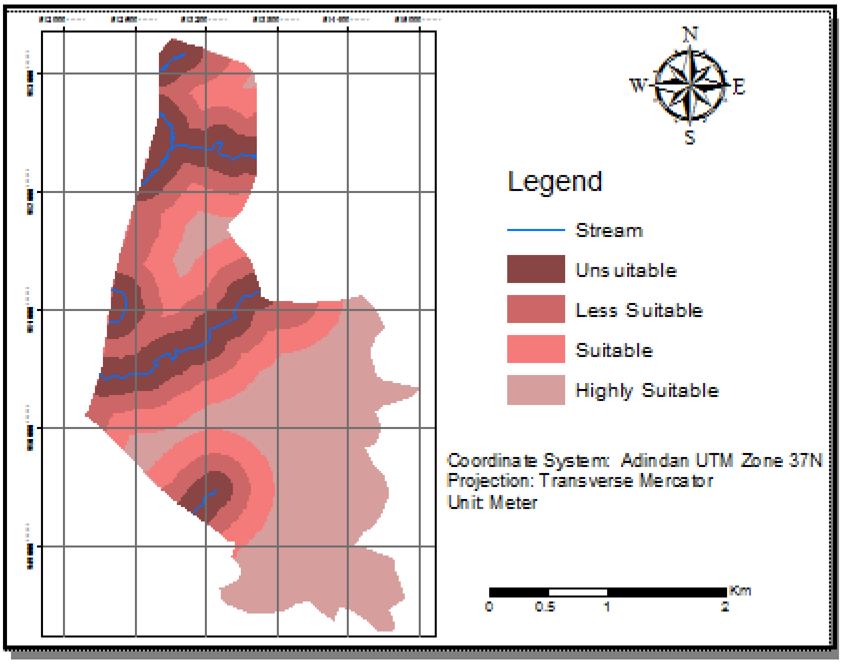

Figure 4.5 Steam Suitability Map

4.6 Soil Type of the Study Area

Soil is a product of the influence of climate, relief, organisms, and parent materials interacting over time. According to soil classification of MOA, the type of soil that exists in Mojo town is only Pellic vertisols. These are important to agriculture with very high dark-colored clay minerals having high water storage capacity. The most important characteristics of vertisols are their water holding capacity. This clayey soil is one of the best sites for landfill sitting because clay can prevent leachate problems. This is because leachate migration from the landfill could be a potential source of surface and groundwater contaminations. Leachate refers liquid that has percolated through solid waste or another medium. Leachate from landfills usually contains extracted, dissolved and suspended materials, most of which may be harmful.

4.7 Protected Areas

The protected area in this study includes the Mojo dry-port, churches, mosques, schools and health centers. The landfill should not be located in close proximity to sensitive areas listed above to a minimum limit of 1,000 meter buffer surrounding. When the distance increases from these areas suitability also increases. In this study the X,Y coordinates for the above listed protected areas were gathered using GPS during the field survey and buffered using the standards of MUDC, 2012, to locate suitable sites for landfills. Accordingly, four different zones were specified: in which far buffers from protected areas are more suitable while near buffers are less suitable for landfill sitting. The study considered the reclassified distance as unsuitable from 0 to 1000meter, less suitable from 1000m to 1500m, suitable from 1500m to 2000m and highly suitable above 2000meter.

Table 4.5 Protected Areas Suitability Class

Suitability Class	Level of Suitability	Class	Area (ha)	% of total area
<1000 m	Unsuitable	1	978.91	21.6
1000m- 1500 m	Less suitable	2	815.75	18
1500m- 2000 m	Moderately Suitable	3	897.34	19.8
>2000 m	Highly Suitable	4	1840	40.6
Total			4532	100

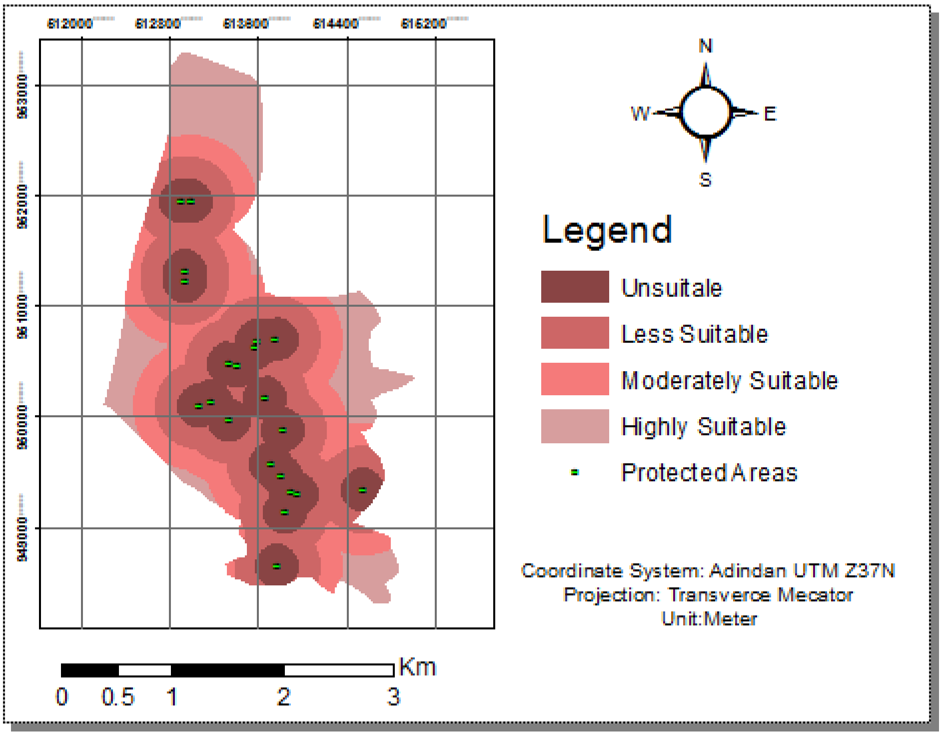

Figure 4.6 Protected Areas Suitability Map

4.8 Settlement

The waste disposal sites should not be sited or located near to populated areas. The extent of the residential areas were derived from reclassification, and distance of 1500 m and above are considered as suitable while 1000m and below were considered unsuitable. Hence the land suitability for landfill increases with the increase in distance from the residential areas.

Table 4.6 Table 4.4 Settlement Suitability Class

Suitability Class	Level of Suitability	Class	Area (ha)	% of total area
<1000 m	Unsuitable	1	1314.29	29
1000m- 1500 m	Less suitable	2	1133	25
1500m- 2000 m	Suitable	3	725.12	16
>2000 m	Highly Suitable	4	1359.58	30
Total			4532	100

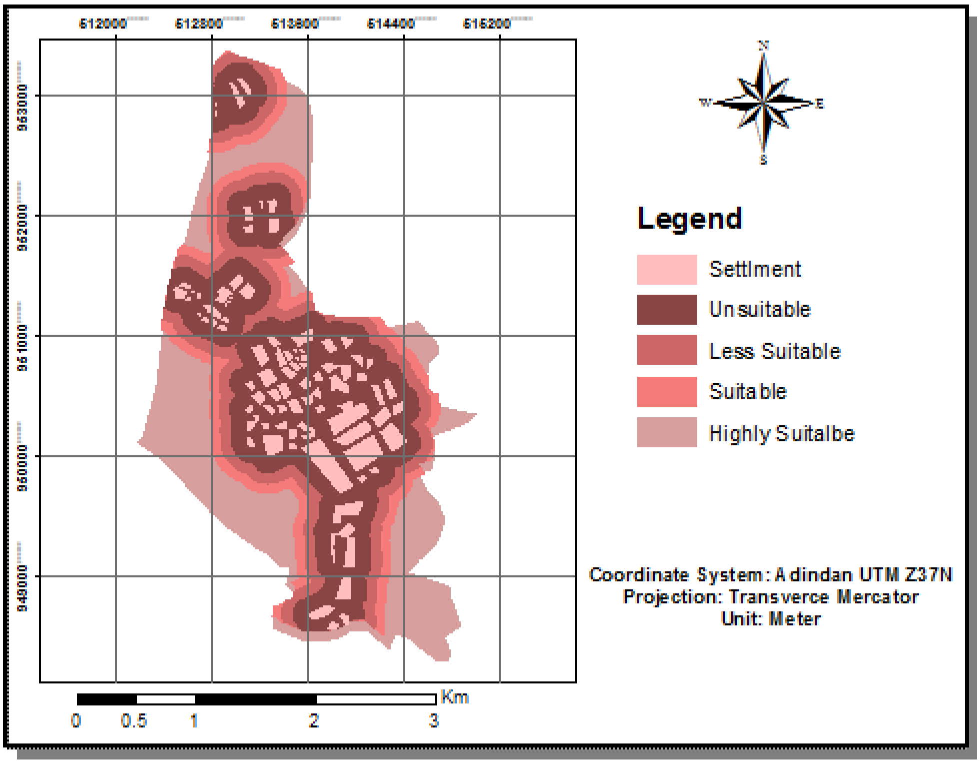

Figure 4.7 Settlement Suitability Map

4.9 Hydro-geologic Characteristics

4.9.1 Ground water

The ground water circulation and downward flow of pollutants through rocks and soils is depending on the hydro geological condition of materials more specifically hydraulic properties such as porosity and permeability.

The ground water map of the study area was collected from Ministry of Water, Irrigation and Energy. Accordingly, there are a group of boreholes in the study area, and there are four levels of permeability: which are high, moderate, low and very low.

As it is stated above, under the soil suitability, the material which is less permeable is suitable for landfill. This is because; the leachate from solid waste cannot spread out easily. Therefore, the area indicated by red colour, Figure 4.8, is highly suitable. In addition with its less permeability, the boreholes are out of this area. Areas shown by yellow, light green and light blue represents moderately suitable, less suitable and unsuitable respectively.

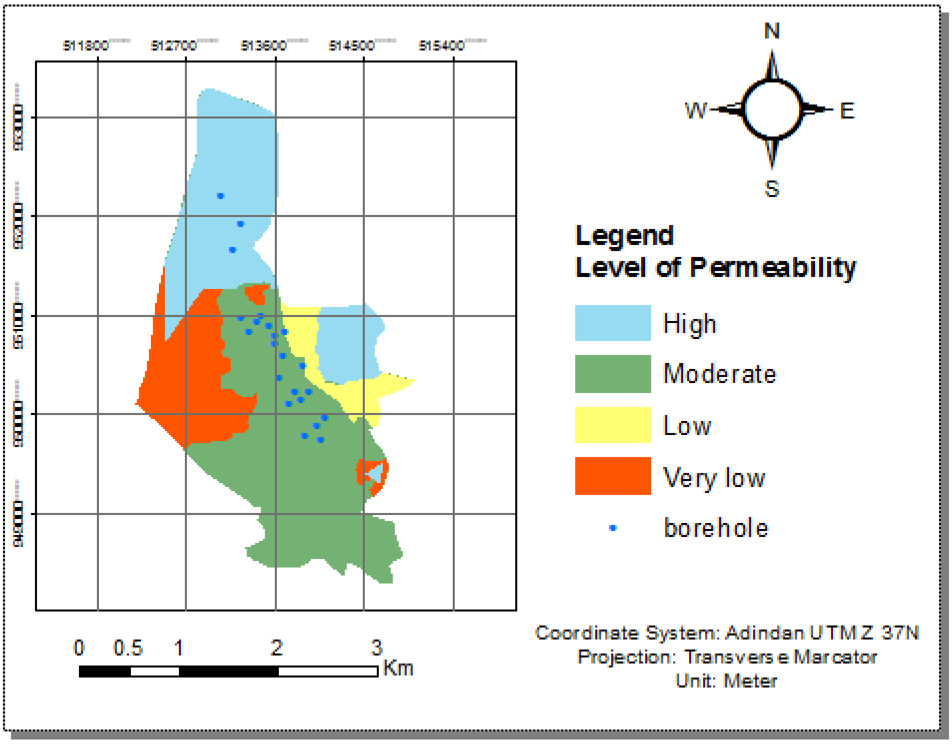

Figure 4.8 Ground water Map

4.9.2 Geological Characteristics

In the study area, the lacustrine sediment is the dominant geology around central and south of the town. Bofa basalt also exists covering the northern part and some of the east of Mojo town. Alkalin and Nazret rocks are found in the study are to the west and east direction respectively (GSE). According to Tsegaye, (2006), the Nazret group rock and lacustrin sediments are highly suitable for landfill site.

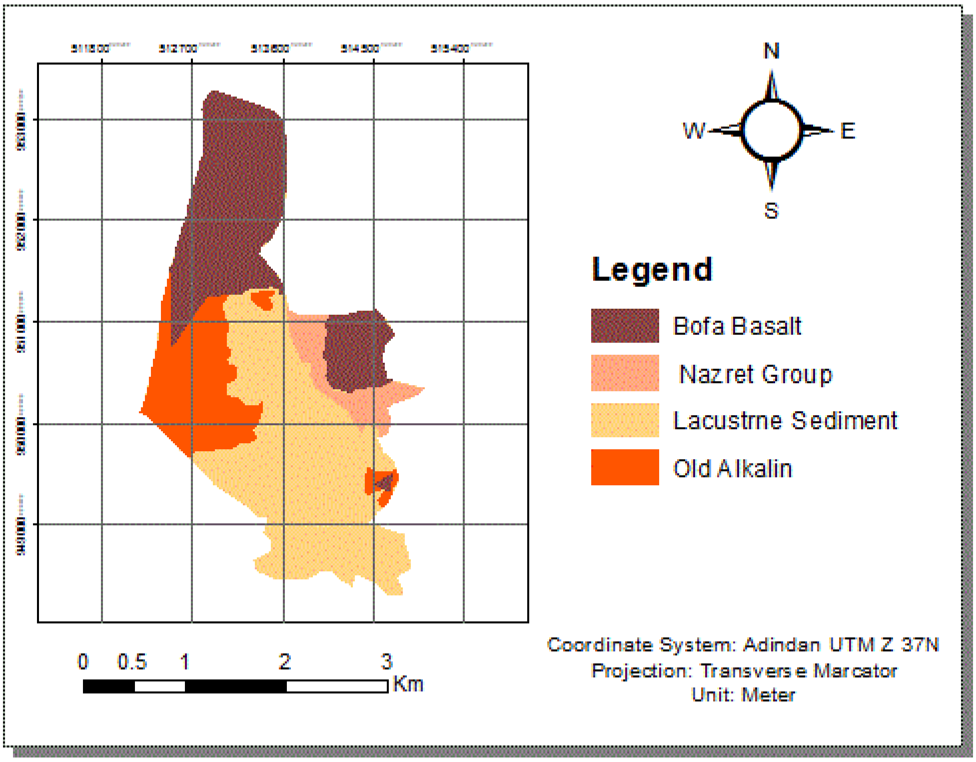

Figure 4.9 Geological Map

4.10 Urban Land Use

The land cover of the town was analyzed from Landsat ETM+ acquired in 2014. The image was georeferenced to a projection of Universal Transverse Mercator, Grid of UTM Z 37N and datum with Adindan. The image was undertaken under supervised classification with the help of 59ground control points that were collected during the field survey, to update the information. Classified pixels were clustered into six general categories as: residential area, urban agriculture, stream, commercial centers, industries and green space (figure 4.8).

Accordingly, the land use types were ranked based on their importance to evaluate suitable site to locate landfills. These are; Green spaces are ranked as highly suitable, urban agriculture as moderately suitable, residential area, commercial centers and industries as less suitable and areas near to streams and urban infrastructures as unsuitable.

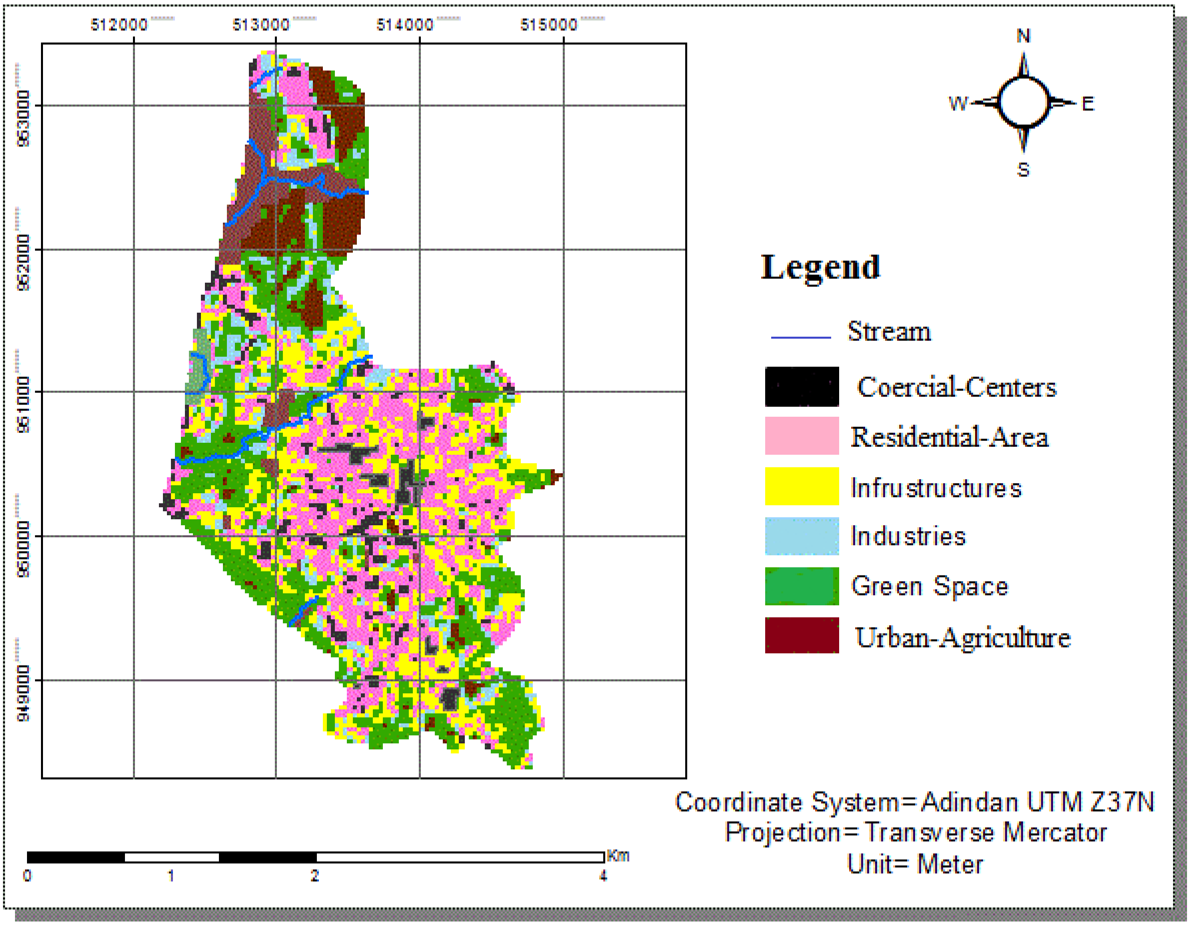

Figure4. 10 Major Urban Land Use Categories Map

Table 4.7 Land Use Suitability Classes

Land Use/Cover type	**Level of Suitability**	**Rank**	**Area (ha)**	**% of total area**
Stream, Infrastructures	Unsuitable	1	63.84	12
residential area, commercial centers and industries	Less Suitable	2	2719.2	60
urban agriculture	Moderately Suitable	3	453.2	10
Green spaces	Highly Suitable	4	815.76	18
Total			4532	100

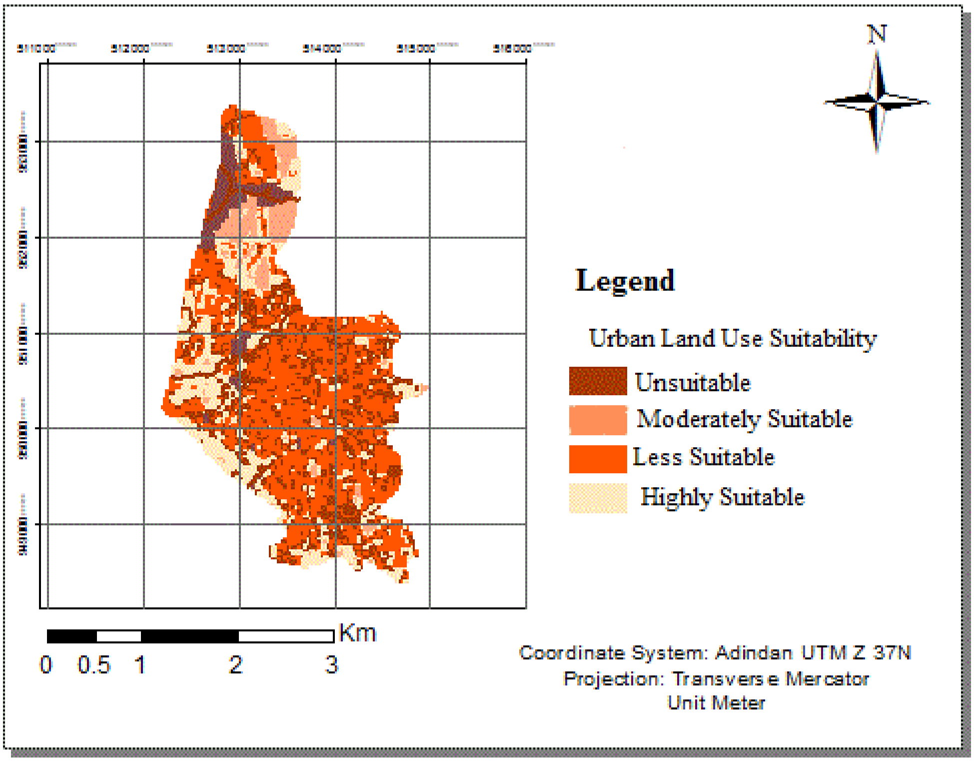

Figure 4.11 Urban Land Use Suitability Map

4.11 Calculating Factor Weights and Overlaying Identified Suitable Sites

The site selection for solid waste disposal dumping site involves comparison of different options based on environmental, social and economical impacts. Hence, based on experience and likely impact on surrounding environment, different weights were assigned to all the parameters. The larger the weight, the more important is the criterion in the overall utility. The weights were developed providing a series of pair wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. The procedure by which the weights were produced follows the logic developed by Saaty (1980) under the Analytical Hierarchy Process (AHP). Weight rates were given based on pair wise comparison 7 point continuous scale (Table 4.8). These pair wise comparison were then analyzed to produce of weights that sum to 1. The factors and their resulting weights were used as input for the multi criteria evaluation (MCE) module for weighted linear combination of overlay analysis.

Table4.8 Pair wise comparison, 9-point weighting scales

1/9	1/7	1/5	1/3	0	3	5	7	9
Absolutely	Strongly	More	Slightly	Equally Important	Slightly	More	Strongly	Absolutely

Source: Saaty, 1980

According to Lawal et al. (2011) if the consistency ratio is less than or equal to 0.1, it signifies acceptable reciprocal matrix. The consistency ratio of this study indicated that 0.01 was acceptable In order to combine all the layers to process overlay analysis, standardization of each data set to a common scale of 1, 2, 3, 4 (value 1 = unsuitable, value 2 = less suitable, value 3 = moderately suitable, value 4 = highly suitable) was performed.

Table4.9 Pair wise comparison in seven Point continuous Scale

	Road	Urban LU	Stream	Protected Areas	Slope	Settlement	Ground Water	Geology	Soil	Eigenvector weight	Percentage %
Road	1									0.176	17.6
Urban LU	½	1								0.158	15.8
Stream	½	1/3	1							0.138	13.8
Protected Area	2	1/3	1/2	1						0.131	13.1
Slope	1/3	1/2	2	1/3	1					0.105	10.5
Settlement	1/3	1/2	1/2	1/3	½	1				0.084	8.4
Ground Water	1/3	1/2	3	½	½	½	1			0.079	7.9
Geology	1/3	1/3	1/3	2	½	½	3	1		0.076	7.6
Soil	1/3	1/2	1/3	1/21/2		½	1/3	2	1	0.053	5.3
Total										1	100

Consistency Ratio= 0.01

Table 4.10 Weight of Suitable Solid Waste Dumping Site Selection Factors

Factor	**Class**	**Value**	**Level of Suitability**	**Influence (%)**
Distance from Roads	< 400 m	1	Unsuitable	
	400m- 1000	2	Less Suitable	17.6%
	1000m-1600 m	3	Suitable	
	1600m-2000 m	4	Highly Suitable	
Urban Land use	Water body	1	Unsuitable	
	Built-up and/ Agricultural lands	2	Less Suitable	15.8%
	Vegetation lands	3	Suitable	
	Barren and grass land	4	Highly Suitable	

Factor	Class	Value	Level of Suitability	Influence
Distance from Streams	<300 m	1	Unsuitable	
	300m- 500 m	2	less suitable	13.8%
	500m- 1000 m	3	Suitable	
	>1000 m	4	Highly Suitable	
Distance from Protected Areas	<1000m	1	Unsuitable	
	1000m- 1500m	2	less suitable	13.1%
	1500m-2000m	3	Suitable	
	>2000m	4	Highly Suitable	
Slope	<10%	4	Highly Suitable	
	10%-13%	3	Moderately Suitable	10.5%
	13%-16%	2	Less Suitable	
	>16%	1	Unsuitable	
Distance from Settlement	<100m	1	Unsuitable	
	1000m-1500m	2	less suitable	8.4%
	1500m-2000m	3	Suitable	
	>2000m	4	Highly Suitable	
Ground Water				7.9%
Geology				7.6%
Soil				4.3%

The final map (Figure 4.12) has four classes. Out of the total area of the town, about 6% (271.92 ha) fall under highly suitable area for landfill site. The moderately suitable area (3) covers an area of 22% (997.04 ha). The area which covers 26.6% (1205.51ha) is under less suitable class and the remaining 45.4% (2057.52 ha) under unsuitability class and the value is 1 (Table 4.11). By using the stated criteria, suggested areas as suitable for solid waste dumping site fall on the south and south west direction from the town (Figure 4.12).

Table 4.11 Suitability area level of suitability and the percent of total area coverage

Level of Suitability	Rank	Area (ha)	Percent of total area
Unsuitable	1(Brown)	2057.52	45.4
Less Suitable	2 (Violet)	1205.51	26.6
Suitable	3 (Yellow)	997.04	22
Highly Suitable	4 (Green)	271.92	6%
Total		4532	100

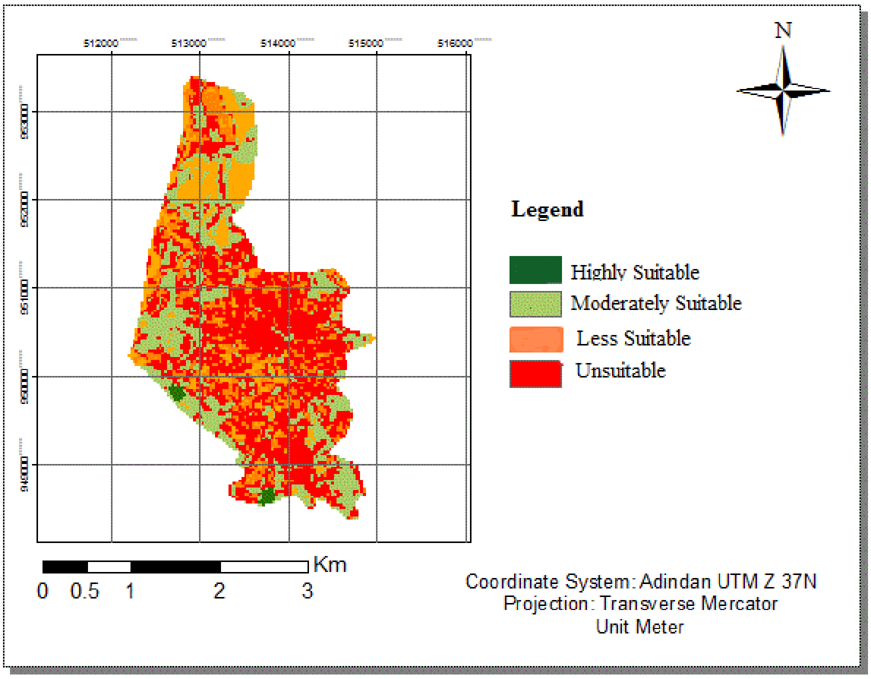

Figure 4.12 Landfill Suitability Map

Figure 4.13 shows the two class of landfill suitability in relation with settlement, rivers and road net-works. As this figure shows, sites which are highly suitable for landfills are located in the southern and south-western peripheries of the town. These areas are mainly green spaces. These areas are at the suitable distance from roads and far from settlement and water body.

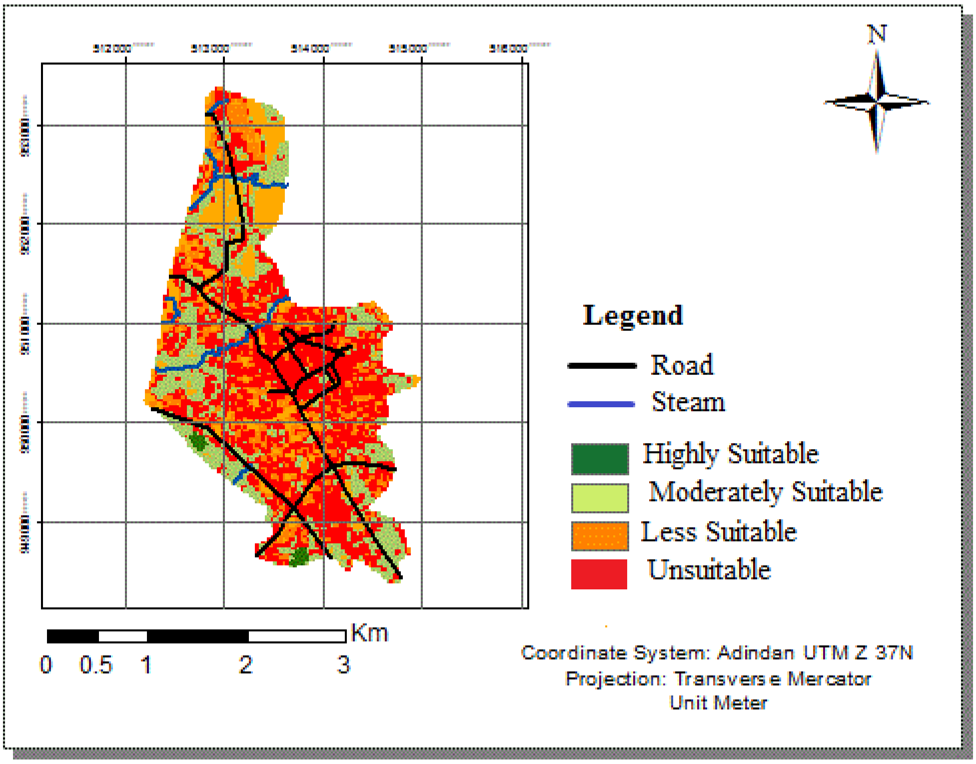

Figure 4.13 Overall Landfill Suitability Map

CHAPTER FIVE

5. Conclusion and Recommendations

5.1 Conclusion

Landfills are an environmentally acceptable disposal of solid waste on the ground. The main purpose of establishing landfills is to protect the safety of the environment by minimizing effects on resources and community health. Similarly the main purpose of this study was finding suitable sites for landfills using GIS and remote sensing technologies.

As the study shows GIS requires collecting different data from different sources with different formats and the data must be updated to show the current information of the study area. Remote sensing also helps in having information about the study area through satellite images.

The findings have shown the ability of GIS and remote sensing as a veritable tool for analyzing the criteria for decision support. The analysis has taken important factors to minimize the negative impacts of landfills. These are land use type, slope, water sources, protected areas, settlement, type of soil, road, ground water and geology as determining factor in order to find appropriate site for solid waste dumping site. But as it is stated the anticipated airport site is not included as a factor, this is because the exact location is not identified. The results have shown that two sites were suggested as highly suitable for solid waste landfills. The sites are easy to access and manage for disposal of solid wastes. These places are far way from any water sources and other variables put into analysis. They are located in western and south west peripheries of the town and are in areas of green spaces with less than 10% slope.

5.2 Recommendations

The following recommendations are given for more understandings

- ❖ The selected landfill sites by this study are only for non-hazardous solid wastes. Since the criteria for hazardous wastes area different from non-hazardous wastes, separate landfill should be selected.
- ❖ These suggestive landfill sites do not include the anticipated air port. But during the time for constructing the airport, it should consider these suggestive landfill sites.
- ❖ Detailed hydrological and geological studies for the selected landfill should be investigated.
- ❖ Further studies are necessary about the design and costs of construction of landfills.

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Appendices 1: GPS Points for Protected Areas

No_	**Shape**	**X**	**Y**	**LU/LC**
1	Point	512898	951943	Mosque
2	Point	512981	951943	Clinic
3	Point	513767	950701	School
4	Point	513591	950680	School
5	Point	513560	950629	Mosque
6	Point	513343	950484	Health Center
7	Point	513394	950453	Church
8	Point	513663	950173	Church
9	Point	513167	950132	School
10	Point	513063	950070	Church
12	Point	513322	949956	Church
13	Point	513819	949873	Health Center
14	Point	513694	949573	School
15	Point	513908	949470	Health Center
16	Point	513881	949325	School
17	Point	513932	949283	Church
18	Point	513829	949139	Health Center
19	Point	513767	948663	Church

Source: Field Survey, 2016

Appendix 2: GPS Points for Different LU Types

No_	**Shape**	**X**	**Y**	**LU/LC Type**
1	Point	513131	953110	Residence
2	Point	513305	952730	Commercial area
3	Point	512828	952988	Residence
4	Point	512691	952200	Residence
5	Point	512896	950834	Residence
6	Point	513408	950963	Residence
7	Point	513867	950895	Infrastructures
8	Point	513169	952897	Infrastructures
9	Point	513700	948923	Infrastructures
10	Point	513779	949295	Infrastructures

11	Point	513131	953110	Green Space
12	Point	513305	952730	Green Space
13	Point	512828	952988	Green Space
14	Point	512691	952200	Green Space
15	Point	512896	950834	Green Space
16	Point	513408	950963	Green Space
17	Point	513867	950895	Green Space
18	Point	513169	952897	Commercial area
19	Point	512987	952526	Residence
20	Point	512759	951540	Residence
21	Point	512987	951343	Residence
22	Point	513283	931054	Residence
23	Point	513533	950834	Residence
24	Point	513927	950789	Residence
25	Point	513427	950808	Commercial area
26	Point	512365	950364	Commercial area
27	Point	513336	949993	Commercial area
28	Point	514047	949970	Commercial area
29	Point	514193	949720	Residence
30	Point	514200	948969	Residence
31	Point	514610	949366	Residence
32	Point	514579	950190	Commercial area
33	Point	513284	952692	Commercial area
34	Point	513768	951024	Commercial area
35	Point	513063	950433	Industrial area
36	Point	514033	950425	Industrial area
37	Point	512630	950106	Industrial area
38	Point	512987	959492	Residence
39	Point	513584	952488	Green Space
40	Point	512873	951555	Green Space
41	Point	512661	951525	Green Space
42	Point	513048	950834	Green Space
43	Point	512471	950531	Green Space
44	Point	512979	950402	Green Space
45	Point	512706	949742	Green Space

46	Point	513108	949458	Green Space
47	Point	514602	949576	Green Space
48	Point	534423	949257	Green Space
49	Point	513995	950342	Green Space
50	Point	514807	950326	Green Space
51	Point	513487	952844	Urban Agriculture
52	Point	513465	952451	Urban Agriculture
53	Point	513040	952086	Urban Agriculture
54	Point	512873	951745	Urban Agriculture
55	Point	513230	951502	Urban Agriculture
56	Point	513148	950819	Urban Agriculture
57	Point	51512714	950594	Urban Agriculture
58	Point	513798	949487	Urban Agriculture
59	Point	514279	949257	Urban Agriculture

Source: Field Survey, 2016