School of Graduate Studies

College of Social Science

Department of Geography and Environmental Studies

Selection of Potential Sites for Solid Waste Transfer Stations in Addis Ababa: A Decision Support System using GIS and RS Techniques.

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, in Partial Fulfillment of the requirement for the Degree of Masters of Art in Geography and Environmental Studies.

By: Netsanet Habtamu

Advisor: Aklilu Amsalu (PhD)

June, 2015

Selection of Potential Sites for Solid Waste Transfer Stations in Addis Ababa: A Decision Support System using GIS and RS Techniques.

By: Netsanet Habtamu

Approved by Board of Examiners

Dr. Akililu Amsalu Signature__________________ Date____________
Advisor

Dr. Tesfaye Shiferaw Signature__________________ Date_____________
Chairman

Dr. Yohannes G/Michael Signature_________________ Date_____________
Internal Examiner

Dr. Birhan Gessese Signature__________________ Date_____________
External Examiner

DECLARATION

I hereby declare that the thesis entitled "Selection of Potential Sites for Solid Waste Transfer Stations in Addis Ababa: a Decision Support System using GIS and RS Techniques" has been carried out by me under the supervision of Dr. Aklilu Amsalu Department of Geography and Environmental Studies, Addis Ababa University during the year 2014- 2015 as a part of Master of Art program in GIS and Remote Sensing Specialization. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Name: Netsanet Habtamu

Place: Addis Ababa

Date: June, 5/2015

Table of Contents

Contents page

ACKNOWLEDGEMENTS

For the success of this work many individuals and institutions have contributed a lot. First and foremost, however, I would like to thank Almighty God who made everything to happen in time. Next, greatest thanks go to my advisor Dr. Aklilu Amsalu for his valuable comments and contributions of ideas as well as sharing of his precious time to read the earlier drafts of this paper.

For various data and information I received; my foremost thanks goes to Ethiopian Geological Survey, Ministry of Agriculture, Central Statistical Authority (all librarians) and Great thanks also go to Administrators, experts and staffs of Addis Ababa City Sanitation, Beautification and Park Development Agency. People in the study area also deserve acknowledgements for their kindness and hospitability during my stay in field work.

To all my classmates (Werkaferaw, Teshome, Akililu, and Bireda) are also acknowledged for their friendship and cooperation during my stay in data collection and the university.

Finally, my heartfelt thanks go to all my families for assisting me both in ideas and in materials to accomplish this paper.

Netsanet Habtamu

June, 2015

List of tables

List of Figures

Acronyms

AASBPDA	Addis Ababa Sanitation, Beautification and Parks Development Agency
AHP	Analytical Hierarchy Processes
CI	Consistency Index
CR	Consistency Ratio
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ENDA	Environmental Development Agency
EPA	Environmental Protection Authority
FAO	Food and Agriculture Organization
GCPs	Ground Control Points
GSE	Geological Survey of Ethiopia
GIS	Geographic Information System
GPS	Global Positioning System
HHW	Households Hazardous Waste
MAA	Municipal of Addis Ababa
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
MSEs	Micro and Small Enterprises
MSW	Municipal Solid Waste
MSWMS	Municipal Solid Waste Management System
NIMBY	Not in My Back Yard
SMCDA	Spatial Multi-Criteria Decision Analysis
USEPA	United States Environment Protection Agency
UNDP	United Nation Development Program
UNEP	United Nation Environmental Program
WHO	World Health Organization
WLC	Weighted Linear Combination

Abstract

Municipal Solid Waste (MSW) management is one of the most issues in the contemporary urban environments particularly in Ethiopia. An increase in population size makes solid waste management system complex and difficult especially in the city of Addis Ababa. Solid waste transfer station is a component of solid waste management system that established near to residential areas used to store solid wastes temporarily. The objective of this study is to select potential sites for solid waste transfer stations using GIS and RS techniques in the city of Addis Ababa. GIS based Multi-Criteria Evaluation method was used to select the potential sites in the study area. About ten physical and social criteria were used to select the sites. All factor maps were geo-referenced and reclassified according to their suitability based on norms and standards of solid waste transfer station sites selection. Weights for each criterion were assigned based on Analytical Hierarchy Process using pairwise comparison matrix. The value judgment consistency of this study was 7.4% and found within acceptable limits. After assigning weights, all criteria were combined (WLC) to get the most suitable sites for transfer stations and based on the overlay result a thematic map of the selected potential sites was produced. From the total study area about 12.8% was found as the most suitable potential sites and 73.3% was unsuitable for the stations among the selected potential sites the largest part was found in the southern part of the study area specifically in Akaki sub-city. The selected potential sites were fulfilled social, economic and environmental norms and standards used to select solid waste transfer stations potential sites in the study area. Therefore, decision makers should give a due attention towards social, economic, and environmental norms and standards to select solid waste transfer stations potential sites to improve solid waste management system in the city of Addis Ababa.

Chapter One

1. Introduction

1.1. Background

Waste is a material discharged and discarded from each stage of daily human life activities, which leads to adverse impacts on human health and the environment (Bringi, 2007). Whereas, municipal solid waste is commonly known as trash or garbage, consists of discarded items such as packaging materials, grass clippings, furniture, clothing, glass, food scraps, paper and paper products, appliances, paint, and batteries. Municipal solid waste (MSW) is one of the unavoidable products of society that necessitates establishment of a municipal solid waste management system (Erkut *et al*., 2008).

A solid waste management system consists of prepared plans and plants that are built for final disposal of waste as well as recycling, reuse, composting, and incineration (Liu *et al.*, 1997). It deals with the municipal solid waste from its source of generation until its final disposal, which includes all the operations and transformation of this waste. The most common problems associated with improper management of solid waste include diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses (Basagaoglu, 1997).

A transfer station is one of the elements in solid waste management facility located close to residential areas that is used to receive and hold waste temporarily until it is transported to distant landfills, processing centers, or composting facilities (USEPA, 2004). The facility ownership, sizes, and services offered vary significantly among transfer stations, they all serve the same basic purpose which is consolidating waste from multiple collection vehicles into larger, high-volume transfer vehicles for more economical shipment to distant disposal sites (US EPA, 2002). It may result in approximately 38 percent reduction in energy consumption along with reduced emission of toxic components into the air and water due to reduced fuel consumption resulting from fewer trips (Khorasani and Rafiee, 2007).

One of the main goals of the MSWMS is to determine the type, location, and capacity of facilities that will be used for disposal and/or treatment of the waste, based on environmental, economic, social, and health considerations. Suitable location of disposal facilities is a major issue in waste management. Most studies have focused on location of the landfill alone, with limited attention given to site selection for transfer stations (Kao *et al.*, 1997, Kontos *et al.*, 2005).

Dealing with the environmental costs in rapidly growing economic development, urbanization and improving living standards in cities have led to an increase in the quantity and complexity of generated waste, representing a phenomenal challenge (UNDP, 2004). This is particularly true in the area of solid waste management. While cities are generating an ever-increasing volume of waste, the effectiveness of their solid waste collection and disposal systems are declining. In urban centers throughout African regions, less than half of the solid waste produced is collected, and 95 percent of that amount is either indiscriminately thrown away at various dumping sites on the periphery of urban centers, or at a number of so-called containers based temporary sites, typically empty lots scattered throughout the city (Mohammed and Elsa, 2003).

Addis Ababa city started its solid waste management some three decades back. The service cannot meet changing demands. The social waste collection service is unsatisfactory, and scenes of scattered waste are common in most part of the city (UNDP, 2004). Most of the waste is administered by the government with no or little involvement of the private sector and tends to be costly and inefficient. Some communities receive little (in some cases no) solid waste collection services because local governments have no resources to cover all households. Thus, in the absence of collection services, households use forms of disposal most of which are heavily polluting (ENDA, 2006).

Data on the composition, volume and weight of solid waste generated and collected in Addis Ababa carried out in early 1980s and mid 1990s indicates that the estimates of waste generated per capita per day varies in volume from 0.4 to 1.23 lit/capita/day, in weight from 0.11 to 0.25 kg/capita/day and in density from 205 to 370 kg/m3 (MAA, 2002). In other studies, the daily waste generation is estimated to be 0.5 kg/capita/day (AASBPDA, 2014). Regardless of increasing volume of waste generated, the performance of the city's solid waste collection and disposal system is poor (WHO, 1996). Currently only 65% of the solid waste produced per day is collected and disposed by the municipality in the dumpsite, 5% is recycled, 5% is composted and the remaining 25% of the solid wastes are uncollected and dumped in unauthorized areas such as open fields, ditches, sewers, streets and many other available spaces in the city (AASBPDA, 2014). Uncollected garbage is a serious environmental hazard for all, especially in areas where the roads are not accessible for collection by the municipality. These cause bad smells and attract various disease vectors and pests resulting in deteriorated aesthetic quality of the city. Thus, the health situation of the community is under serious threat (ENDA, 2006).

Therefore, to protect the society from solid waste hazards the establishment of transfer stations play pivotal role. However, identifying a suitable site for a waste transfer station can be a challenging process. Site suitability depends on numerous technical, environmental, economic, social, and political criteria. When selecting a site, a balance needs to be achieved among the multiple criteria that might have competing objectives. It requires a multiple criteria and objectives which require the use of spatial analysis models for its solution (USEPA, 2004).

The site selection process for transfer stations depends on several criteria that require sophisticated spatial analysis, so an informed decision-making and problem-solving process relies on GIS based spatial multi-criteria evaluation (SMCE). Weights for each criterion were assigned based on AHP using pairwise comparison matrix which developed by (Saaty, 1980). In the context of data in line with integration of SMCE, two procedures are commonly used. The first is the Boolean overlay, whereby all criteria are assessed by implementing a threshold for suitability, and the second procedure is weighted linear combination (WLC). In the Boolean overlay a crisp decision is made regarding the suitability of each criterion such that the resultant image simply has two classes indicating the suitable and unsuitable areas. In contrast, with the WLC method, each criterion is standardized in terms of suitability in a numerical range, and criteria are then combined using weighted averaging. In this procedure the final image is a continuous map that can be used as a useful tool for decision making (Jiang and Eastman, 2000).

1.2. Statement of the Problem

In view its impact on broader socio–economic development and the environment, an increase in volume and complexity of solid waste with poor solid waste management system is one of the major challenges of developing countries like Ethiopia.

Solid waste transfer stations are intermediate places at which solid wastes are deposited and stored until transported to the final disposal site. However, they are not given due consideration to be incorporated as one of the components in the solid waste management system of Addis Ababa development plan therefore, the city still lacks well developed transfer stations. However, the collected wastes are stored on the road sides and some other corners of the city until they are transported to the city's disposal site. Moreover, the collected wastes are totally kept open without cover and exposed to rain and sun making them to produce superfluous odor, cause hideous urban panorama, attract vectors and disturb human activities in the surrounding areas.

But people seem not be carrying about the way wastes are handled may be because of ignorance about the likely consequences of poor waste management and the institutions like Addis Ababa recycling and reusing project office is not played its part very well. It may be due to lack of proper technologies, controlling system, awareness in areas of segregation, recycling, and also lack of private and public partnership. The problem is high and it needs solution. Solid waste disposal system should be environmentally sound and socially acceptable so as to protect the environment and safeguard public health. However, the traditional and manual method used to select suitable solid waste temporal storage (container based) site is inaccurate, not environmentally and socially sound, time consuming and costly. In addition to this, they did not consider some very important evaluation criteria like soil structure, geology, proximity to protected/sensitive areas, distance from drainage etc. of the area that can easily be analyzed using GIS and RS techniques.

Although several researchers have carried out many studies on solid waste management and land fill site selection provided a number of solutions to waste management in different parts of this country and the world at large, no research has been conducted on one of the basic elements of SWMS which is called solid waste transfer station at Addis Ababa level using GIS and RS techniques.

It can be concluded that there is a relative neglect of the problem that affects efficient solid waste management system. The determinants of poor solid waste management practices observed in the city were unclear. Therefore, this study prompted to select the most appropriate locations of solid waste transfer station sites for the city by considering social, economic, and environmental factors to improve the performance of the SWMS as a whole for the benefit of the public.

1.3. Objectives of the Study

1.3.1. General Objective of the Study

The general objective of this study was to determine the most appropriate locations for solid waste transfer stations using GIS and RS techniques that meet the social, economic, and environmental criteria in Addis Ababa.

1.3.2. Specific Objectives of the Study

The specific objectives of this study include:

- ✓ To produce thematic map showing potential sites that met environmental, economic and social norms and standards for solid waste transfer stations.
- ✓ To identify the main determinant factor maps of solid waste transfer station potential sites selection.
- ✓ To identify the environmental and social norms and standards used to select solid waste transfer station potential sites.

1.4. Research Questions

- What are the main criteria used to select GIS based solid waste transfer station potential sites?
- What are the procedures used to produce thematic map of the identified solid waste transfer station potential sites?
- What are the environmental and social standards used to select solid waste transfer station potential sites?

1.5. Significance of the Study

The main significance of the study would be to bring desirable changes in solid waste management system. Hence the study findings and suggestions would be used:

- ✓ As a baseline study for further studies related to solid waste transfer station potential sites selection using GIS and RS techniques.
- ✓ As a guide line for solid waste management decision making process in the city.

- ✓ To suggest an appropriate solution for decision makers to improve the existing solid waste management system of the city.

1.6. Scope of the Study

This study was conducted in Addis Ababa city administration. Research on solid waste transfer station potential site selection requires a wide scale study in different areas of the country. But, with the available time and resource in order to make the study more manageable and due to severity of solid waste threat, its scope is delimited to Addis Ababa city.

1.7. Limitations of the Study

While carrying out this thesis, the researcher was encountered by several constraints such as financial related problems and shortage of time. Because of the constraints of time and budget, the researcher doesn’t conducted solid waste transfer station potential sites construction cost analysis.

1.8. Organization of the Paper

This thesis has five chapters. Chapter one is an introduction part which consists of the introduction, statement of the problem, the objectives, significance, limitations and the scope of the study. Chapter two presents the review of related literature. Chapter three describes the study area and the research methodology. Chapter four contains the analysis, results and discussion parts of the study and the fifth chapter presents the conclusion and recommendations of the study.

Chapter Two

2. Review of Related Literature

2.1. Definition of Terms and Concepts

2.1.1. Solid Waste

Solid waste is a very general term which encompasses all waste materials except hazardous waste, liquid waste, and atmospheric emissions, although ‘‘most solid waste regulations include hazardous waste within the definition of solid waste’’ (Liu *et al*., 1997). Solid wastes are divided into three main categories: municipal, industrial, and agricultural. Municipal solid waste has several sources such as residential, commercial, institutional, construction and demolition, and municipal services (Tchobanoglous *et al*., 1993). Solid waste arises from human activities includes domestic, commercial, industrial, agricultural, waste water treatment, etc. If the waste is not properly handled and treated, it will have negative impacts on the hygienic conditions in urban areas and pollute the air and surface and groundwater, as well as the soil and crops (World Bank, 1999).

A hygienic and effective system for collection and disposal of solid waste is fundamental for any community. Generally, the demands for a solid waste management system increase with the size of community and its per capita income. Residues from waste treatment processes are returned to the waste mainstream and end up in the landfill with untreated waste. Hence, the backbone of any waste management system is an effective collection system and an environmentally sound sanitary landfill (World Bank, 1999).

Solid waste handling and treatment system components; among these components are; the principal solid waste activities including collection, transportation, treatment and disposal; the principal technology such as sorting, composting and incineration; and the final products covering recycling, composting and land reclamation. The solid waste material can be recycled such as organic waste, metal, plastic, etc. The solid waste material can be changed also to energy by using incineration technology. The final destination of solid waste residue is always a disposal site (World Bank, 1999).

2.1.2. Solid Waste Management

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

A solid waste management system consists of prepared plans and plants that are built for final disposal of waste as well as recycling, reuse, composting, and incineration. The municipal solid waste management system deals with the municipal solid waste from its source of generation until its final disposal, which includes all the operations and transformation of this waste (Liu *et al.,* 1997).

2.1.3. Solid Waste Reuse and Recycling Concepts

Recycling has increasingly been adopted by communities as a method of managing municipal solid waste. It is the process used to convert certain waste materials to new materials or products. This achieved by the separation of the waste at the source (curbside collection or drop-off center) by the residents, waste pickers, and waste collectors, and/or separation at the site (recycling plant at a landfill). Some recycled materials have high percentage of organic waste such as leaves, grass, food waste, etc. that can be used for soil improvement due to controlled decomposition of organic materials. The conversion of waste materials into soil additives is called composting (USEPA, 2002).

Reuse is the practice of using a material more than once in its original form, preserving some or all qualities to use it again. In some societies reuse is practiced in an organized manner by the residents, waste pickers, and scavengers, who sell items again at a low price. Ruse-Recycling is a series of activities, which includes separation, collection, transferring, transporting, sorting and processing. Materials disposed after use are recycled from the municipal waste stream and used as raw materials to manufacture products. Recycling prevents pollution, conserves resources and diverts the reusable and recyclable waste from landfills to industries. Reusable and recyclable materials are processed to be used for manufacturing to different items like paper, furniture, plastic materials and metals. There are many benefits associated with applying solid waste reuse and recycling system, which are as follows (USEPA, 2004):

- Extension of lifetime of landfills through saving space
- Reducing the cost of waste disposal
- Conservation of natural resources
- Reducing emissions of gases and water pollutants from landfills and decreasing the leachate generation
- Supplying valuable raw materials to industry
- Saving of energy to produce new primary material
- Creation of jobs.

2.2 Solid Waste Management in Developing Countries

Solid waste management is becoming a big challenge for the cities' administrations in many developing countries mainly due to the magnitude of rapid urbanization and increasing population growth which in turn have greatly accelerated the municipal solid waste generation rate in the urban environment (Zhang *et al.,* 2010; Guerrero *et al.*, 2013). The burden of increased waste generation poses on the municipal budget as a result of the high costs associated to its management, the lack of understanding over a diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system functioning (Mohghadam, 2009).

In most urban centers of developing countries, municipal solid waste management (MSWM) is highly unsatisfactory and beyond the capabilities of their economic setup for handling and disposal (Henry et al., 2006; WHO, 1996; and World Bank, 1999). The low-income countries are characterized by poor methods and low capacities of MSWM (Agunwamba, 1998). Between one-third and one-half of the solid wastes generated within most cities of low income countries are not collected and the waste generated is dumped at many undesignated sites (Bartone, 2001). Therefore, their management is a complex task that requires appropriate organizational capacity and cooperation between numerous stakeholders both from the private and public sectors from collection to resource recovery and from treatment to disposal practices (Cointrea- Levine, 1994).

Solid waste collection in urban centers throughout African regions, less than half of the solid waste produced is collected and 95 percent of that amount is indiscriminately thrown away at various dumping sites (Mohammed and Elsa, 2003). This has been proved to be true in Addis Ababa as only 65% of generated wastes are collected and transported to the disposal site and the rest is disposed informally in a manner of polluting the environment and the remaining amount is left uncollected thereby disposed in sanitary drainage channels, rivers, open spaces, street sides among other improper places (Abdulwahid, 2003).

Solid Waste Collection in Addis Ababa

Currently the daily solid waste generation in the city of Addis Ababa is estimated to be 0.5 kg per capita per day, the density ranges from 205 to 370 kg m^3 and the daily waste generation has reached to 2,750 m^3. Therefore, considering the city's population of 3.5 million people (CSA, 2007), it is estimated that approximately one million m^3 of solid waste is generated per year. Most of the solid wastes generated in the city of Addis Ababa are organic in their natures with households, institutions, commercial centers, factories, hotels, health facilities and streets as the major sources of generation types. In Addis Ababa as only 65% of generated wastes are collected and transported to the disposal site and the rest is disposed informally in a manner of polluting the environment and the remaining amount is left uncollected thereby disposed in sanitary drainage channels, rivers, open spaces, street sides among other improper places (Abdulwahid, 2003).

The Municipal solid waste collection service is unsatisfactory and observation of scattered waste is common in most part of Addis Ababa. Nonetheless, the collection system does not fully cover all residences, commercial centers and institutions especially those that are distant from the center. The solid waste collection policy in Addis Ababa has been decided by the city administration. According to the existing policy, solid wastes are collected by the government employees, private companies' based on contractual agreements and Micro and Small Enterprises (MSE). However, the principle stating that the waste producers are subject to put their wastes into different containers based on specific type of wastes is not practiced in the city (UNDP, 2004).

According to AASBPDA (2014), solid waste collection methods with the existing infrastructure facilities and manpower capacity, it is being attempted to collect and transport MSWs to a disposal site on daily basis. However, some distant parts of the city have very often less frequent collection than those in the center. In general, the collection is currently handled in different types of collection systems namely the door-to-door, curbside, set out, the block (container) collection systems and the street sweeping.

a) Door to Door Collection System

The door-to-door collection system is applied for households and is carried out by MSEs by walking the short distances from house to house. Each house owner put wastes in baskets, sacks, plastic bags or other suitable materials at the door side so that the collectors pick up and bring wastes using the pushcarts to common temporary storage points for the trucks to pick up them to the disposal site. Some of the storage areas could be street sides and pedestrian walkways. However, the regularity and frequencies of collection are not always maintained due to the less number of labors with their low payment. But the method is not implemented in apartments and condominium houses.

b) Curbside Collection System

Curbside collection system is the second most common practiced method where different sized containers are kept by the city administration near the street corners and street crossings so that householders deposit their wastes on them using baskets, plastic bags, sacks, or other suitable materials on regular frequencies. However, due to their low level of awareness some of the city dwellers end up throwing carelessly and littering the surrounding areas of the containers causing unclean and ugly view and attracting scavengers.

c) Setout Collection System

Setout collection system is not so popular in all parts of the city. It exists only in areas where there are no door-to-door collection systems especially in apartments and condominium houses. In this method, collectors are blowing horns as a signal indicating that they are there to collect wastes. After receiving the signal, the housing community members take out and deposit their wastes on pushcarts placed at convenient corner, which will later be taken to the transport trucks' site.

d) Block Collection System

The block (container) collection system is carried out by private companies from hotels, hospitals, schools and other service delivery and manufacturing organizations and the last solid waste collection method is street sweeping is held by the Addis Ababa Solid Waste Management Agency.

Solid Waste Preliminary Treatment in Addis Ababa

The integrated SWM principles state that the collected solid wastes need to be segregated into various types for the purpose of recycling, reuse or transformation at various levels involving all stakeholders (Van De Klundert and Lardinios, 1995). Therefore, there must be treatment processes before disposal to separate the recyclable and reusable resources out of the wastes. However, consciousness among the residents in Addis Ababa is so little that almost all the collected wastes are transported to the open disposal site without segregation. It is not also binding at present to separate recyclable or reuse materials from the collected wastes at the city level. However, informal recyclers at small-scale level are accomplishing some form of sporadic recycling manually though it is insignificant. There are craftsmen who recycle metal, wood, rubber, clay to provide essential goods to great number of customers in the city of Addis Ababa. However, facilities are not available to enhance their contribution for the purpose of waste treatments. Furthermore, the participation of the informal waste collectors and recyclers are not encouraged with the financial or technical support from the city government to make them formal (ENDA, 1999).

2.3 Solid Waste Transfer Station

A transfer station is a facility located close to residential areas that is used to receive and hold waste temporarily until it is transported to distant landfills, processing centers, or composting facilities. It can reduce energy consumption and environmental problems in solid waste management (USEPA, 2004).

Waste transfer stations play an important role in a community’s total waste management system, serving as the link between a community’s solid waste collection program and a final waste disposal facility. While facility ownership, sizes, and services offered vary significantly among transfer stations, they all serve the same basic purpose consolidating waste from multiple collection vehicles into larger, high-volume transfer vehicles for more economical shipment to distant disposal sites. In its simplest form, a transfer station is a facility with a designated receiving area where waste collection vehicles discharge their loads. The waste is often compacted, then loaded into larger vehicles (usually transfer trailers, but intermodal containers, railcars, and barges are also used) for long-haul shipment to a final disposal site typically a landfill, waste to- energy plant, or a composting facility. No long-term storage of waste occurs at a transfer station; waste is quickly consolidated and loaded into a larger vehicle and moved off site, usually in a matter of hours (USEPA, 2002).

According to USEPA (2002), some transfer stations also offer programs that manage specific materials separately to divert waste from disposal and to achieve recycling objectives. These materials could include construction and demolition debris, yard waste, household hazardous waste, or recyclables. The types of materials processed often vary depending on where the facility is located (urban, sub-urban, rural) and who owns and operates the operation at the transfer station. The types of waste that are commonly handled at transfer stations are municipal solid waste (MSW), residential, commercial, and construction and demolition.

2.3.1. Types of Transfer Stations

There are five types of solid waste transfer stations. These are direct dump-no floor storage, direct dump-floor storage, Compactor, Pit, and Combination. All these types are well established and many successful examples of each type of transfer station are in operation. There are larger numbers of compactor stations, in part because this concept has been promoted by sales representatives of equipment manufacturers. The pit concept has traditionally been popular on the west coast of America, whilst the direct-dump concept has gained popularity as improved self-unloading; open-top trailers have been developed (Herbert, 2001).

a) Direct Dump - no Floor Storage

The direct-dump transfer station is a two-level facility in which collection vehicles on the upper floor discharges waste through hoppers directly into open-top transfer trailers on the lower floor. The concept is inherently efficient because equipment and labor necessary to load the trailers are minimized (USEPA, 1995). A significant feature of this concept is that the trailer-loading operation must be capable of handling wastes as they are received. The concept dates back to at least 1950s, when it was used by Los Angeles County Sanitation District. It is appropriate for small or large stations with the capacity determined by the number of direct-direct dump hoppers. Several variables control the capacity of a hopper, including the pay loader of collection vehicles, average unloading time, number unloading simultaneously at a hopper, and capacity of the transfer station trailer. Based on these conditions, the 20 tones transfer station trailer would be loaded in 12 min and 7 min, would be required to level the load, move it out and replace it with an empty trailer. Three transfer trailers would be loaded each hour, providing a peak capacity of 30 tons per hopper. Direct-dump transfer stations typically use a stationary clamshell device to distribute the solid waste in the transfer trailer. The clamshell also provides a degree of compaction of the solid waste in the trailer. The clamshell is typically provided with specially designed grapple. The grapple can be opened and closed to move solid waste around in the trailer and it can be closed to allow it to be used in compacting the solid waste (Brown *et al*, 1981*)*.

b) Direct Dump - Tipping-Floor Storage

Many stations that have the capability for direct dumping of waste from the collection vehicles to the transfer trailer also utilize floor storage to increase station capacity during peak hours. This concept results in substantial changes to both station construction and operation. The station construction cost is significantly increased due to the larger tipping area required to accommodate the stored waste. This larger tipping floor area results in the need for larger building space and therefore significant increase cost. Operation methods and cost are increased. Storage of waste on the tipping floor results in the need for a larger wheel to load waste into the open-top trailer. The advantage of this concept is that during peak period, the station capacity is not limited by the rate at which transfer trailers can be loaded. There are economic trade-offs between station cost and trailer cost that must be evaluated by the design engineer (Brown *et al*, 1981).

The direct-dump type of facility with tipping-floor storage is also more suitable for a combined transfer station and materials-recovery facility. The tipping –floor storage provides the ability to separate materials that can be recycled before the waste is loaded into the trailer. Provided there is enough space, barriers can be erected on the tipping floor to provide storage bunkers for various materials such as yard waste, old corrugated cardboard, and other recyclable material (Tchobauoglous *et al.*, 1993).

c) Compactor

Many compactor transfer station have been constructed in the United States in the past few decades. Typically, they are two-level operation with collection vehicle unloading onto a receiving floor or into a hopper at the upper level. The solid wastes are then moved in to the compactor and compacted in to a transfer trailer at the lower level. When compactor stations use the receiving floor as a waste storage area, a wheel loader is used to pick up the waste and loaded into the hopper. Depending on the loader equipment capability and the operators' skill, it may be practical for one operator to load more than one compaction hopper. Another compactor station concept is to provide a large bunker to receive wastes directly from collection vehicle. The receiving bunker is at a right angle to the compaction hopper and the transfer trailer. The waste is pushed by a large hydraulically operated blade from the receiving bunkers into the compaction hopper and then compacted in to the transfer trailer. The transfer trailers are closed-top mechanical or hydraulic system types sized to handle the maximum legal payload (USEPA, 1995).

d) Pit

The pit concept has been in use for many years in some of the largest transfer stations in Europe. The principal advantage is the large storage capacity provided by the pit. It provides storage for peak deliveries and allows transfer haul to be operated on as much as a 24-h basis, if desired. Pit station has proven to be capable of handling bulky waste. The pit type transfer station is not conducive to recycling efforts. The emphasis with this type of transfer station is to unload the material as quickly as possible in to the pit (Brown *et al*, 1981).

d) Combination

Larger transfer stations may include more than one transfer method. Several stations include both pit and direct. The pit portion provides storage for waste received during peak periods. The direct-dump portion reduces handling of the waste and provides economical operations. The collection vehicles maneuvering area is generally in the center of the station and serves both the pit and direct dump. The Montgomery County, Maryland, transfer station, constructed in the mid-1980s, is an example of this combination concept (US EPA, 1995).

2.3.2. The Benefits of Transfer Stations

The main objective of transfer stations is reducing the cost of waste transportation. The loading of several waste collection vehicles can be transported in one trip to the landfill. The laborers and operation costs of transporting the waste a distance to the disposal site is saved. Besides reducing the transportation costs, there are many benefits from considering the system of a transfer station. These are (USEPA, 2002):

- Reduces overall community truck traffic by consolidating smaller loads into larger vehicles.
- Offers more flexibility in waste handling and disposal options. Decision-makers can select among different disposal options and secure the lowest disposal fees or choose a desired method of disposal (e.g., landfilling, waste-to-energy).
- Reduces air pollution, fuel consumption, and road wear by consolidating trash into fewer vehicles.
- Allows for screening of waste for special handling. At many transfer stations, workers screen incoming wastes on concrete floors or conveyor belts to separate out readily recyclable materials or any inappropriate wastes (e.g., tires, automobile batteries) that are not allowed in a landfill or a waste-to-energy facility.
- Reduces traffic at the disposal facility. The fact that fewer vehicles go to the landfill or waste-to-energy facility reduces congestion and operating costs and increases safety.
- Offers citizens facilities for convenient drop-off waste and recyclables. Some transfer stations have a designated area, often called a convenience center, where residents drop off waste or recyclables in collection containers.

2.3.3. Wastes Commonly Handled at Transfer Stations

According to USEPA (2004), the following types of waste are commonly handled at transfer stations and specific definitions of these wastes vary locally:

a) Municipal Solid Waste

Municipal solid waste (MSW) is generated by households, businesses, institutions, and industry. MSW typically contains a wide variety of materials including discarded containers, packaging, food wastes, and paper products. MSW includes a mixture of putrescible (easily degradable) and no putrescible (inert) materials. Three types of MSW are commonly diverted and handled separately: Yard waste (green waste) commonly includes leaves, grass clippings, tree trimmings, and brush. Yard waste is often diverted so that it may be composted or mulched instead of going for disposal.

b) Household Hazardous Waste

The second types of waste accepted is, household hazardous waste (HHW) includes hazardous materials generated by households, such as cleaning products; pesticides; herbicides; used automotive products such as motor oil, brake fluid, and antifreeze; and paint.

c) Recyclable Waste

Thirdly, recyclables include discarded materials that can be reprocessed for manufacture into new products. Common recyclables include paper, newsprint, ferrous metals, plastic, glass containers, aluminum cans, motor oil, and tires and finally, construction and demolition (C&D) debris results from demolition or construction of buildings, roads, and other structures. It typically consists of concrete, brick, wood, masonry, roofing materials, sheetrock, plaster, metals, and tree stumps. Sometimes construction and demolition debris is managed separately from MSW; other times it is mixed with MSW.

2.3.4. Transfer Stations site selection

One of the main goal of the MSWMS is to determine the type, location, and capacity of facilities that will be used for disposal and/or treatment of the waste, based on environmental, economic, social, and health considerations. Suitable location of disposal facilities is a major issue in waste management. Most studies have focused on location of the landfill alone, with low attention given to site selection for transfer stations (Kao *et al.,* 1997 and Kontos *et al.*, 2005).

Identifying a suitable site for a waste transfer station can be a challenging process. Site suitability depends on numerous technical, environmental, economic, social, and political criteria. When selecting a site, a balance needs to be achieved among the multiple criteria that might have competing objectives. For example, a site large enough to accommodate all required functions and possibly future expansion might not be centrally located in the area where waste is generated. Likewise, in densely developed urban areas, ideal sites that include effective natural buffers simply might not be available. Less than ideal sites may still present the best option due to transportation, environmental, and economic considerations. Yet another set of issues that must be addressed relates to public concern or opposition, particularly from people living or working near the proposed site. The relative weight given to each criterion used in selecting a suitable site will vary by the community's needs and concerns. Whether the site is in an urban, suburban, or rural setting will also play a role in final site selection (USEPA, 2002).

2.3.5. Criteria to select solid Waste Transfer Stations

As it is mentioned earlier identifying a suitable site for establishment of a waste transfer station can be challenging. The USEPA (2002), published a user manual that can be used by decision makers for planning, site selection, design, and operation of transfer stations. This manual has three components which consist of environmental, technical as well as community and social siting criteria.

a) Technical Siting criteria

This manual discuss about the operation and transportation conditions that should be taken into account to ensure that potential sites are suitable to build up a transfer station. For example: central location to collection routes. As a rule of thumb in urban area, transfer station should be less than 2 km away from the end of all collection routes. This is because the aim we build transfer station is to save money and transportation fuel. If we broke this rule, the objective for build a transfer station for community cannot be achieved.

b) Environmental Siting Criteria

Land use, geology, groundwater, surface water, ecology, visibility, traffic and topography are important in environmental siting criteria. As a result, site topography should be taken into consideration to reduce the prevalence of potential wind blown litter and to minimize the number of vantage points that the site is visible from. The impact of site topography on construction requirements should also carefully considered because a transfer station with well equipped will reduce the amount of excavation works and additional fell requirements.

c) Community and Social Criteria

The third category of criteria to consider is impact that the facility will have on the surrounding community. These criteria are typically less technical in nature and incorporate local, social, and cultural factors. Examples of these criteria include environmental justice considerations (e.g.: clustering, cumulative impacts), impact on air quality, impact on the local infrastructure, proximity to schools, churches, recreation sites, and residences, number of residences impacted, impact on historic or cultural features, impact on neighborhood character and impacts on existing businesses.

2.4. Empirical Results of Solid Waste Transfer Stations

Transfer stations reduce energy consumption and environmental problems in solid waste management. As investigated in Mashhad City (Iran), as a result of the large distance to the new landfill, establishment of transfer stations is an appropriate method for efficient waste management (Khorasani and Rafiee, 2007).

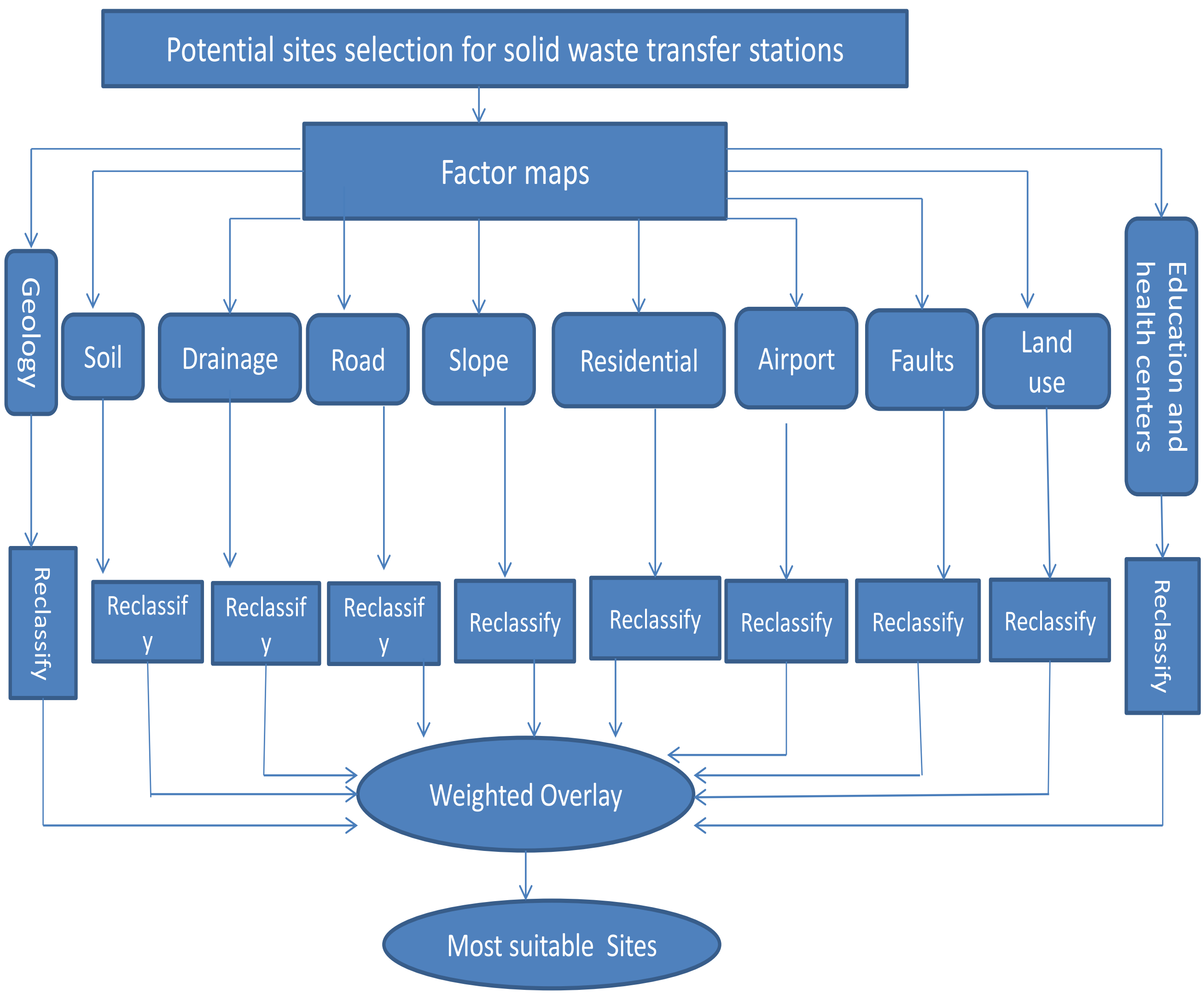
Transfer stations may result in approximately 38 percent reduction in energy consumption along with reduced emission of toxic components into the air and water due to reduced fuel consumption resulting from fewer trips (Khorasani and Rafiee, 2007). Additionally, consolidation and compaction of waste at transfer stations reduces waste volume significantly. From a social viewpoint, transfer stations eliminate other problems, such as ‘‘not in my backyard’’ NIMBY, by locating the landfill in a remote area (Eshet *et al*., 2006).

2.5. The Role of GIS and RS to Select Solid Waste Transfer Stations

As pointed out earlier, the site selection process for transfer station depends on several criteria that require sophisticated spatial analysis, so an informed decision-making and problem-solving process relies on multi criteria evaluation (MCE), which is based on the Geographic Information System (GIS) technology. Remote sensing data are the primary input sources of GIS. Today, application of GIS techniques integrated with MCE is well documented: for example, Malczewski, (1999, 2004) and Carver, (1991) have provided a comprehensive review of GIS and MCE. In the context of integration of GIS and MCE, two procedures are commonly used (Jiang and Eastman, 2000). The first is the Boolean overlay, whereby all criteria are assessed by implementing a threshold for suitability, and the second procedure is weighted linear combination (WLC). In the Boolean overlay a crisp decision is made regarding the suitability of each criterion; afterward the criteria maps are combined using logical operations OR and AND, such that the resultant image simply has two classes indicating the suitable and unsuitable areas. In contrast, with the WLC method, each criterion is standardized in terms of suitability in a numerical range, and criteria are then combined using weighted averaging. In this procedure the final image is a continuous map that can be used as a useful tool for decision making (Jiang and Eastman, 2000).

Land suitability analysis is another field in which MCE could be used along with GIS capabilities. While GIS functions accommodate the manipulation of spatial data, MCE would be applied for combination of spatial data and for grouping them into a land suitability index (LSI). In this case, the aim of the procedure is to select the best location for a facility after assessment of the entire area rather than choosing from a few candidate sites (Joerin *et al.*, 2001 and Kontos *et al.*, 2005).

Conceptual framework



d Figure 2.1 Conceptual framework.

Chapter Three

3. Materials and Methodology

3.1. Description of the Study Area

3.1.1. Location

Geographically, Addis Ababa is located between 8°55' and 9° 0 5' N Latitude 38°40' and 38°50' E Longitude. The city is located at the center of Ethiopia with an area of 530 km² of which 18.174 km² is rural. Addis Ababa is a seat both for Federal Democratic Republic of Ethiopia (FDRE) and Oromiya National Regional State Government. It is bordered with Oromiya National Regional State in all directions. There are 10 sub-cities (Kifleketema) and about 116 Kebeles (AACA, 1998).

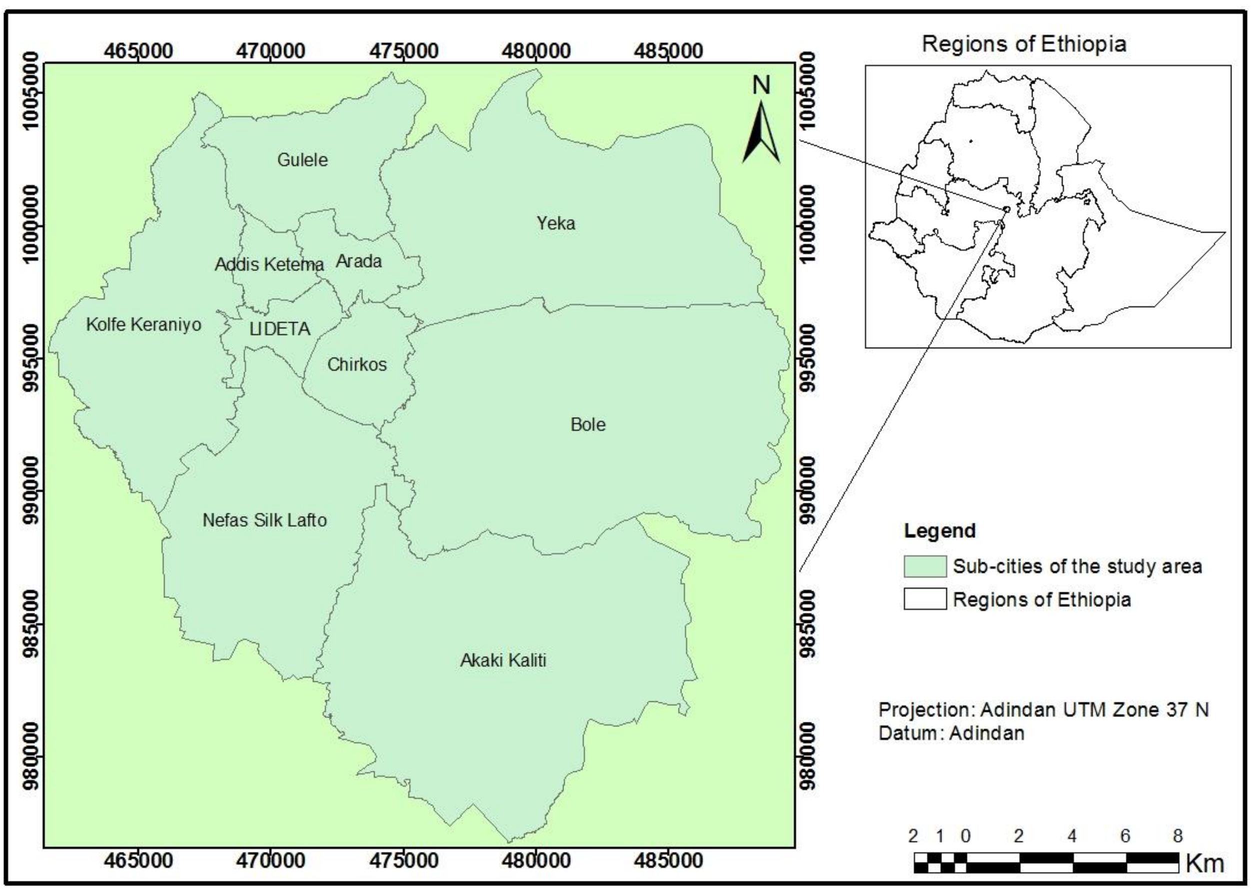


Figure 3.1 Map of the study area (Source: CSA, 2007).

3.1.2. Population

Understanding of the human population dynamics is very important when we select potential sites of solid waste transfer stations. The population of Addis Ababa has grown from 443,728 in 1961 to 683,530 in 1967, 1,167,315 in 1978, 1,423,111 in 1984, 2,112,737 in 1994 and to its value (2,738,251) in 2007. Compared to the 1984 census, the 1994 population size has shown 3.26% increase. This change has occurred due to not natural increase and migration but also area size expansion of the city. It must be noted that area size of Addis Ababa has increased from 2,204 hectares in 1984 to 53021 hectares in 1994 and to 54,000 hectares in 2007. The current size of the estimated population of the City is 3,147,000, of which 1,511,000 is men and, 636,000 is women with 3.8 annual growth rate and density of 5936.2/km². The household size varies from 7, 6, 5 persons per household in lower, middle, and higher income families respectively (CSA, 2007).

Table 3.1: Population distribution by sub city:

No.	Sub city name	Area in (hectares)	Population size	Percentage (%)	Population density/km²
1	Addis Ketema	8,98	255,092	9.3	28,407
2	Akaki Kalti	12,614	181,202	6.7	1,437
3	Arada	1,156	212,009	7.78	18,340
4	Bole	12,094	308714	11.2	2,553
5	Gulele	3,273	267,381	9.76	8,169
6	Kirkos	1,626	220,991	8	13,591
7	Kolfe Keraneo	6,510	428,654	15.6	6,585
8	Ledeta	1,240	201,613	7.4	16,259
9	Nifas Silk	6,359	316,108	11.5	4,971
10	Yeka	8,230	346,484	12.6	4,210
Total		**54,000**	**2,738,251**	**100**	**5,071**

(Source: CSA, 2007).

From the above table 3.1, there is a disparity in Sub City population distribution which shows uneven distribution. The majority of the city population lives in Kolfe Keranyo (15.6%), Yeka (12.6%), and Nefas silk Lafto (11.5%) whereas; Arada and Kality have the smallest share from the City's total population. Regarding density, Addis Ketema has the highest (28,407 persons/ km²) followed by Arada (18,340 persons/ km²) and Lideta (16,259 persons/ km²) while, Akaki Kality (1,437 persons/ km²) is the most sparsely populated Sub City of Addis Ababa.

3.1.3. Climate

Addis Ababa has a subtropical highland climate. The highland climate regions are characterized by dry winters, and this is the dry season in Addis Ababa. During this season the daily maximum temperature is not more than 23^{0}C. The short rainy season is from February to May. During this period, the city experiences warm temperature and pleasant rain fall. The long wet season is from June to mid- September and it is the main winter season of the country. The rainy season for Addis Ababa which is also the same for the most parts of Ethiopia extends from July to late September. These wet periods, especially July and August are not convenient for any construction works, as far as the rain fall pattern is considered. The annual precipitation of the city is 1,018 mm/year. The summer has warm sunny days and cool nights. The highest temperatures are during the months of July and August. November and December also have low temperature with low rain fall. The average annual temperature is 16^{0}C whereas the mean annual potential evapotranspiration is 98.03 mm (National Meteorological Agency, 2014).

3.1.4. Topography of the study area

Addis Ababa is located in the western margin of the rift valley and the vicinity of the city is surrounded by hills and mountains like Entoto mountain chains in the northern part of the city (Zenettin et al., 1974). Based on FAO (2013) slope classification the largest part (64.4%) is covered by rolling to hill slope class and about 23.6% is covered by gentle to level slopes, while about 12% of the study area is covered by steeply dissected to mountainous slope types.

Elevation: the elevation map was generated from the study area DEM in the Arc GIS environment using Spatial Analyst tools. Therefore, based on the map shown below, the elevation of the study area ranges from the highest point of 3,133 m to the lowest point of 2015 m above sea level as it is indicated in the following contour map (Figure 3.2).

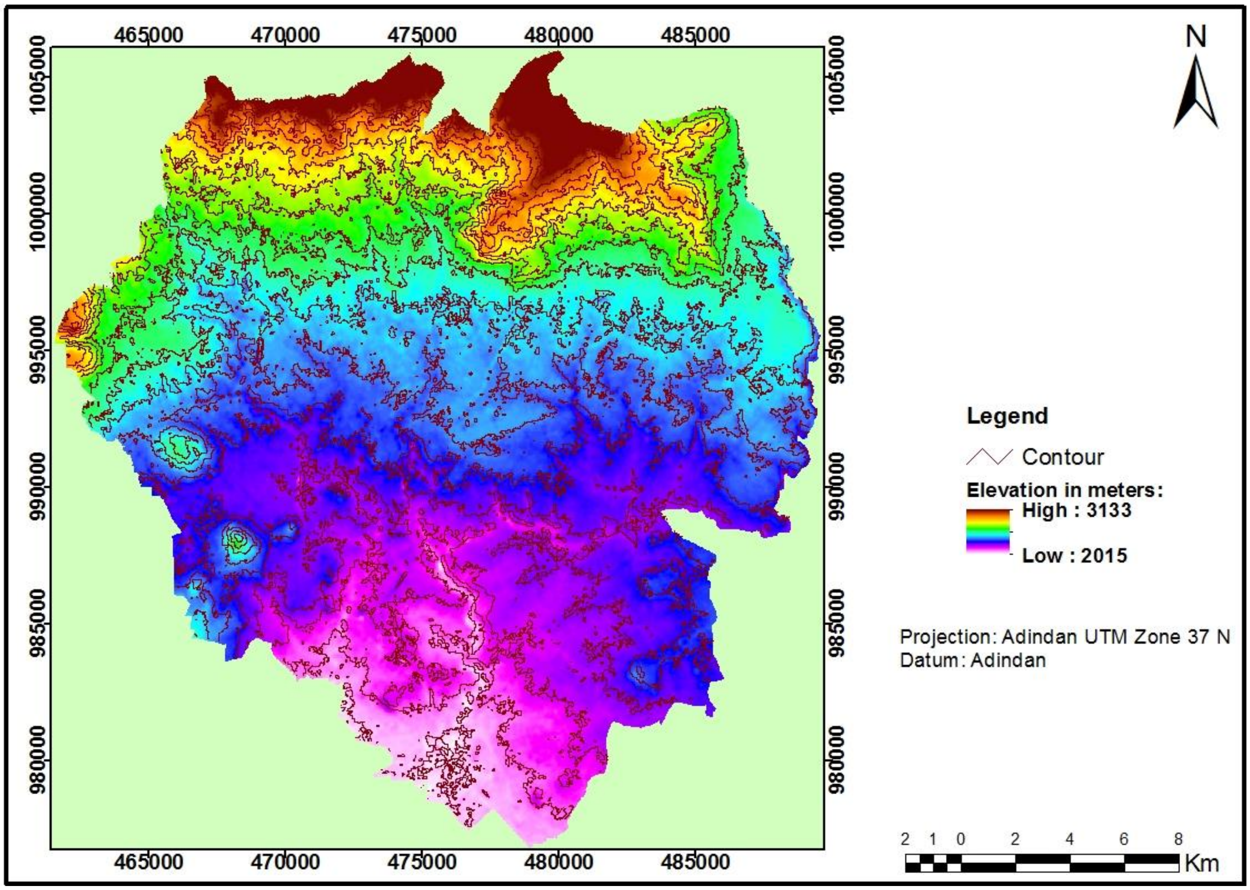


Figure 3.2 Contour map of the study area (Source: Generated from DEM, 2015).

3.1.5. Soil of the Study Area

The term "soil", typically used by engineers to indicate fragmented material that can be excavated without blasting or other mechanical loosing. According to Kebede and Tadesse (1990), the engineering geological soil units in Addis Ababa area are grouped in to four genetic (origin) soil units as alluvial soils, alluvial fan deposits, colluvial residual, and lacustrine.

a) Alluvial Soils

These deposits are found in some places along Akaki river in west and south west of the city and along Kebena river North West of Bole area. Alluvium consists of more or less stratified deposits of gravel and clay moved by streams from higher to lower ground. Channel and terrace deposits are taken together as alluvium deposits. Alluvial soil sampled from terrace deposits (near Bole) consists of 46% silt, 34% clay, and 20% sand.

b) Alluvial Fan Deposits

Alluvial fan is a mass of sediments deposited at a point along a river where there is a decrease in gradient from a hill or mountain to a plain. Such deposits are mainly found in the Entoto region. The change in gradient is formed by a fault scrap. These deposits at present are dissected by deep gully.

c) Residual Soils

Soils developed in situ by the decomposition of rocks on which it lies. These soils are located mainly in central part, Gulele and Kolfe regions. Few samples from residual soil were obtained and the average grain size is 62% clay, 33% silt, and 5% sand.

d) Lucstrine/ Black Cotton Soils

Soils located around Bole, Ledeta, and Mekanissa areas are lacustrine origin. These regions are fat and relatively low in altitude as compared to the other parts of the city. The name black cotton soil is given due to their physical properties. Black is because of the color and cotton to their high moisture (water) absorbing capacity. On sample taken from Bole and Mechanissa area, grain size of soils has 76% clay, 22% silt, and 2% sand.

3.1.6. Geology

According to Assegid (2007), the geological units of the study area include the following categories and the details of each geological unit presented as follows:

a) Foota Basalt

This unit is exposed in the north western part of the city. It mainly forms ridge with the maximum thickness measure being 480 m. This basalt is dark grey on fresh outcrops. Upon weathering, it has developed a laterite with maximum thickness of 2 m and locally it shows spheroid weathering. It is characterized by sub horizontal layering.

b) Tertiary Sediment

This unit is exposed in southern part of the study area. Out crops are mainly observed at the banks of the river and small creeks. It generally forms very gentle slope and lower topography. It is overlain by the young quaternary basalt and Repi basalt. The maximum thickness is about 9 m which is around Akaki area.

c) Wechecha –Yerer- Furi Trachayte and Trachy Basalt

This unit is located in the western and south eastern part of the area. This unit mostly forms big mountains such as Furi, Wechecha, and Yerer. It is found overlying the Repi basalt and contact is marked by a thick paleosoil. It is an aphanitic to medium grained in texture with vesicular varieties mostly at its lower part.

d) Repi Trachy Basalt

This unit is found in general in the central and eastern part of the area and forms mainly flat and except that at some places it form ridges. In the central part it overlain by Wechecha Yerer Furi igimbrite where as in the central western part it is overlain by Yerer Furi Wechecha trachyte. Spheroid weathering is more conspicuous phenomenon.

e) Chelekleka Basalt

This unit is found in the north eastern and southern parts of the area. This unit is formed by different layers which are aphanitic basalt agglomerate and pyroclastic rocks. This rock is highly fractured and dens below which there is 40 m thick crystalline and coarse grained trachayte.

f) Intoto Trachyte

Intoto trachyte is exposed in the northern part of the city. This unit is generally coarse grained porphyritic and highly weathered. This makes it to have weathering color of light pink to white. It is covered by patches of quaternary olivine basalt.

g) Intoto Mixed Rocks

The Intoto mixed rocks are exposed in the northern and north east of the area. This unit consists of trachyte, ignimbrite, pyroclastic rocks and sediments. All the rocks are highly weathered and joined with few layers of agglomerate at some places. It develops a thick red soil and covered by patches of quaternary basalt except in southern margin.

h) Wechecha- Yerer -Furi Ignimbrite

This unit is found cropping out in the eastern part of the study area. It is grey, which contains Fragments of ignimbrite, rhyolite, and pumice with sanidine phenocrysts. It is fine to medium gained in texture and overlain by Wechecha Yere Furi trachy basalt and trachyte to the central and western part but to the north and eastern part it overlies the lower ignimbrite, Intoto mixed rocks and Repi basalt.

i) Lower Ignimbrite

This unit outcrops in the eastern, central, south western and north eastern parts of the study area with the eastern part being extensive than the western part. The rock is medium to fine grained and composed of sanidine phenocrysts and fine grained ground mass. This unit is generally consists of two layers. The top layer is coarse whereas the lower layer is fine grained. In between the two layers there is a baked soil horizon. At the center, the lower part is very fine but to the periphery it becomes more coarse grained than the central.

j) Quaternary Scoria

This unit is found in the central part of the study area. These scoria cones are found as either cones or simple domes. Mostly they are layered and sometimes contain grey vesicular basalt bombs. This unit is mainly cut by basaltic dyke of different orientation.

k) Quaternary Basalt

This unit is exposed in the northern central and south central part of the study area. It mainly forms ridge and the maximum thickness measured is 50 m. this rock unconformably overlies the Wechecha –Yerer - Furi ignimbrite and the Wechecha – Yerer – Furi trachyte and trachy basalt. Thin section studies of samples from this unit show about 60% plagioclase, 20% pyroxene, and 5% opaque minerals and 15% ground mass.

3.2. Methods

3.2.1. Data Sources

Both primary and secondary data were used in the study. The primary data like GPS points were collected from field surveys and observation. Whereas, secondary data were acquired from internet, reports, books, journals, governmental institutions, and from other documents.

Table 3.2 A Short summary of data and their sources:

No	Data	Data Sources
1	Geology of the study area	From Ethiopian geological survey.
2	Land use/ cover	From the municipal land management office
3	Soli	From Ministry of Agriculture
4	Road network	Digitized from the existing land use of the of the study area.
5	DEM (resolution 30*30)	Generated from SRTM (Global Land Cover Facility: www.landcover.org) raw = 54, path = 168
6	Slope and contour	Generated from DEM of the study area.
7	Drainage	Generated from DEM.
8	Protected areas (airport, hospitals, schools areas etc.)	Digitized/extracted from the existing land use/land cover map of the study area.
9	Software and equipment employed	Arc GIS 10.1 and ERDAS imagine 9.2, GPS, etc.

3.2.2. Data Collection

The data collected from different institutions were geo-referenced and the projection type was re-defined accordingly in the Arc GIS environment for further processing. Therefore, the geo-referenced data were manipulated and analyzed in Arc GIS environment to select the appropriate solid waste transfer station potential sites.

3.2.3. Spatial Multi -Criteria Analysis Approach

GIS based Spatial Multi-Criteria Approaches (SMCA) have the potential to reduce the costs and time involved in siting facilities by narrowing down the potential choices based on predefined criteria and weights and permitting sensitivity analysis of the results. The suitability map was produced by overlay analysis on Arc map (Higgs, 2006). Therefore, this method was employed to identify the most suitable solid waste transfer stations potential sites in the study area.

There are several methods for deriving weights, among many some of them are ranking, rating, pairwise comparison and trade off. The simplest way is straight ranking (in order of preference: 1=most important, 2= second most important, etc.). Then the ranking is converted into numerical weights on a scale from 0 to 1, so that they sum up to 1 (Malczewski, 1999).

In this study the weights were developed based on Analytical Hierarchy (AHP) method which developed by (Saaty, 1980) using pairwise comparison matrix. A matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9 and the higher the weight, the more important is the criterion. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons, If $CR > 0.10$, then some pairwise values need to be reconsidered and the process is repeated till the desired value of $CR < 0.10$ is reached. The main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting conflicting objectives and its ability to detect inconsistent judgments using consistency ratio (CR). The factors and their resulting weights were used as input for the spatial multi-criteria evaluation (SMCE) technique for weighted linear combination of overlay analysis (Malczewski, 1999).

3.2.4. Weighted Linear Combination (WLC) in the GIS Environment

Weighted Linear Combination (WLC) is a type of multi-criteria evaluation method in GIS environment used to evaluate the suitability of solid waste transfer station sites. It is more flexibility than the Boolean approaches in the decision making process. The approach allows the decision maker to assign weights according to the relative importance of each suitability map and combines the reclassified maps to obtain an overall suitability score. WLC implemented via the following four steps. The first step is determination of data, second step is development of attributes of criteria and their standardization, the third step is determination of the relative importance weights, and at final step is overlay analysis/combining of all criteria used in this study to find the most suitable sites for solid waste transfer station potential sites (Malczewski, 2004). In short, to select solid waste transfer station potential sites the researcher has followed the following procedures/steps:

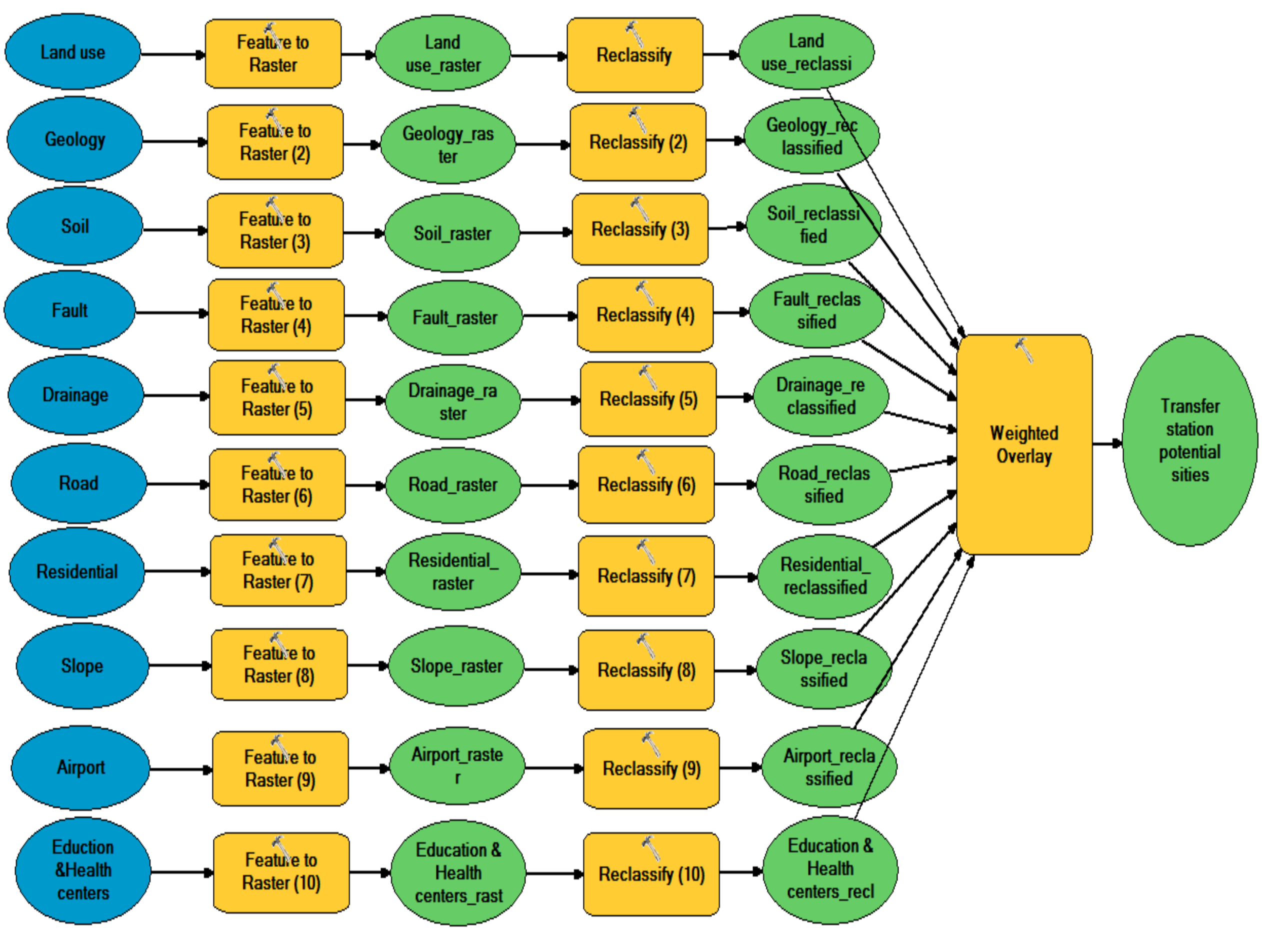


Figure 3.3 Procedures to select potential sites.

Chapter Four

4. Data Analysis and Interpretation

In this chapter, all factor maps/criteria used in the analysis would be geo-referenced, converted in to raster format, and reclassified according to their suitability classes in Arc GIS environment. After the reclassification process, weights are assigned for each criterion based on AHP model using pairwise comparison matrix. Finally, all standardized criteria would be combined to perform weighted overlay analysis so as to obtain the potential sites and to produce the thematic map of the most suitable sites for solid waste transfer stations.

The potential site selection process in the city of Addis Ababa considered the following criteria namely geology, drainage, slope, land use, soil, road networks, protected areas (airport, education, health centers, etc.) and other related factors of the study area. Based on various reviews, all of the above mentioned factor maps were converted in to raster format and reclassified in to four suitability classes (unsuitable, moderately suitable, suitable, and highly suitable) with weight ranging from 1- 4, where value 1 assigned to least suitable and value 4 assigned to the most suitable for all criteria used to select potential sites.

The major criteria used to select the potential sites, the suitability index, and standards based on various reviews for each criterion, and their respective sources are presented in (Table 4.1) below.

Table 4.1: Criteria/Factor maps, standards with their respective sources:

	Factor maps	Suitability standards	Sources
1	Land use/ cover	Less economic importance lands are highly suitable (open space, agricultural areas etc.)	UNEP (2005).
2	Slope	Areas with a slope of > 17% unsuitable, Areas with a slope of 4-11% most suitable,	Makhdoum (1993).
3	Soil permeability	Soil permeability of < 10 – 5 m/s is suitable.	UNEP (2005).
4	Distance from road networks	Areas within 500 m unsuitable while, areas above the distance of 500 m suitable with an increase in distance.	EPA (1995) and Rafiee *et al.* (2011)
5	Geology	Unconsolidated geological units are not suitable	Ersoy and Bulut (2009).
6	Fault	-Areas within 1000 m are not suitable and the suitability increases as proximity distance increases.	Rafiee *et al.* (2011)
7	Distance from Drainage networks	Areas within 500 m unsuitable	UNEP (2005). Rafiee R. (2007).
8	Distance from protected areas	Areas within 5,000 m from airport and 2000 m from schools, health centers etc. unsuitable.	Ayat, (1994) and USEPA (2004).
9	Residential	Areas found within 1000m unsuitable	Rafiee *et al.* (2011) and USEPA (2004).

4.1. Slope of the Study Area

According to FAO (2013), slope classification the study area is characterized by level to gentle undulating dominant slopes ranging between 0 – 8%, rolling to hill dominant slopes ranging between 8 – 30%, and steeply dissected to mountainous dominant slopes over 30%.

Table 4.2: Slope of the study area and area coverage:

No.	Slope classes	Areal coverage in (ha.)	Area in (%)
1	Gentle to level	12,720.7	23.6
2	Rolling to hill	34,796.8	64.4
3	Steep	6,482.5	12.0
Total		**54,000**	**100**

Source: Extracted from reclassified slope map attribute table.

Based on the above slope and area coverage (Table 4.2), from the total study area the largest part (64.4%) is covered by rolling to hill slope types and 23.6% is covered by gentle to level slopes, while, 12% of the study area is covered by steeply dissected to mountainous slope class and this type of slopes are more available in the northern parts of the study area.

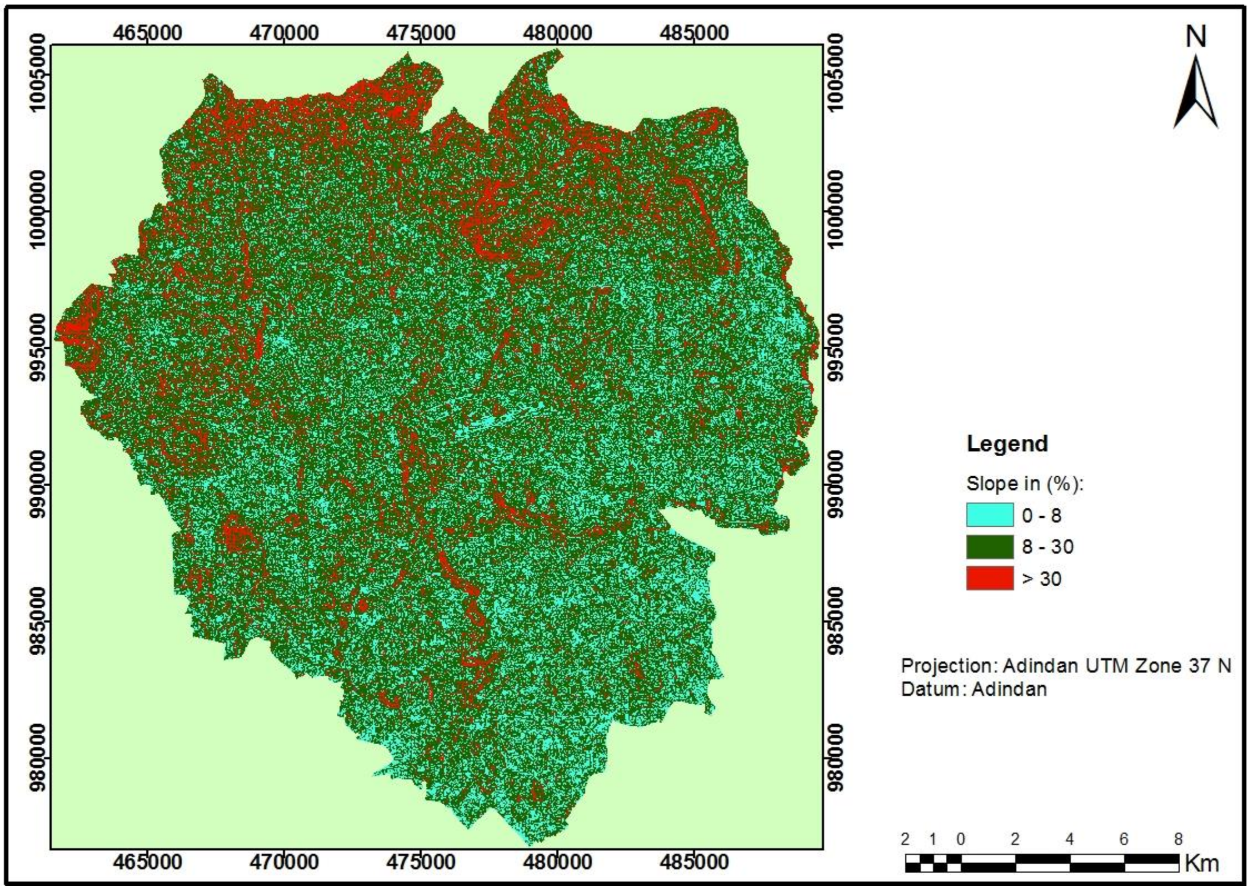


Figure 4.1 Slope map of the study area (Source: Generated from DEM).

Slope Suitability Analysis of the Study Area

To calculate the slope suitability index of the study area for solid waste transfer station potential sites selection, the slopes were reclassified in to four classes in Arc GIS environment. Based on the standard used by Makhdoum (1993), areas with a slope of (0 - 4%) were considered as suitable for solid waste transfer station sites, because areas with this slope are more vulnerable to water logging problems. Swaps and water logging areas are not more suitable due to their impact on ground water pollution. Areas with a slope of (4 - 11%) were found highly suitable because these areas are easy to manage and construct the stations, less vulnerable to swap and water logging formation etc. Areas found within a slope of (11 - 17%) were considered as moderately suitable whereas, areas with (> 17%) were evaluated as unsuitable for the stations as a result of steepness of the topography. Steep slope areas are more vulnerable to erosion due to high acceleration of surface water and this affects the life of the transfer stations as well as the leachates generated from the solid waste pollute the environment.

Table 4.3: Slope suitability and area coverage:

No.	Suitability classes	Suitability rank	Area in (ha.)	Area in (%)
1	Highly suitable	4	15,985.7	29.6
2	Suitable	3	3,367.1	6.2
3	Moderately suitable	2	13,007.8	24.1
4	Unsuitable	1	21,639.4	40.1
Total			**54,000**	**100**

Source: Extracted from reclassified slope map attribute table.

During slope reclassification process the highest value (4) was assigned to highly suitable areas/gentle slopes whereas, the lowest value (1) was assigned to unsuitable areas/steep slopes in the Arc GIS environment. Areas with steep slopes are not suitable for transfer stations due to difficulty to construct stations and high vulnerability of erosion as it was mentioned before. Generally, based on the above slope suitability (Table 4.3), the study area is dominated by unsuitable slope classes (40.1%) and 29.6% of the area was highly suitable while, only 6.2% of the study area was considered as Suitable for solid waste transfer station potential sites. The slope suitability map of the study area depicted as follows (Figure 4.2):

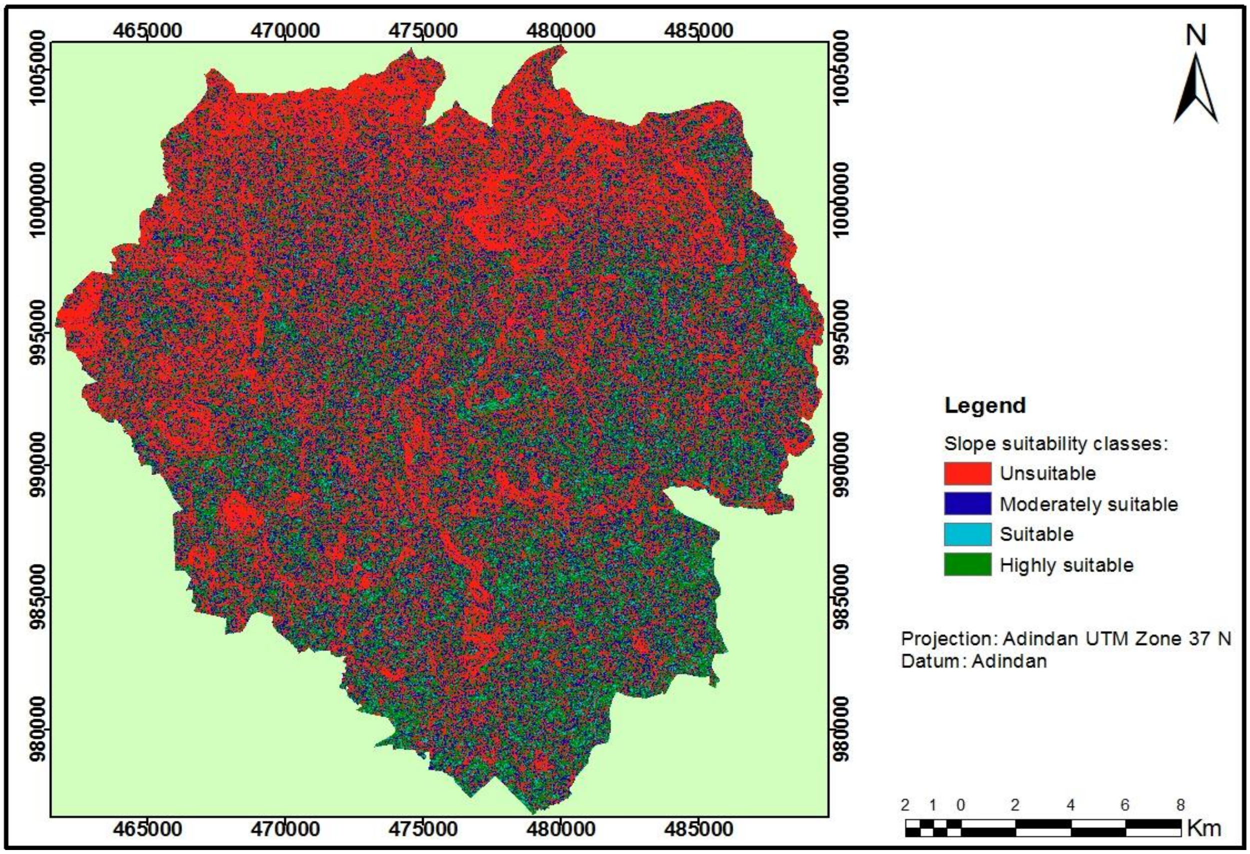


Figure 4.2 Slope suitability map of the study area.

4.2. Hydrology of the Study Area

All the streams of Addis Ababa rise from the Intoto Mountain, that forms long range and this ridge is a water shade of the Abay (Blue Nile) and the Awash basins. In general, all streams are drained into the Awash. Kebena and Akaki are the main rivers crossing the city and drain towards south and join the Awash river. In west, south west, and central part of the city they form terraces and alluvial deposits (Kebede and Tadesse, 1990).

The present day landforms of Addis Ababa are influenced by geological processes specially faulting and denudation. The layering of lava flows is dipping nearly southwards and similarly the unconformity surfaces. For this reason the general ground water flow is from the north to south. Hence, the central and the southern parts are subjected to pollution from waste waters upstream. The ground water flow of eastern side is from east to west and the western part is from west to east and therefore, pollution risk from the city waste waters is minimum (Kebede and Tadesse, 1990). The drainage network of the study area is clearly indicated in the following map (Figure 4.3).

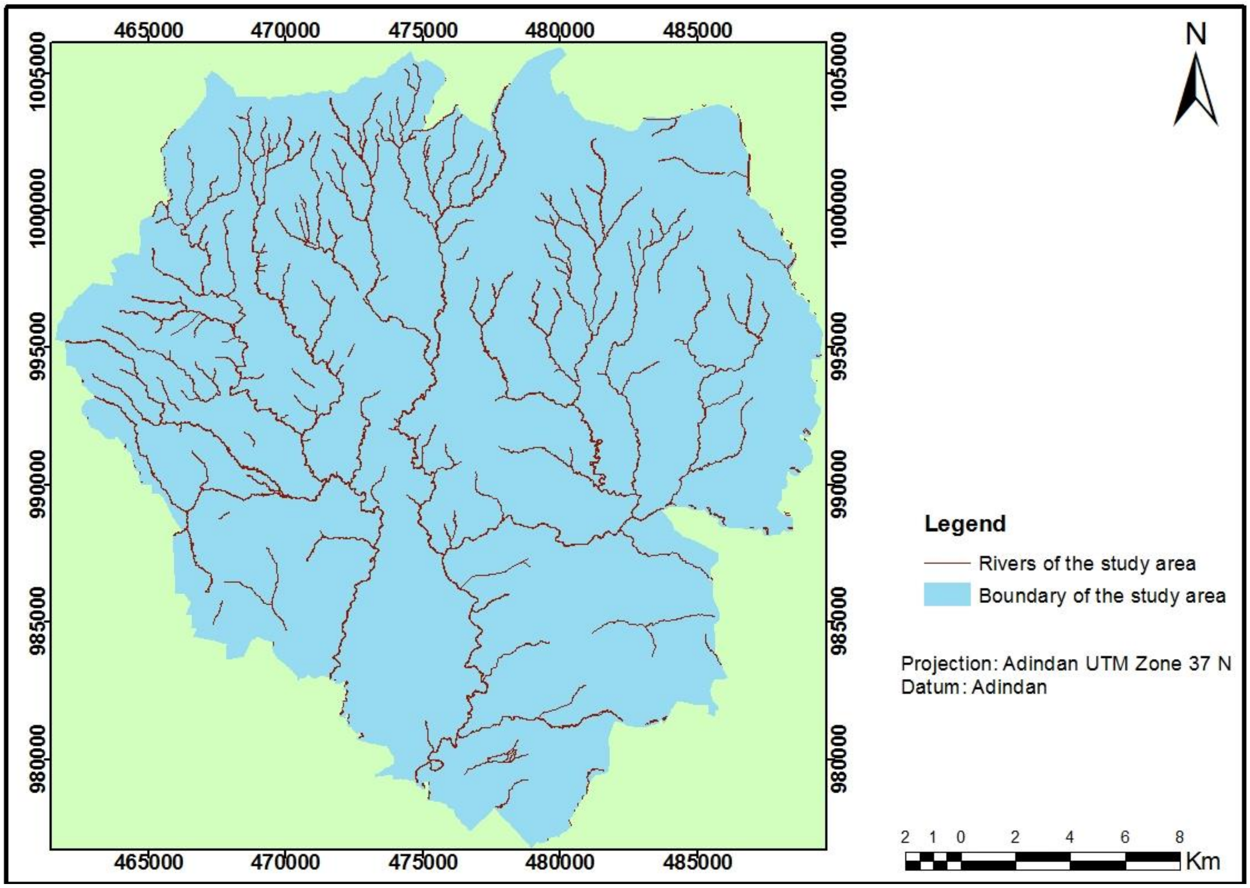


Figure 4.3 Drainage network map of the study area (Source: Generated from DEM)

Drainage Suitability Analysis

Based on UNEP (2005) and Rafiee R. (2007), areas far away from streams are more suitable for solid waste transfer station potential sites. Buffer distance was used to determine the proximity of areas found from the drainage networks. The four drainage proximity suitability ranges were also determined by the buffer distance performed in the Arc GIS environment using Spatial Analyst tools.

Table 4.4: Drainage proximity suitability and areal coverage:

No	Suitability classes	Buffer distance (Meters)	Area in (ha.)	Area in (%)
1	Highly suitable	>1500	9,55.1	1.8
2	Suitable	1000 -1500	3,089.9	5.7
3	Moderately suitable	500 – 1000	13,123.6	24.3
4	Unsuitable	0 – 500	36,831.4	68.2
Total			**54,000**	**100**

Source: Extracted from reclassified drainage map attribute table.

The highest suitability rank (4) was assigned to areas found far away from the drainage networks (buffer distance > 1500 m) and the lowest value (1) was assigned to areas nearest to the streams (buffer distance within 500 m) and they were considered as unsuitable for solid waste transfer station potential sites because of high vulnerability of pollution by hazardous solid wastes. In short, based on the above drainage suitability (Table 4.4), the largest portion of the study area (68.2%) was found as unsuitable whereas, 1.8% of the area was highly suitable for solid waste transfer station potential sites.

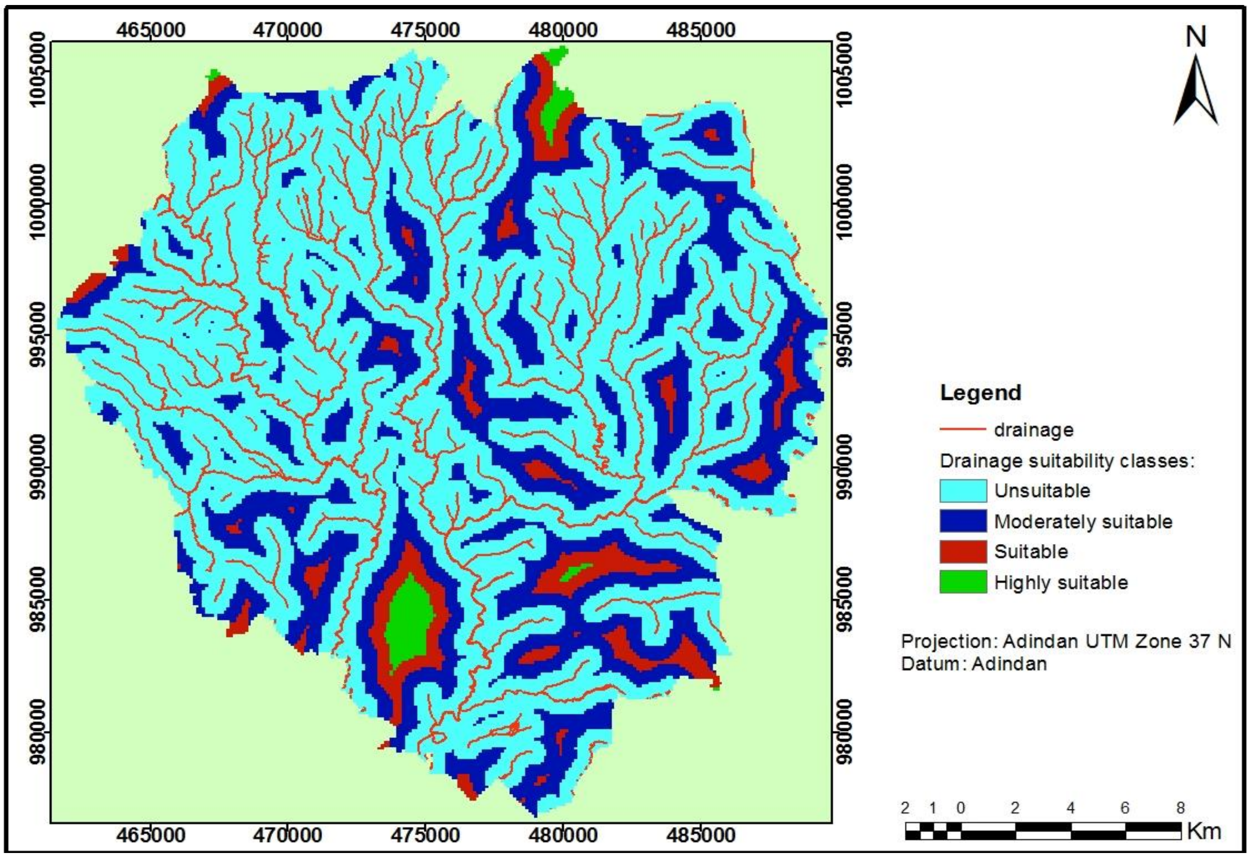


Figure 4.4 Drainage proximity suitability map of the study area.

4.3. Land use of the Study Area

Land use map of the study area is one of the criteria used to select potential sites for solid waste transfer stations in the city of Addis Ababa. The land use map was collected from the City Government Administration of Addis Ababa land management office. As it is clearly shown in the following (Figure 4.5) the study area classified in to 23 land use/cover categories. The area coverage of each land use type indicated in the following (Table 4.5).

Table: 4.5: Areal coverage of existing land use/cover of the study area:

No	Land use type	Area in (ha.)	Area in (%)
1	Administrative areas	1,067.6	2.0
2	Commercial areas	8,25.1	1.5
3	Cultural & social welfare	2,03.2	0.4
4	Education	9,43.1	1.7
5	Field crops	14,207.6	26.3
6	Health	2,74.5	0.5
7	Infrastructure & utilities	1,12.2	0.2
8	Manufacturing & storage	1,813.2	3.4
9	Mixed forest	1,316.6	2.4
10	Mixed residential	9,01.6	1.7
11	Municipal services	5,73.5	1.1
12	Open space	4,494.6	8.3
13	Plantation	4,175.5	7.7
14	Recreation	2,02.5	0.4
15	Religious institution	7,04.4	1.3
16	Residential	12,862.2	23.8
17	River	1,179.5	2.2
18	Riverine	1,35.6	0.3
19	Road network	5,333.4	9.9
20	Special use	4,34.5	0.8
21	Transport terminal	6,18.2	1.1
22	Under construction	1,226.1	2.3
23	Vegetable farms	3,95.3	0.7
	Total	**54,000**	**100**

Source: AACA land management office, 20014

The land use analysis of the study area helps us to know which areas are more suitable and not suitable for solid waste transfer station sites based on various reviews. Based on the above (Table 4.5), the largest part of the study area is covered by field crops (26.3%), residential (23.8%), road networks (9.9%), and open spaces (8.3%) respectively while the smallest land use of the city occupied by infrastructure and utilities (0.2%), riverine (0.3%), cultural and social welfare (0.4%) as well as recreational (0.4%) areas respectively.

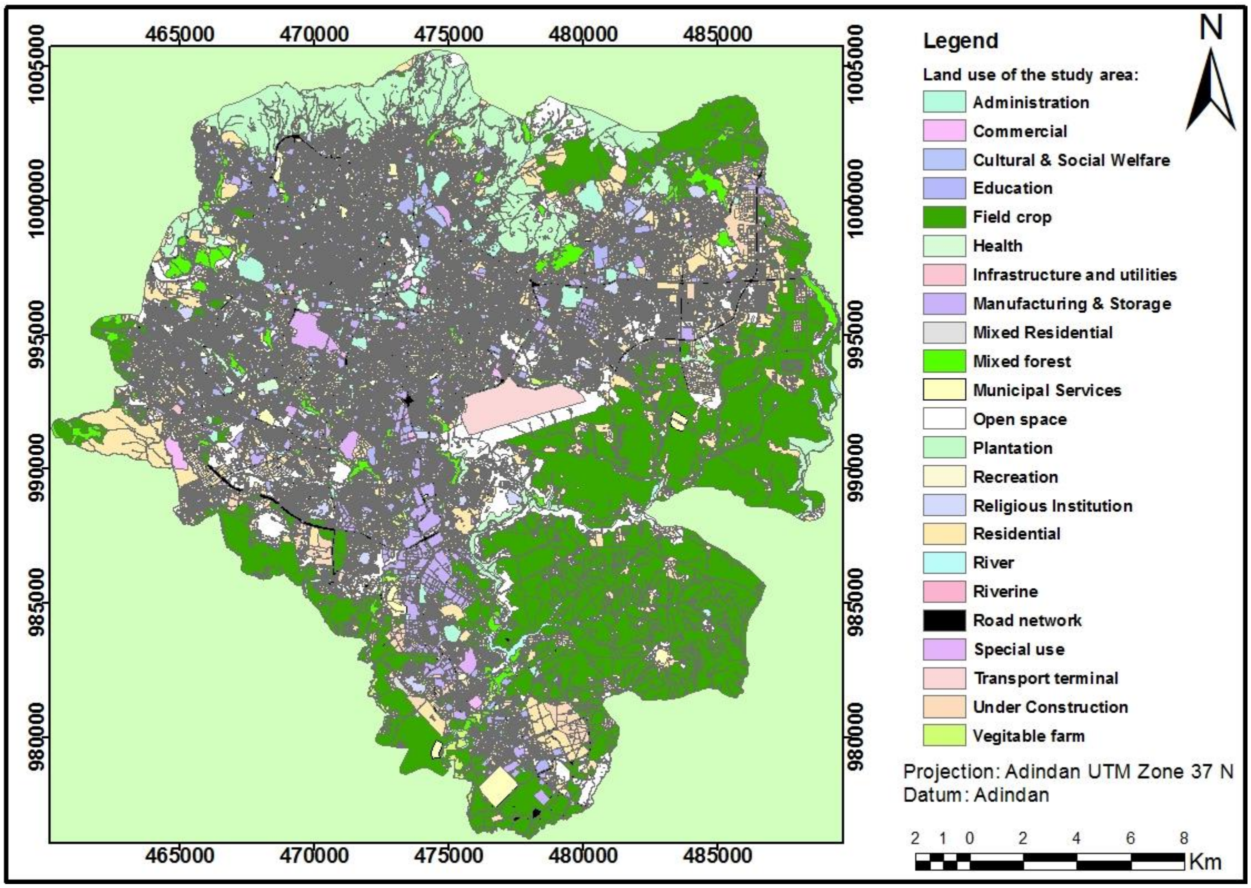


Figure 4.5 Land use map of the study area (Source: AACA land management office, 2014).

Land use Suitability Analysis

According to UNEP (2005), low economic value lands (like open areas, agricultural areas etc.) are the most suitable for solid waste transfer stations than residential, commercial, industrial and other related high economic value lands. The reclassification was performed in Arc GIS environment using spatial analyst tools (reclassify tool). Land use suitability weights were assigned based on the standard formulated by UNEP (2005). According to this standard, areas which have low economic value were considered as highly suitable than other types of land use.

In the land use reclassification phase, the highest value (4) was given to open space while, the lowest value (1) was assigned for less economic value land. The following (Table 4.6) shows the land use suitability classes and area coverage in hectares and percentages respectively.

Table 4.6: Land use suitability classes and area coverage

No	Suitability classes	Suitability rank	Area in (ha.)	Area in (%)
1	Highly suitable	4	5,023.5	9.3
2	Suitable	3	14,966.7	7.7
3	Moderately suitable	2	5,793.8	10.7
4	Unsuitable	1	28,216	52.3
Total			**54,000**	**100**

Source: Reclassified land use map attribute table.

Based on the above land use suitability (Table 4.6), from the land use suitability point of view the largest part of the study area (52.3%) was found as unsuitable for solid waste transfer station sites whereas, 9.3% and 27.7% of the areas were highly suitable and suitable respectively. The remaining 10.3% of the study area was found moderately suitable for transfer stations. The data displayed on the above land use suitability table was extracted from the land use reclassified map of the attribute table and the data was converted in to the respective units of measurements.

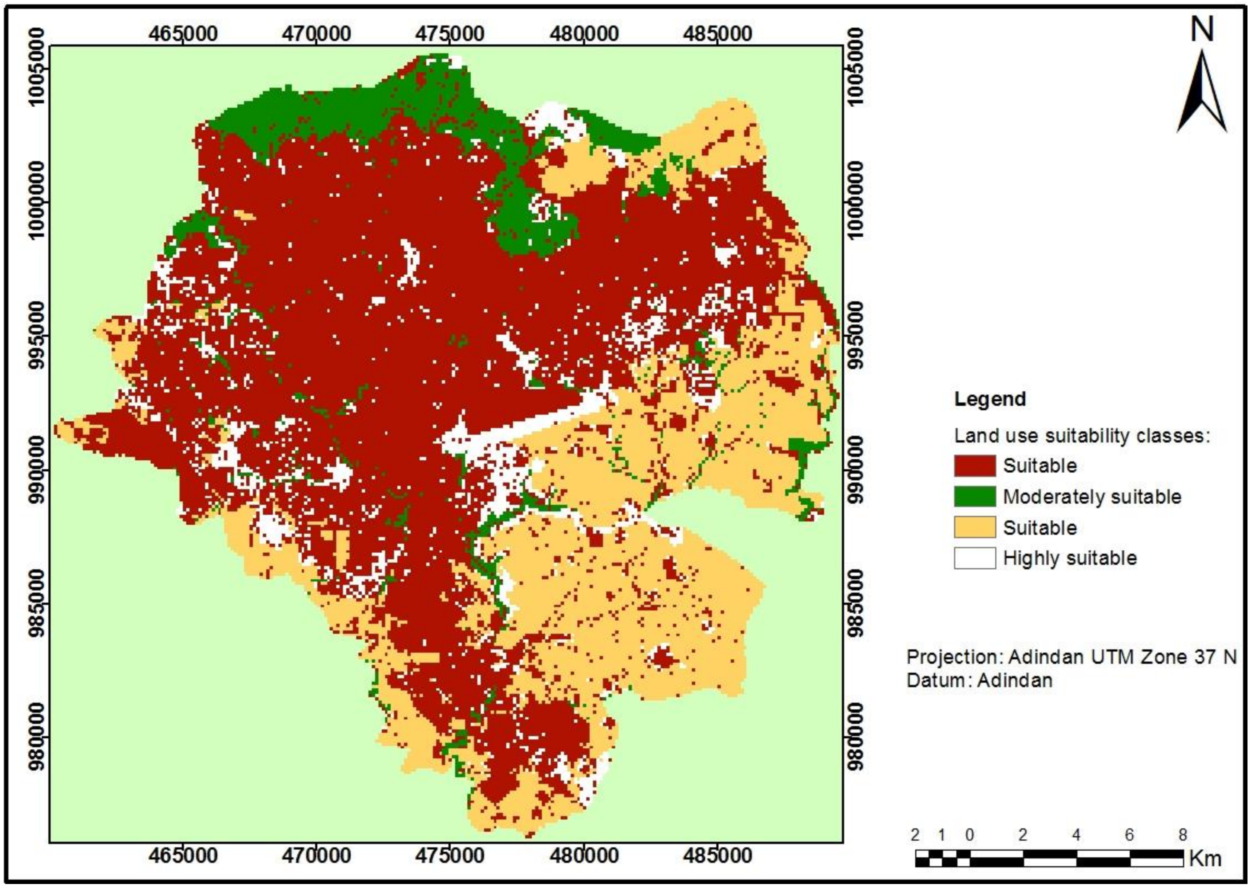


Figure 4.6 Land use/cover suitability map of the study area.

4.4. Geology of the Study Area

Addis Ababa is located in the western margin of the rift valley and consists of different volcanic rocks that range from basic to acidic composition. The vicinity of the city is surrounded by trachyte and rhyolite hills and mountains. In the northern part, the Entoto mountain chains are composed of trachyte and rhyolite which are called the Entoto silicic of the Addis Ababa area. Volcanism initiating the Alaji cycle occurred in late Oligocene early Miocene periods. This period coincides with the well-known phase of rifting in the red sea (Zenettin *et al.*, 1974).

Volcanic mountains such as Wechecha in SW, Furi in southern part and Yerer in SE part of Addis Ababa are mainly trachyte in composition. These volcanic cases are situated at western side of the Ethiopian rift escarpments. Volcanic activity giving these trachytic hills is related to the Ethiopian rift. The source of ignimbrites, tuff and trachy basalts of Addis Ababa was volcanic hills. The basalts are outcropping in the central part of the city, to the south and north of Entoto hills some small patches of basalts are capping the Entoto silicic. The basalts outcropping on tops of Intoto silicic are product of the Termaber basalt but basalts at the center of the city are called Addis Ababa basalts and they are younger than Termaber basalt (Mohr, 1967).

Table 4.7: Types of geology and area coverage:

No	Geology types	Area in (ha.)	Area in (%)
1	Ti3- Wchecha–Yerer- Furi Ignimbrite	13,823.4	25.6
2	Tt2- Wechecha-Yerer-Furi Terachyte	4,284.2	7.9
3	Ti1- Intoto Mixed Rocks	6,785.8	12.6
4	Tb1- Foota Basalt	9,53.7	1.8
5	Qs -Quaternary eluvial sediments	2,94.1	0.5
6	Qsc-Quaternary Scoria	1,88.2	0.3
7	Tt1-Intoto Trachyte	7,37.1	1.4
8	Qb-Quaternary Basalt	9,737	18.0
9	Tb3-Repi Basalt	8,328.6	15.4
10	Ts-Tertiary Sediments	7,72.6	1.4
11	Ti2-Lower Ignimbrite	4,642.2	8.6
12	Tb2-Chelekleka Basalt	3,453.1	6.5
Total		**54,000**	**100**

Source: GSE, 2014.

Based on the above geology and areal coverage (Table 4.7), the largest part of study area is covered by Ti3- Wchecha–Yerer- Furi Ignimbrite (25.6%) which is found in the Eastern, central and south western parts. The second most available geological unit which is found in southern and northern parts of the study area is Qb-Quaternary Basalt (18%), and the third dominant geological unit is Repi Basalt (15.4%) that covers western, northern, and central parts of the study area. The least geological units of the study area are found in the southern parts namely Qsc-Quaternary Scoria (0.3%), Qs -Quaternary eluvial sediments in the south (0.5%), and Ts-Tertiary Sediments (1.4%).

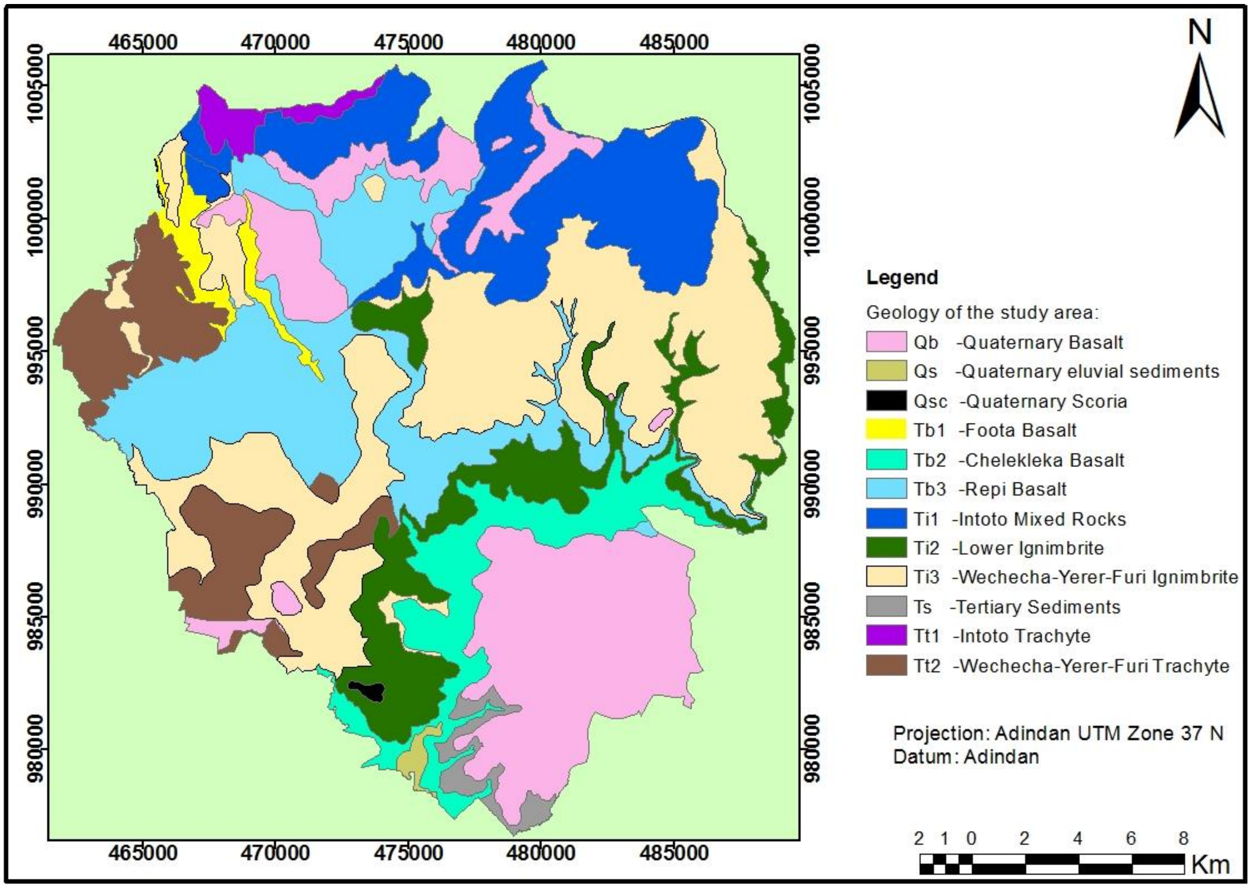


Figure 4.7 Geology map of the study area (Source: GSE, 2014).

Geology Suitability of the Study Area

Geological suitability helps to identify permeability, faults, consolidation of the rocks and other related factors of the geological units of the study area. According to Erosoy and Bulut (2009), unconsolidated geological units are not suitable for solid waste transfer station potential sites.

The strength of basalt varies from 640-880 kg/cm² and joint spacing ranges from 15-200 cm. Basalts have higher density and resistance to weathering than trachytes and ignimbrites. Therefore, based on the standard basalts of the study area were more consolidated and highly suitable for solid waste transfer stations compared to other geological units. Terachytes and rhyolites have less density, strength, and resistance to weathering. The strength of trachay, rhyolite, and trachyte ranges from 480-820 kg/cm² and joint spacing of 5-100 cm (Kebede and Tadesse, 1990). Therefore, these geological units were considered as suitable for transfer station potential sites.

Ignimbrite and some narrowly spaced jointed rocks of rhyolite and trachytes have medium rock mass strength. The strength of ignimbrite varies from 420-680 kg/cm² and joint spacing of 2-100 cm. they have low density as compared to the other geological units of the study area (Kebede and Tadesse, 1990). These geological units cover about 34.7% of the study area and were considered as moderately suitable for transfer station potential sites.

Tuff and agglomerate geological units of the study area are highly weathered and changed in to soils as well as moisture easily weakens them and have low water resisting property (Kebede and Tadesse, 1990). Areas covered by these types of geological units were considered as unsuitable for solid waste transfer station potential sites. Because unconsolidated geological units affect the life of the transfer station as well as aggravates environmental pollution by solid waste leachates.

The geological units of the study area were reclassified in to four suitability classes in the Arc GIS environment using spatial analyst tools (reclass tool). During reclassification phase, the required weights were assigned based on Erosoy and Bulut (2009), geologgical units suitability standard. The suitability of the geological units of the study area ranges from highly suitable to unsuitable and the highest weight (4) wsa assigned to highly suitable and the lowest value (1) was assigned to unsuitable geological units for solid waste transfer station sites.

Table 4.8: Geological suitability ranges and areal coverage:

No.	**Geological suitability ranges**	**Suitability rank**	**Area in (ha.)**	**Area in (%)**
1	Highly suitable	4	22,511	41.7
2	Suitable	3	4,669.5	8.6
3	Moderately suitable	2	18,713	34.7
4	Unsuitable	1	8,106.5	15.0
Total			**54,000**	**100**

Source: Extracted from reclassified geology map attribute table.

From the above geological units suitability (Table 4.8), the largest part of the study area (41.7%) was covered by consolidated geological units and were considered as highly suitable for solid waste transfer station potential sites, 8.6% was suitable, and 34.7 of the area was moderately suitable, while, only 14.7% from the total study area was unsuitable for transfer station potential sites. The geological units suitability map of the study area shown in the following (Figure 4.8):

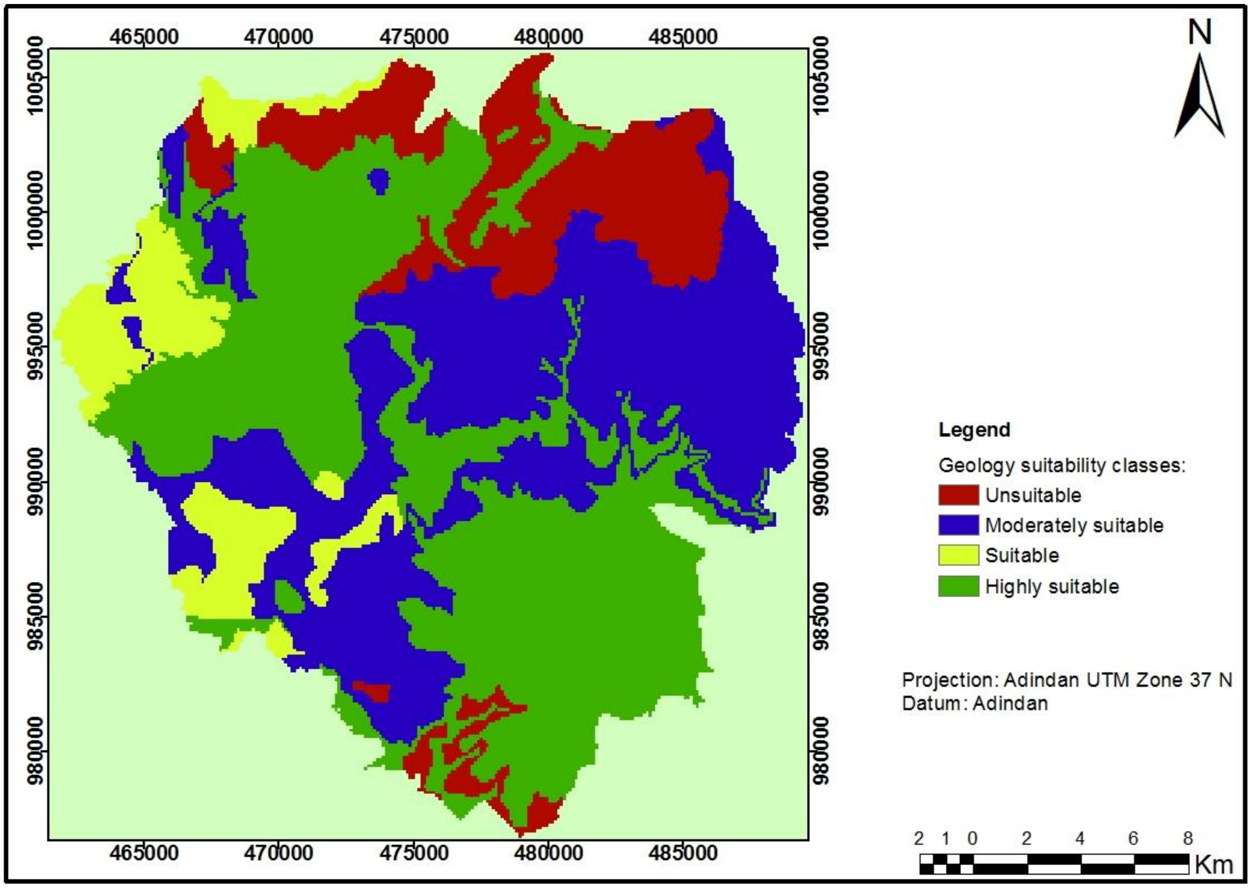


Figure 4.8 Geology suitability map of the study area (Source: GSE, 2014).

2.5. Fault Lines

There are a number of faults most of which have sub parallel trend as the main Ethiopian rift fault in the study area. The major faults running east west via Kesem to Ambo crossing Addis Ababa were the longest fault in the area. The faults trend in the direction of NE to SW and the rocks along this fault are brecciated. There are some faults in the direction of NW trachytic and basaltic dikes are oriented in the direction of NE, NNE and very few in EW (Assegid, 2007).

The fault of the study area proximity buffer distance was performed based on the standard used by (Rafiee *et al.*, 2011). According to the standard, areas found within 1000 m buffer distance from faults were considered as unsuitable for solid waste transfer station sites because of high permeability of soil near the fault and to protect ground water contamination from leachates. Whereas, areas above 1000 m proximity distance were classified as moderately suitable, suitable, and highly suitable with an increase in proximity buffer distance respectively. The buffer distance is clearly depicted in the following (Figure 4.9):

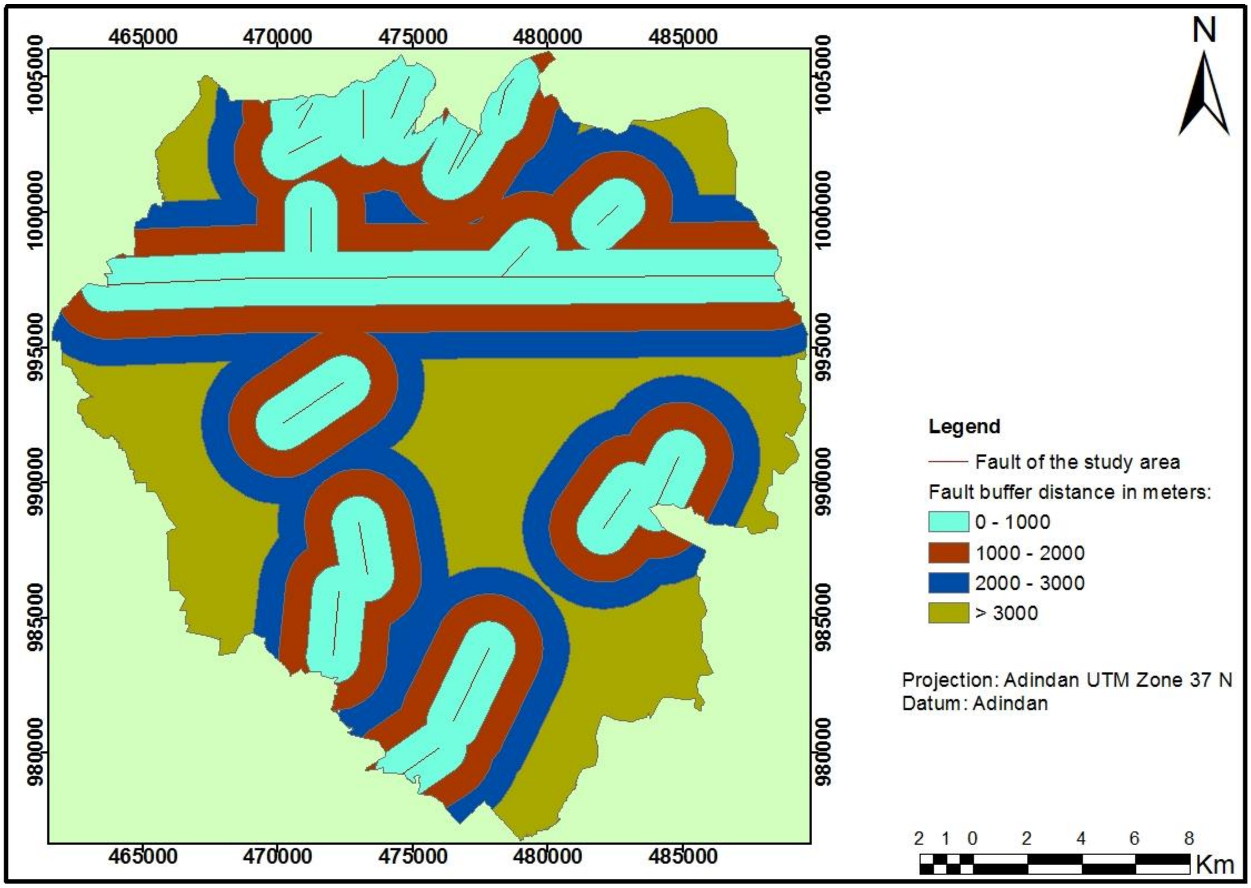


Figure 4.9 Fault buffer map of the study area (Source: GSE, 2014).

Fault Suitability of the study Area

The fault suitability analysis was determined based on Rafiee *et al.,* (2011) fault suitability classification.

Table 4.9: Fault proximity suitability classes and area coverage:

No.	Suitability classes	Suitability ranks	Buffer distance in (meters)	Area in (ha.)	Area in (%)
1	Highly suitable	4	>3000	13915.3	25.7
2	Suitable	3	2000 – 3000	11811.5	21.9
3	Moderately suitable	2	1000 – 2000	14127.8	26.2
4	Unsuitable	1	0 – 1000	14145.4	26.2
Total				**54,000**	**100**

Source: Extracted from reclassified fault map attribute table.

Based on the above fault proximity suitability (Table 4.9), 25.7% was highly suitable and 21.9% of the area was suitable whereas, 26.2% of the study area was found as unsuitable for solid waste transfer station sites. During suitability reclassification phase the highest rank/weight was assigned to a buffer distance greater than 3000 m and the lowest rank/weight was given to unsuitable areas.

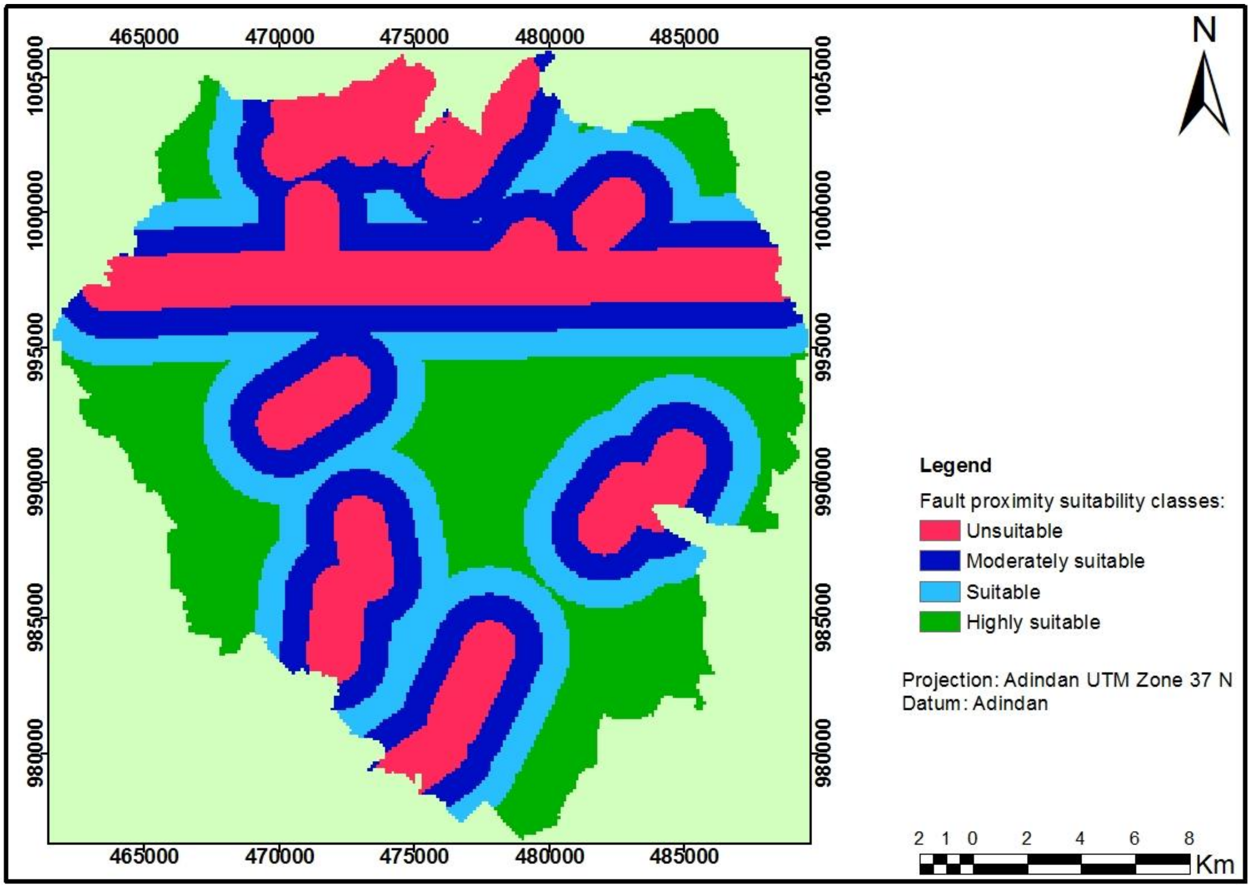


Figure 4.10 Fault proximity suitability map of the study area (GSE, 2014).

4.6. Soil

According to Ministry of Agriculture (2007), the soil of Addis Ababa is classified in to seven categories namely chromic vertisols, pellic vertisols, calcic xerosols, chromic luvisols, eutric nitisols, leptosols, and ortic solonchaks. Each soil types and their areal coverage are clearly shown in the following soil map of the study area. Each of the soil type area coverage was extracted from the respective attribute table in the Arc GIS environment. The soil types and area coverage of the study area are clearly presented in the following (Table 4.11) below:

Table 4.10: Soil types and area coverage:

No.	Soil types	Area in (ha.)	Area in (%)
1	Pellic Vertisols	27,914.5	51.7
2	Chromic Vertisols	4,626.4	8.6
3	Calcic Xerosols	4,176.9	7.7
4	Chromic Luvisols	1,365.9	2.5
5	Eutric Nitisol	11340.5	21.0
6	Leptosols	469.9	0.9
7	Ortic Solonchaks	4105.9	7.6
Total		**54,000**	**100**

Source: Ministry of Agriculture, 2007.

Based on the above (Table 4.10), the study area soil is dominated by Pellic vertisol (51.7%) which is found in the southern and north east part of the study areas, Eutric Nitisol (21%) is the dominant soil type in the central and North West parts, and Chromic Vertisols (8.6%) which is the most available soil type in the central part of the study area. On the other hand, the least available soil types of the study area are Leptosols (0.9%), and Chromic Luvisols (2.5%) which are found in the north and north west parts of the study area respectively.

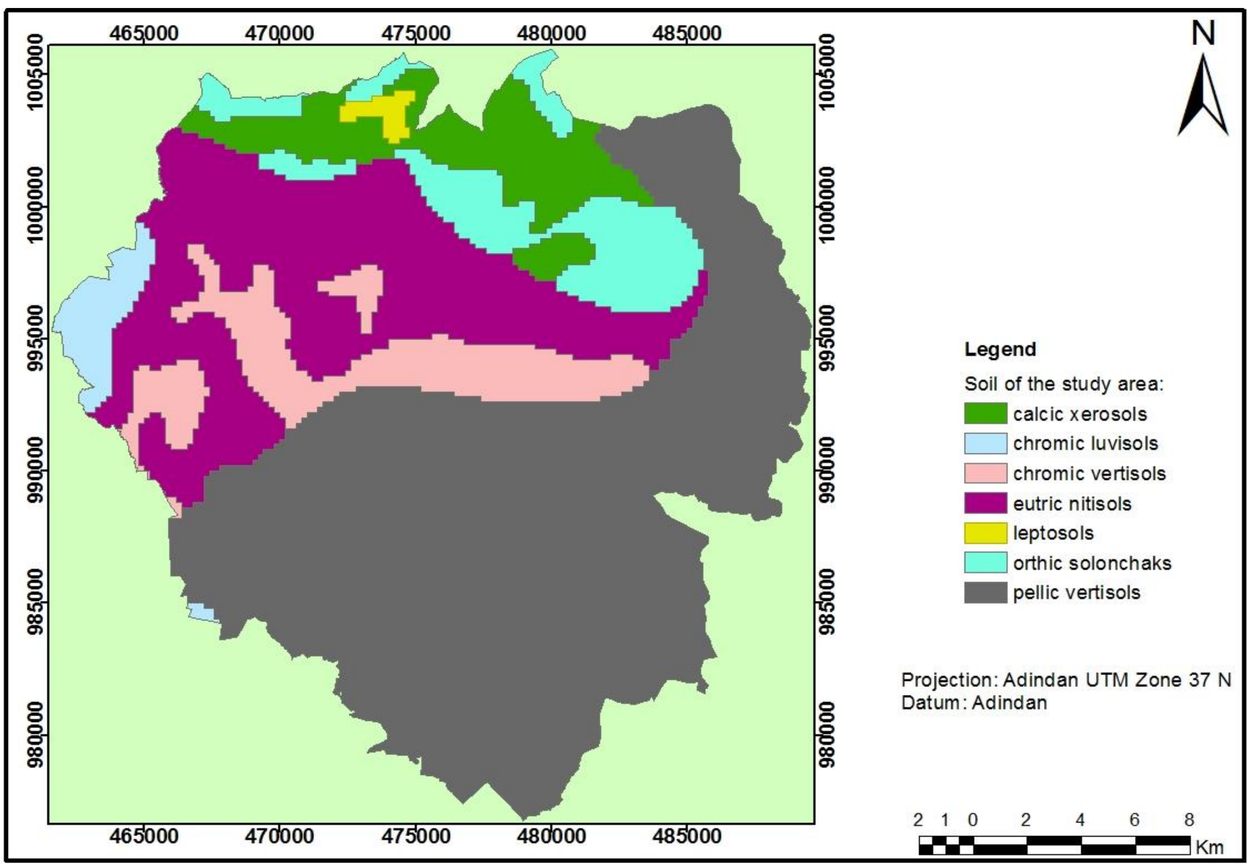


Figure 4.11 Soil map of the study area (Source: Ministry of Agriculture, 2007).

Soil Suitability

The physical characteristic of soil of the study area is one of the main criteria to select potential sites for solid waste transfer stations. The physical properties of Vertisols in Ethiopia generally contain more than 40% clay in the surface horizons and close to 75% in the middle part of the profiles. The sand fraction is low, often less than 20%, and is found in the bottom and the surface (plough layer) horizons (Berhanu, 1985).

Leptosols of the study area characterized by very thin soils over continuous rock and soils that are extremely rich in coarse fragments (FAO, 2014). On the other hand, Luvisols have higher clay content in the sub soil than in the top soil, as a result of pedogenetic processes (clay migration) leading to an argic sub soil horizon in the 50 – 100 cm depth (FAO, 2014).

Nitisols are deep, well drained, and contains 30% of clay contents as well as high aggregate stability. The deep and porous solum and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion and good internal drainage and fair water holding properties. Solonchaks have a high concentration of soluble salts and a clay poorer surface soil over a clay richer nitric horizon that has mostly a columnar structure (FAO, 2014).

Table 4.11: Soil suitability classes and area coverage:

No.	Soil suitability classes	Suitability rank	Area (ha.)	Area (%)
1	Highly suitable	4	32,520	60.2
2	Suitable	3	12,632.4	23.4
3	Moderately suitable	2	4,235.1	7.8
4	Unsuitable	1	4,612.5	8.6
Total			**54,000**	**100**

Source: Reclassified soil map attribute table.

Based on the UNEP (2005), soil suitability standards, during suitability reclassification phase in the Arc GIS environment using analyst tools the highest value (4) was assigned to Vertisols because of their high clay content properties and low permeability of water and other liquid pollutants like leachates down to the ground. Therefore, based on the above soil suitability (Table 4.11), areas covered by Vertisols (60.2%) were considered as highly suitable for transfer station potential sites. The second highest soil suitability value (3) was assigned to Eutric Nitisols and Chromic Luvisols because physically these types of soils are characterized by high stability and less clay contents than Vertisols. As a result of low clay contents permeability of water is higher than Vertisols and areas covered by these type of soils (23.4%) were taken as suitable areas for the stations while, the lowest soil suitability value (1) was assigned to Leptosols and Calcic Xerosols because physically they are characterized by very thin soils over continuous rock and extremely rich in coarse fragments. Coarse texture of soil has high permeability of water and aggravates ground water contamination by leachates. Therefore, areas covered by these type soils (8.6%) were found to be unsuitable for solid waste transfer stations potential sites. The soil suitability map of the study area is depicted in the following (Figure 4.12):

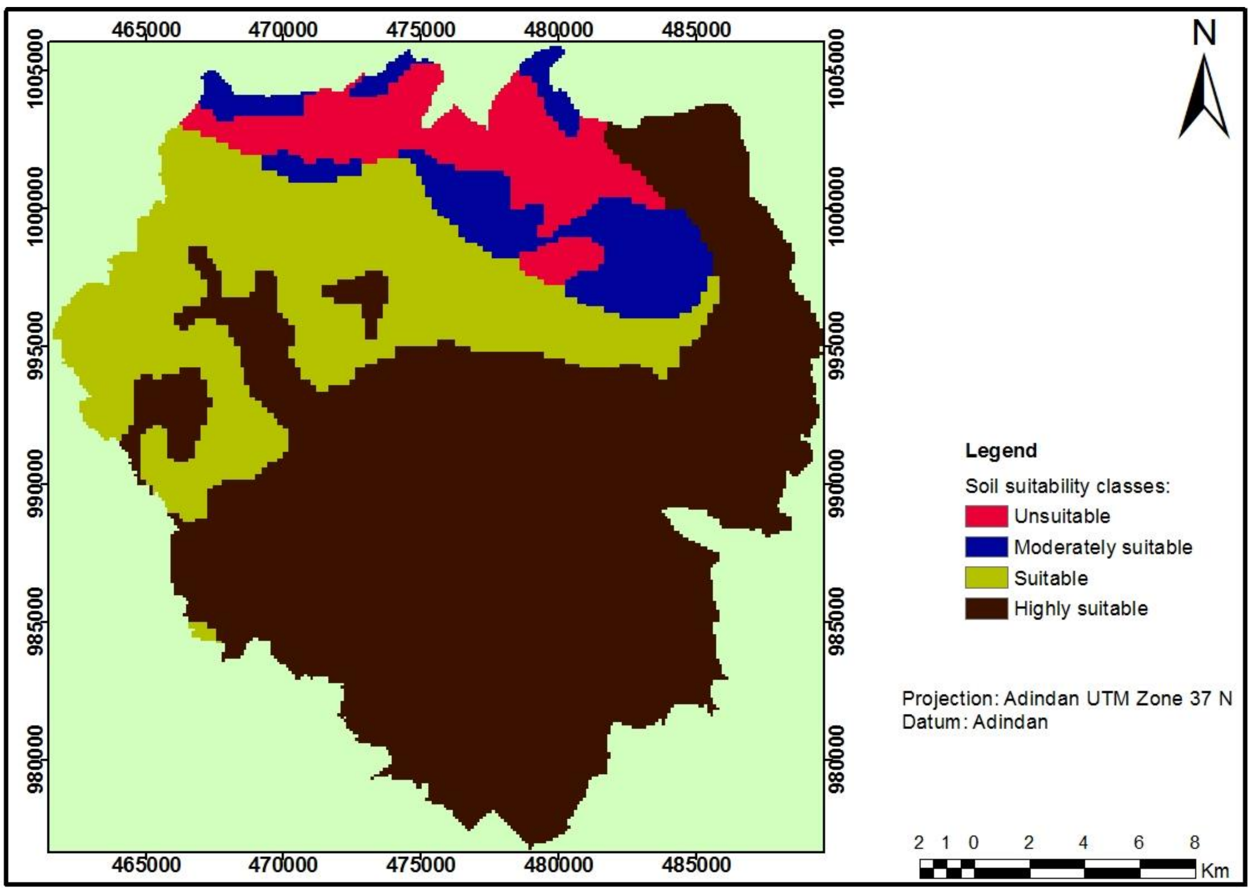


Figure 4.12 Soil suitability map of the study area (Source: Ministry of Agriculture, 2007).

4.7. Road Network

The existing major road network was used to determine the road suitability index for transfer stations potential sites. The existing road network was digitized from the 2014 land use/cover map of the study area and geo-referenced using latitudes and longitudes of the area in the Arc GIS environment. Based on the road network proximity standard mentioned in in the above Table 4.1, areas found within 500 m and above 5,000 m from a highway were considered as unsuitable. Locations situated between 500 to 5,000 m from the highway with an increase in distance were considered more suitable for the transfer stations. The road network map of the study area is depicted in (Figure 4.13) below:

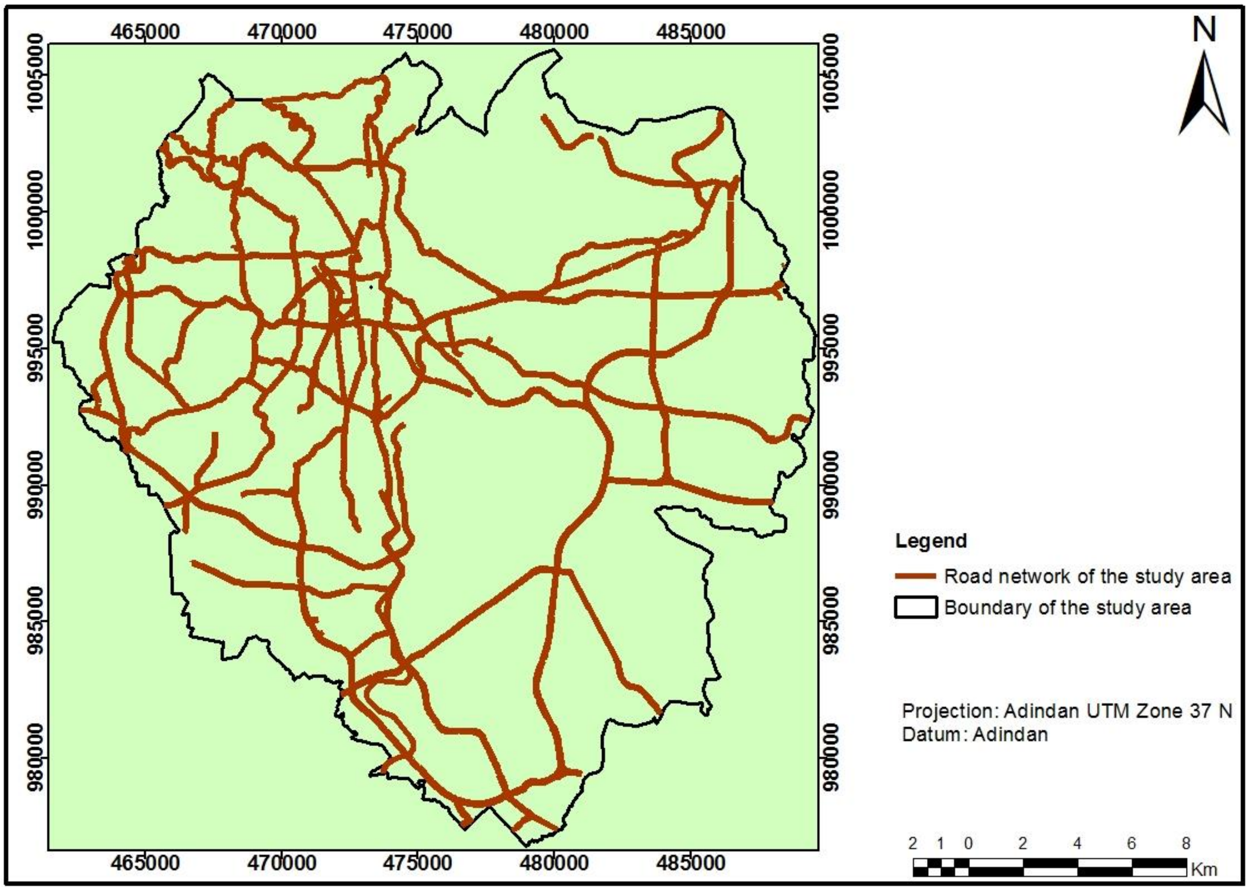


Figure 4.13 Road network of the study area (Source: Digitized from land use map).

Road Network Suitability Analysis

The proximity of road network of the study area to its surrounding was measured by buffer distance produced in the Arc GIS environment using Analysis tools (proximity). Based on the standard of Rafiee *et al.,* (2011) and EPA (1995), areas below 5,00 and above 5,000 m distance from the road network were considered as unsuitable because high proximity to roads can result traffic congestion and when it too far away from road network access results high cost of transportation. Areas found between 3,000 – 5,000 m were classified as moderately suitable while areas found between 5,00 – 1,500 m were considered as suitable and finally areas found between 1500 – 3,000 m were taken as highly suitable for transfer station potential sites selection.

Table 4.12: Road network proximity suitability and area coverage:

No	Suitability classes	Buffer distance (meter)	Areal in (ha.)	Area in (%)
1	Highly suitable	1500 – 3000	5,546.5	10.3
2	Suitable	500 – 1500	17,877.8	33.1
3	Moderately suitable	3000 - 5000	5,97.9	1.1
4	Unsuitable	0 - 500	29,977.8	55.5
Total			**54,000**	**100**

Source: Extracted from reclassified road map attribute table.

Based on the above road network proximity suitability (Table 4.12), form the total study area 10.3% and 33.1% were found highly suitable and suitable respectively while, 55.5% of the area was unsuitable. The remaining 1.1% of the study area road proximity is moderately suitable for solid waste transfer stations potential sites. The road network proximity suitability map of the study area is clearly indicated in the following (Figure 4.14):

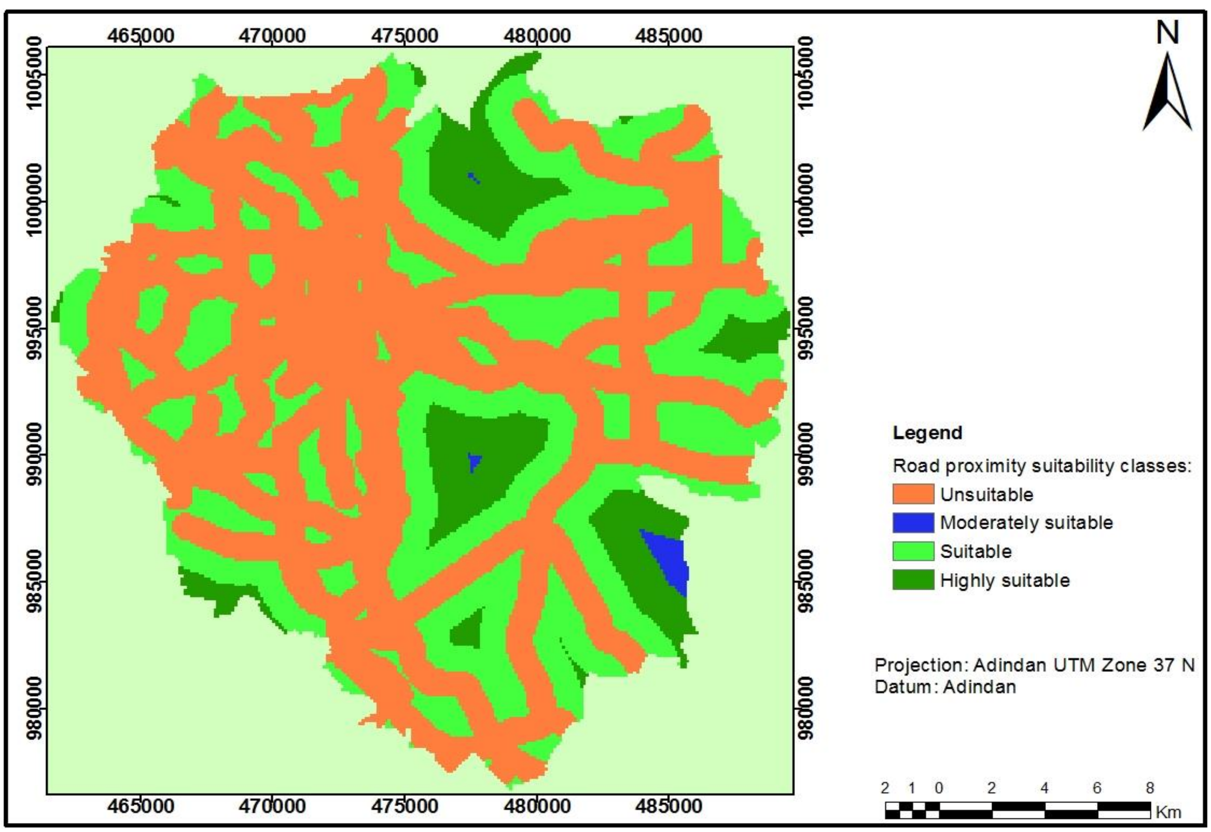


Figure 4.14 Road network suitability map of the study area

4.8. Airport Proximity Suitability Analysis

The Airport map of the study area was digitized from the existing (2014) land use/cover map of the study area and geo-referenced for further processing. The Airport buffer map of the study area was produced in the Arc GIS environment using analysis tools (proximity-- multiple ring buffer). The proximity distance was determined based on Ayat (1994) and USEPA (2004), protected areas norms and standards. Therefore, based on the standards areas found within 5000 meters from the airport were considered as unsuitable because people dump foods and other related organic wastes in the transfer stations and this attracts various types of birds around and affect the flight process. On the other hand, to protect such kinds of constraint areas above 9000 meters from the Airport were taken as highly suitable for solid waste transfer station potential sites.

Table 4.13: Airport proximity suitability and area coverage:

No.	Suitability classes	Buffer distance in meters	Area in (ha.)	Area in (%)
1	Highly suitable	>9000	19,931.4	36.9
2	Suitable	7000 - 9000	11,724.6	21.7
3	Moderately suitable	5000 - 7000	9,484.1	17.6
4	Unsuitable	0 – 5000	12,859.9	23.8
Total			**54,000**	**100**

Source: Extracted from reclassified Airport map attribute table

Based on the above Airport suitability (Table 4.13), the largest part of the study area was covered by highly suitable class (36.9%) and 21.7% of the area was suitable whereas, 23.8% of the study area was not suitable for solid waste transfer stations potential sites. The Airport proximity buffer distance and suitability maps are clearly depicted in the following (Figures 4.15, and 4.16) respectively.

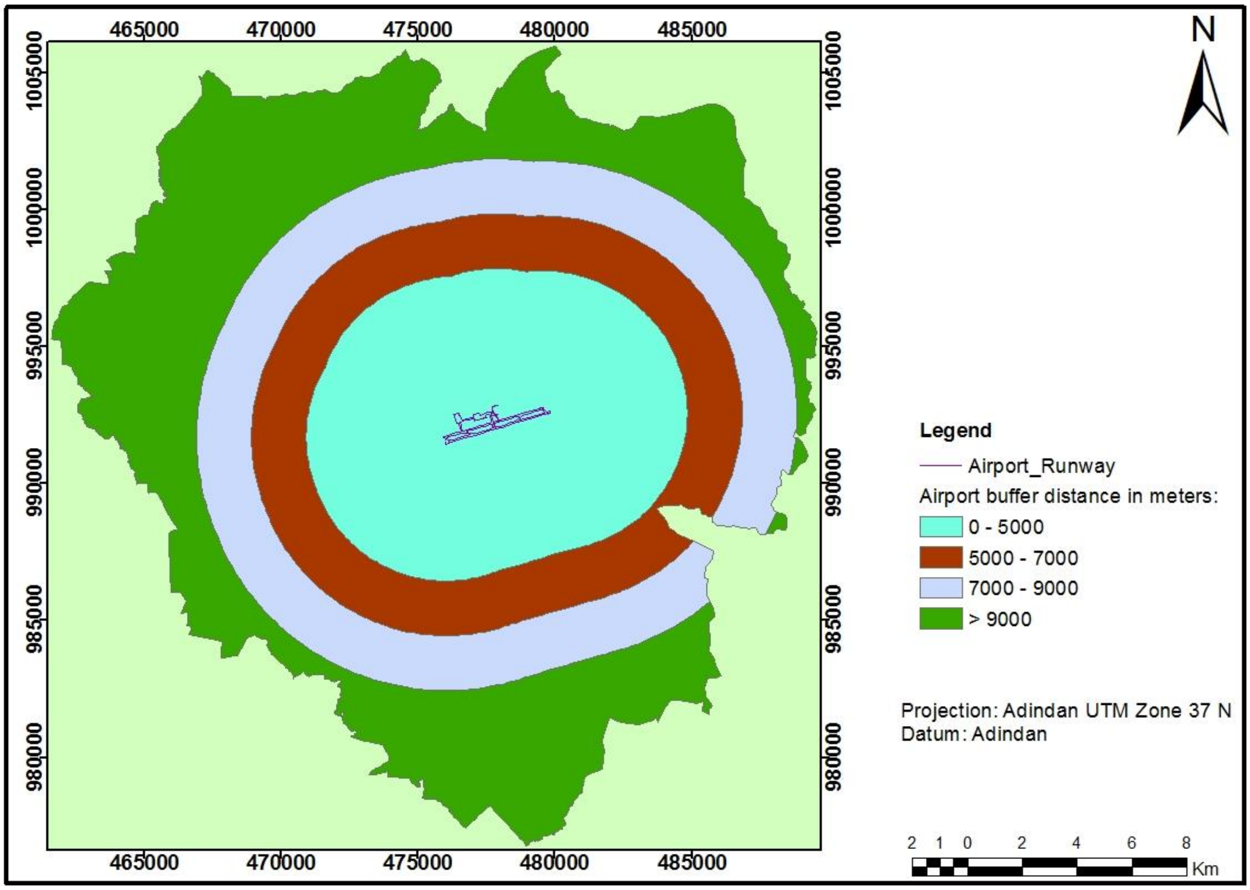


Figure 4.15 Airport proximity buffer map of the study area (Source: Digitized from land use map).

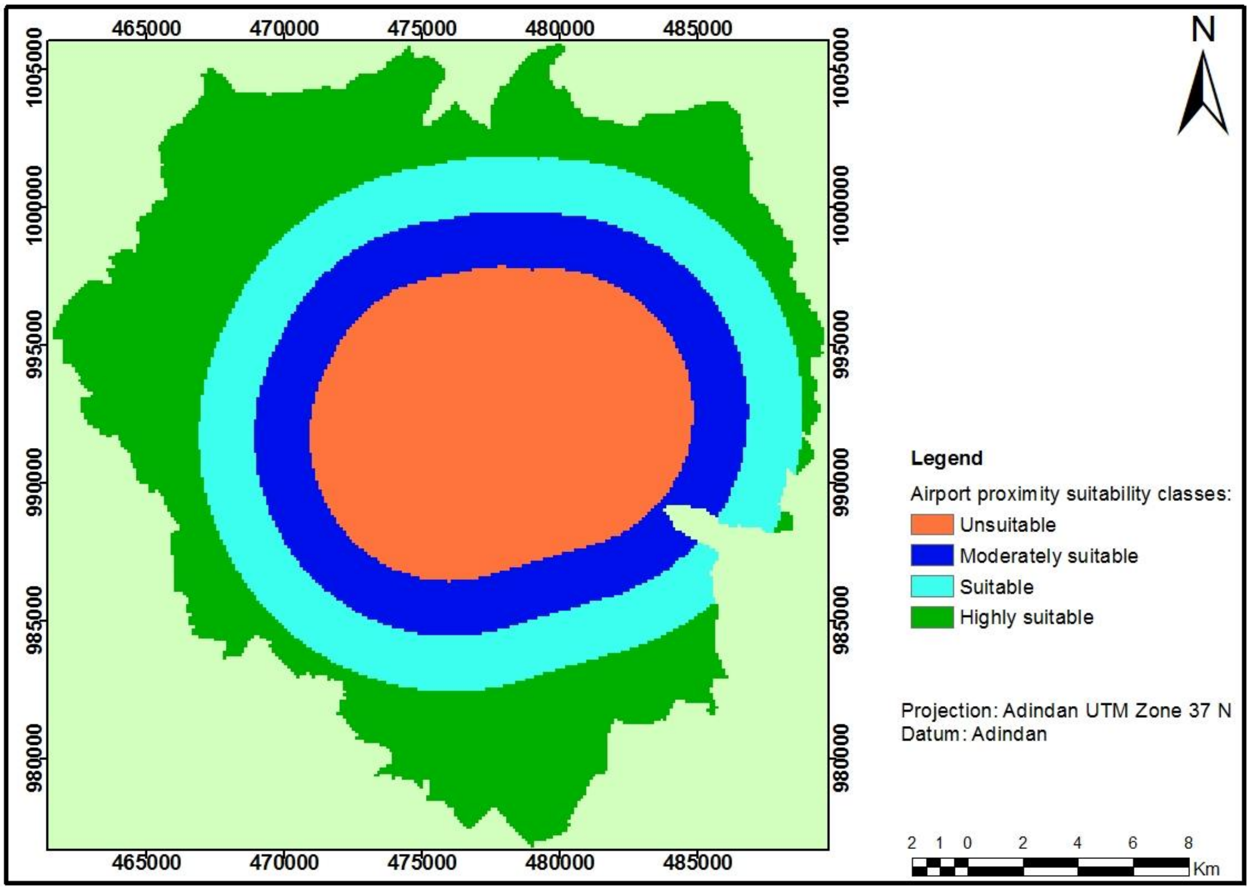


Figure 4.16 Airport proximity suitability map of the study area.

4.9. Education and Health Centers

All education centers of the study area were Digitized from the exiting (2014) land use map of the study area and about 13 GCPs of health centers were collected and changed in to shape file in Arc GIS environment to determine the proximity buffer distance suitability for solid waste transfer station potential sites selection process.

According to Ayat (1994) and USEPA (2004), areas found within the distance of 2000 m from Education and health centers are not suitable because to safeguard the people from offensive bad odor of the wastes accumulated in the transfer stations. In the contrary of this, above 2000 m are suitable with an increase distance from the centers for the potential sites. Therefore, the Education and health centers proximity suitability buffer distances of the study area were performed based on the above mentioned standard. As it is indicated in Table 4.15 below, areas found above 4000 m away from the centers were considered as highly suitable, areas between 3000–4000 m and 2000–3000 m were classified as suitable and moderately suitable respectively.

Table 4.14: Educational and health centers proximity suitability and areal coverage:

No.	Suitability classes	Buffer distance (meters)	Area in (ha.)	Area (%)
1	Highly suitable	>4000	1,046.7	1.9
2	Suitable	3000 - 4000	3,111.2	5.8
3	Moderately suitable	2000 - 3000	5,469.7	10.1
4	Unsuitable	0 - 2000	44,372.4	82.2
Total			**54,000**	**100**

Source: Extracted from reclassified education and health centers map attribute table.

Based the above education and health centers proximity suitability (Table 4.14), the largest part of the study area was dominated by unsuitable sites (82.2%), only 1.9% and 5.8% of the study areas were highly suitable and suitable respectively for solid waste transfer station potential sites. Education and health centers proximity and suitability maps of the study area are shown in the following (Figures 4.17 and 4.18) respectively.

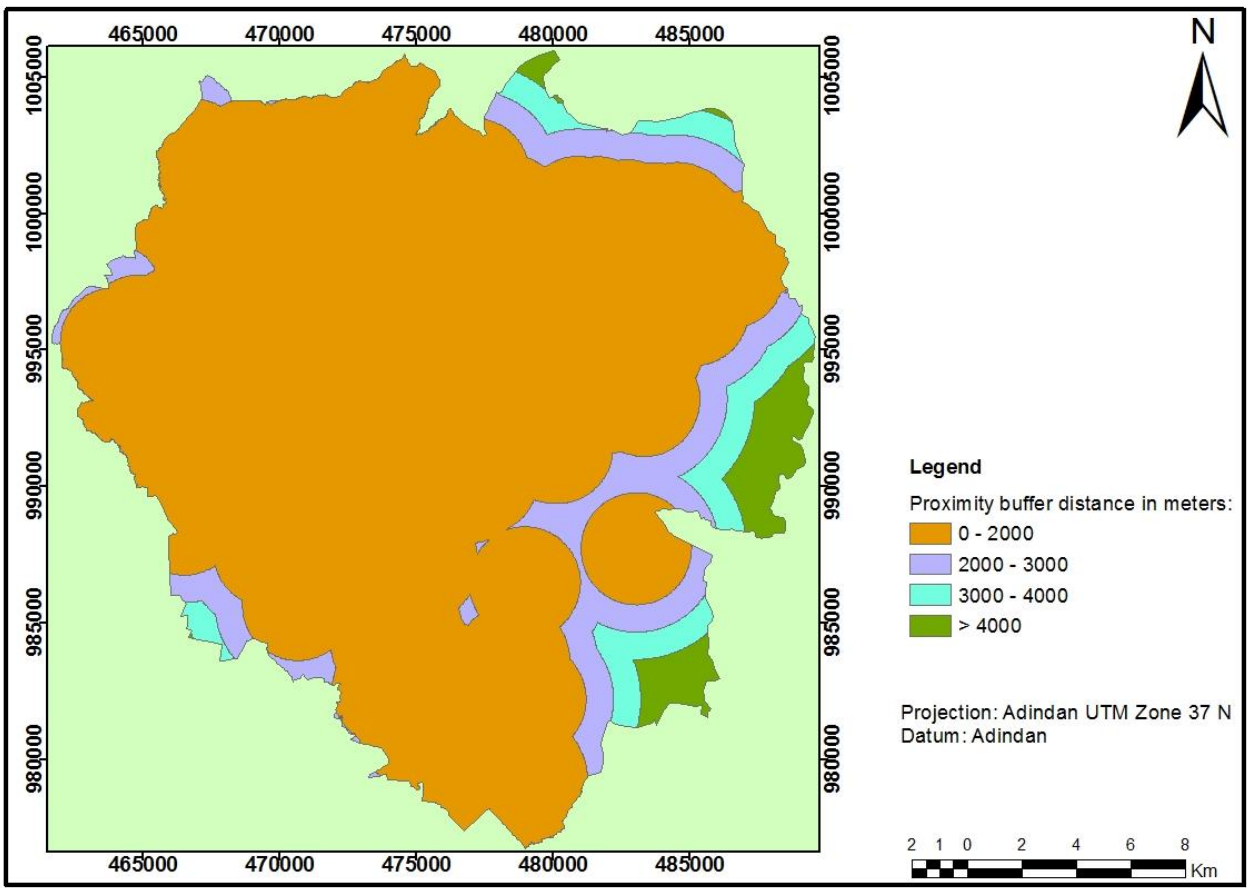


Figure 4.17 Education and health centers proximity buffer map of the study area (Source: Land use map).

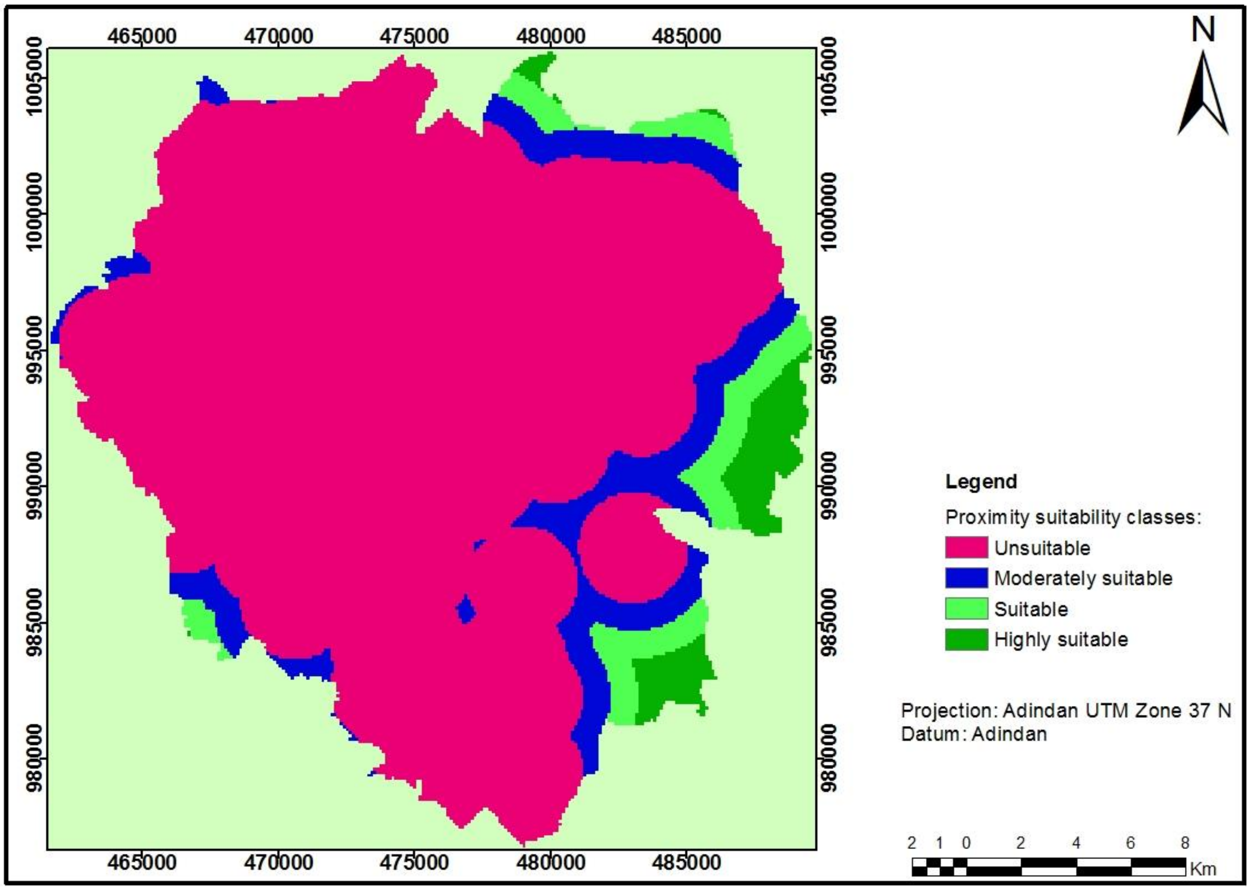


Figure 4.18: Education and health centers proximity suitability map of the study area.

4.10. Residential Area

The residential map of the study area was produced by Digitizing all pure and mixed residential sites from the existing land use/land cover map of the study area to determine the proximity distances. During the digitization process mastre plan of the city was used as refernce. As obviouas the extracted residential areas were geo-referenced based on the eastings and northings of the study area in the Arc GIS environement using geo-referencing tool.

The proximity suitability buffer distance was performed based on USEPA (2004) and Rafiee *et al.*, (2011), residential areas standard. Therefore, areas found within 1000 m from residential areas were considered as unsuitable because of a negative public reaction and opposition from people living close to transfer stations due to bad odor of wastes whereas, areas found between 1000 m and 5000 m were evaluated as suitable, moderately suitable, and highly suitable for solid waste transfer stations potential sites. The residential areas suitability buffer classes are clearly indicated in the following (Figure 4.20):

Table 4.15: Residential areas proximity suitability and areal coverage:

No.	Suitability classes	Buffer distance (meters)	Area in (ha.)	Area in (%)
1	Highly suitable	3000 - 5000	7501.3	14.0
2	Suitable	2000 - 3000	4777.2	8.8
3	Moderately suitable	1000 - 2000	7633.9	14.1
4	Unsuitable	0 – 1000	34087.6	63.1
Total			**54,000**	**100**

Source: Extracted from reclassified residential map attribute table.

Based on the above residential proximity suitability (Table 4.15), 63.1% of the study area was not suitable for the transfer stations potential sites. From the total study area 14% and 8.8% were considered as highly suitable and suitable respectively for the potential sites. The remaining 14.1% of the area was moderately suitable.

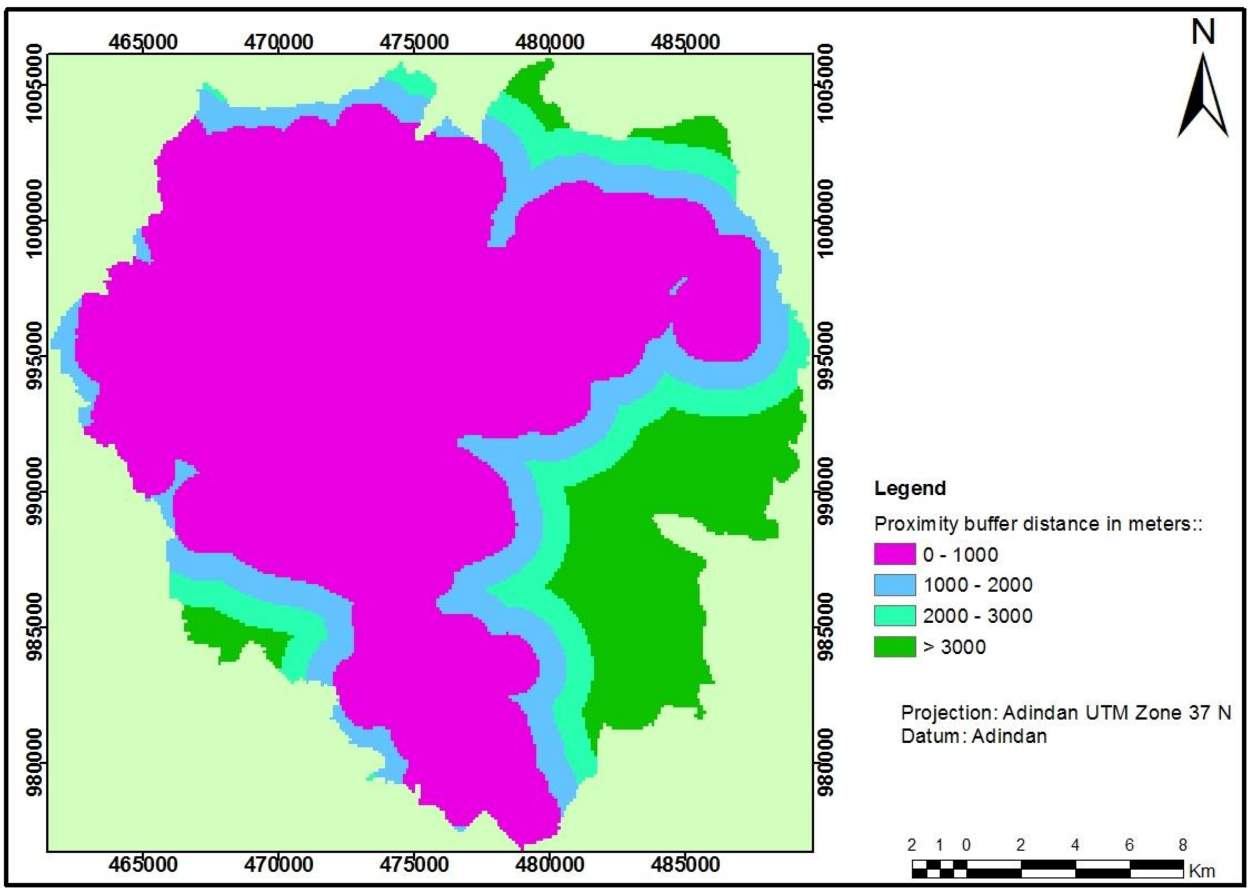


Figure 4.19 Residential proximity buffer distance map of the study area.

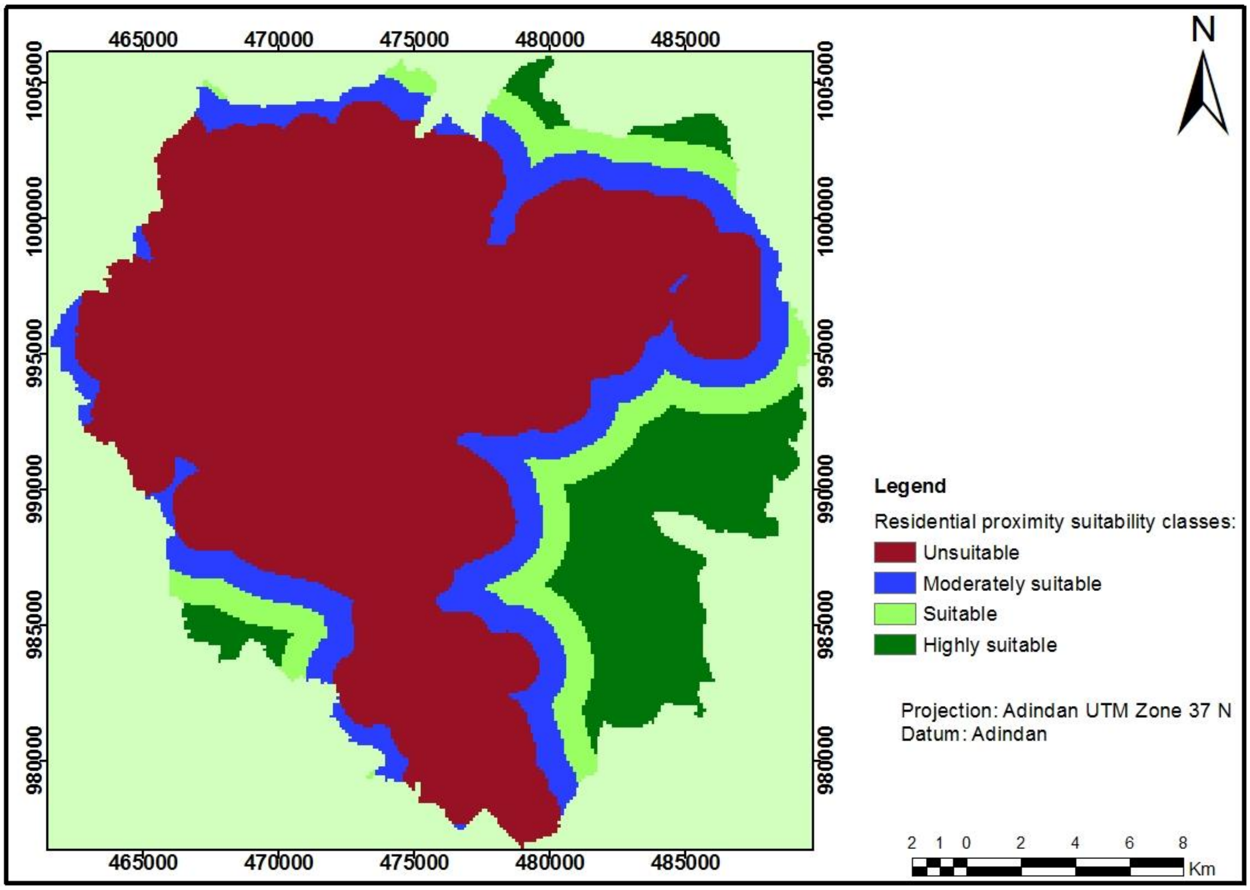


Figure 4.20 Residential areas proximity suitability map of the study area.

4.11. Results and Discussion

4.11.1. Weight Assigning Using Pairwise Comparison Matrix

In this phase the researcher combined all the reclassified criteria in order to find the most suitable solid waste transfer station sites in the study area. The criteria being considered in this study can't have equal degree of importance therefore; in this case the importance of each criterion in relative to the other criteria for transfer station potential sites was determined.

In this study weights for the criteria used to select solid waste transfer station potential sites were assigned and standardized based on the Analytical Hierarchy Process (AHP) which developed by Saaty, (1980) using pairwise comparison matrix. Because, this method is capable to rank choices according to their importance in meeting conflicting objectives and its ability to detect inconsistent judgments using consistency ratio (CR).

Table 4.16: Scale of relative importance according to (Eastman, R., 2001):

Degree of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective.
3	Moderately more important	Experience and judgment slightly favor one activity over another
5	Strongly more important	Experience and judgment strongly favor one activity over another
7	Very strongly more important	An activity is strongly favored and its importance demonstrated in practice
9	Very strongly more important	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocal of above non zero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion. In this approach the decision-maker has to express his opinion about the value of one single pairwise comparison at a time. The values of the pairwise comparisons in the AHP are determined according to the scale introduced by (Saaty, 1980). According to this scale, the available values for the pairwise comparisons are members of the set: {9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9}.

First provide an initial matrix for solid waste transfer station potential sites selection pairwise comparisons in which the principal diagonal contains entries of 1, as each factor is as important as itself. During assigning values in the matrix, the upper triangle holds the importance level of a row variable as compared to the column. Lower triangle is the reciprocal of the upper one. The weight for each criterion was assigned based on various reviews. Table 4.17 below shows pairwise comparison matrix for variables being considered and their relative weights.

Table 4.17: Weights of the criteria using pairwise comparison matrices:

Criteria	DR	LU	RE	SL	EH	FT	AP	RO	GE	SO	n^{th} root	Eigenvector	Normalization	N/E
DR	**1**	2	2	2	3	3	3	3	3	5	2.505	0.212	2.207	10.459
LU	1/2	**1**	2	3	2	2	3	3	3	5	2.094	0.176	1.911	10.861
RE	1/2	1/2	**1**	1/3	2	2	2	3	3	3	1.335	0.113	1.233	10.909
SL	1/2	1/3	3	**1**	2	2	2	3	3	3	1.597	0.135	1.515	11.221
EH	1/3	1/2	½	1/2	**1**	2	2	1/3	3	3	0.933	0.077	0.855	11.104
FT	1/3	1/2	½	1/2	½	**1**	2	1/3	3	5	0.855	0.072	0.803	11.153
AP	1/3	1/3	½	1/2	½	½	**1**	1/3	3	3	0.707	0.060	0.620	10.403
RO	1/3	1/3	1/3	1/3	3	3	3	**1**	2	2	1.029	0.087	1.060	12.226
GE	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/2	**1**	2	0.464	0.039	0.422	10.821
SO	1/5	1/5	1/3	1/3	1/3	1/5	1/3	1/2	1/2	**1**	0.346	0.029	0.312	10.759
Total											**11.864**	**1**	**10.938**	**109.914**

CR = 0.074 << 0.1, Note: if CR< 0.1, it is within acceptable limit.

Where, DR = Drainage, LU = Land use, RE = Residential, SL = Slope, EH = Education and Health centers, FT = Faults, AP = Airport, RO = Road, GE = Geology, SO = Soil of the study area, N= Normalization, and Eigenvector weight.

- Eigenvector = the value of n^{th} root1/∑n^{th} roots….n^{th} root n/∑n^{th} root: where, n^{th} root is each value of n^{th} root and ∑n^{th} root is the sum total of nth root. In our case (n) is number of matrix as it is indicated in the above table 4.18, it is 10 by 10 matrix therefore, the value of (n) = 10

Mean average/Lamda max (λ): ∑N/E/n = 109.914/10 = 10.9914: where, N is each value of Normalization and E is also each value of Eigenvector Weight.

CI = Lamda max (λ) - n/n-1 = 10.9914 – 10/ 10-1 = 0.9914/9 = 0.1102

CR = CI/RI = 0.1102/1.49 = 0.074

Where, CI = consistency index for a matrix, n = no. of matrix, and RI = the corresponding index of consistency for random judgments from (saaty, 1980) AHP model, for 10 by 10 matrix the index from the table is 1.49.

Based on the above Eigenvector weights (Table 4.17), drainage is the most important determinant factor of all other criteria to select solid waste transfer station potential sites in the study area and its Eigenvector weight was 21.1% and the second most important factor was land use of the study area with Eigenvector weight of 17.6% while, the least important criteria employed in this study were geology and soil of the study area with Eigenvector weights of 3.9% and 2.9% respectively. Saaty (1980), argues that a CR < 0.1 indicates that the judgments are at the limit of consistency and above 0.1 indicates the judgments are out of the consistency limit as a result of this, the pairwise values/weights need to be reconsidered and the process is repeated till the desired value of CR < 0.10 is reached. In our case the calculated CR value was 0.074/ 7.4% and found within the consistency limit and the value judgments were consistent.

4.11.2. Weighted Overlay Analysis

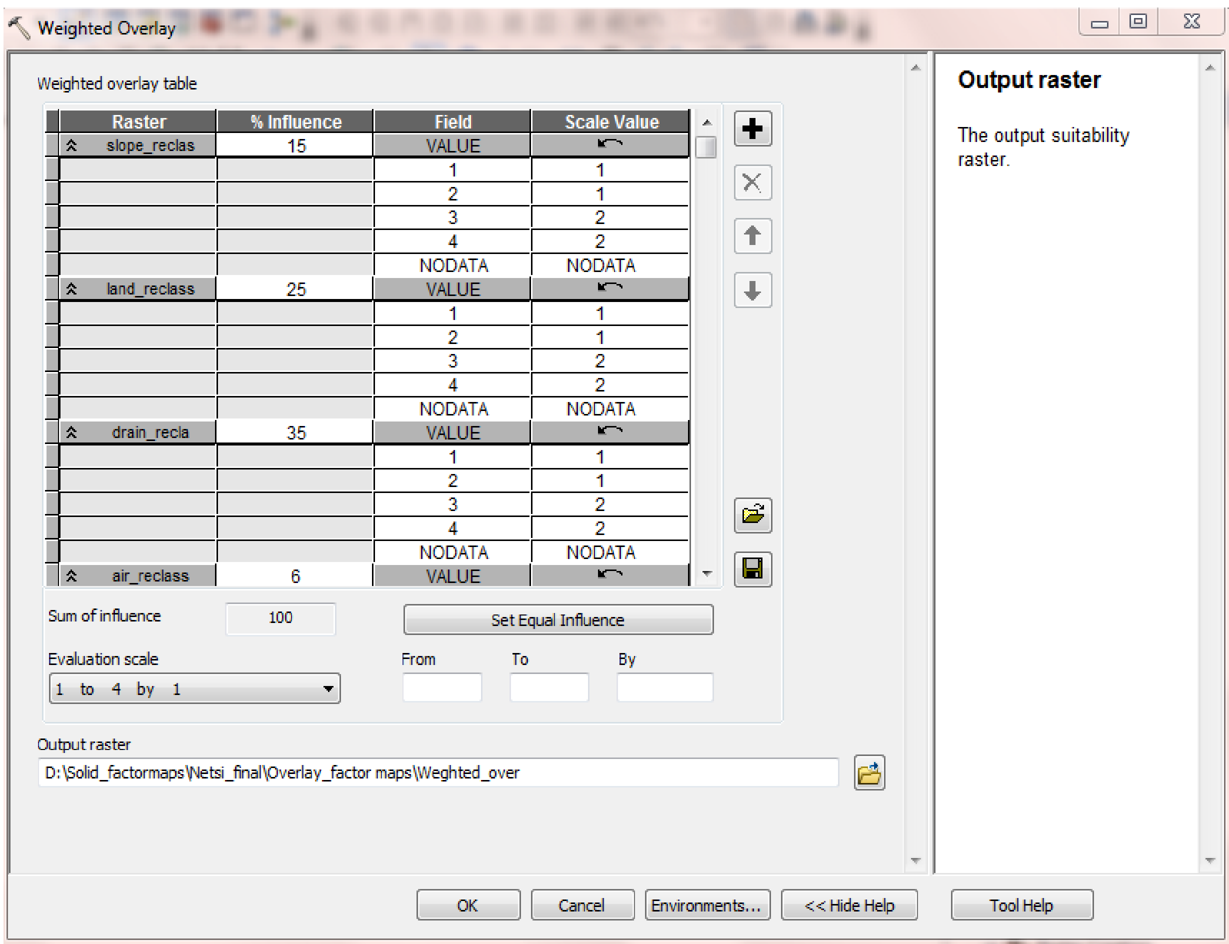


Figure 4.21: Weighted Overlay table.

Weighted overlay analysis is a process of combining all the standardized and weighted criteria used in the analysis to get the intended outcomes in our case potential sites for solid waste transfer stations in the study area. Therefore, based on the following overlay analysis result

(Figure 4.22), the eastern, south eastern, north eastern and south western parts of the study area were highly suitable while, the rest parts of the study area were found as unsuitable for the transfer stations and unable to fulfill the standards of potential site selection. Among the selected highly suitable areas most of them are open areas and agricultural lands.

Table 4.18: Weighted Overlay results suitability classes and area coverage:

No.	**Potential sites ranges**	**Areal in (ha.)**	**Area in (%)**
1	Highly suitable	6910.6	12.8
2	Suitable	3660.5	6.8
3	Moderately suitable	3808.8	7.1
4	Unsuitable	39620.1	73.3
Total		**54,000**	**100**

Source: Extracted from reclassified Weighted overlay result map attribute table.

Based on the above Weighted Overlay result suitability (Table 4.18), from the total study area 73.3% were found as unsuitable for solid waste transfer station potential sites. Because these areas were failed to fulfill the residential proximity suitability norms and standards formulated by (USEPA 2004 and Rafiee *et al.,* 2011). According to this standard transfer station potential sites must not be within 1000 meters from residential areas because of opposition from people living near to the transfer stations due to offensive bad odor of wastes. Therefore, based on the standard areas far away from residents (up to 5000 m) are more preferable for the transfer stations. In addition to this, the identified unsuitable sites were unable to meet land use norms and standard (lack of low economic value lands like open and agricultural areas etc.) which proposed by (UNEP, 2005).

In the contrary of this, 12.8% of the study area was found as highly suitable for transfer station potential sites. The identified highly suitable areas were fulfilled the physical (geology, drainage, soil etc.), social and economic (proximity to residential, roads, Airport, health and education centers etc.) criteria norms and standards used in the analysis part of this study. Even though moderately suitable and suitable sites of the study area shown in the Weighted Overlay result unable to meet the most suitable class standards of the criteria used in this analysis, they can be used as last alternative potential sites for solid waste transfer stations.

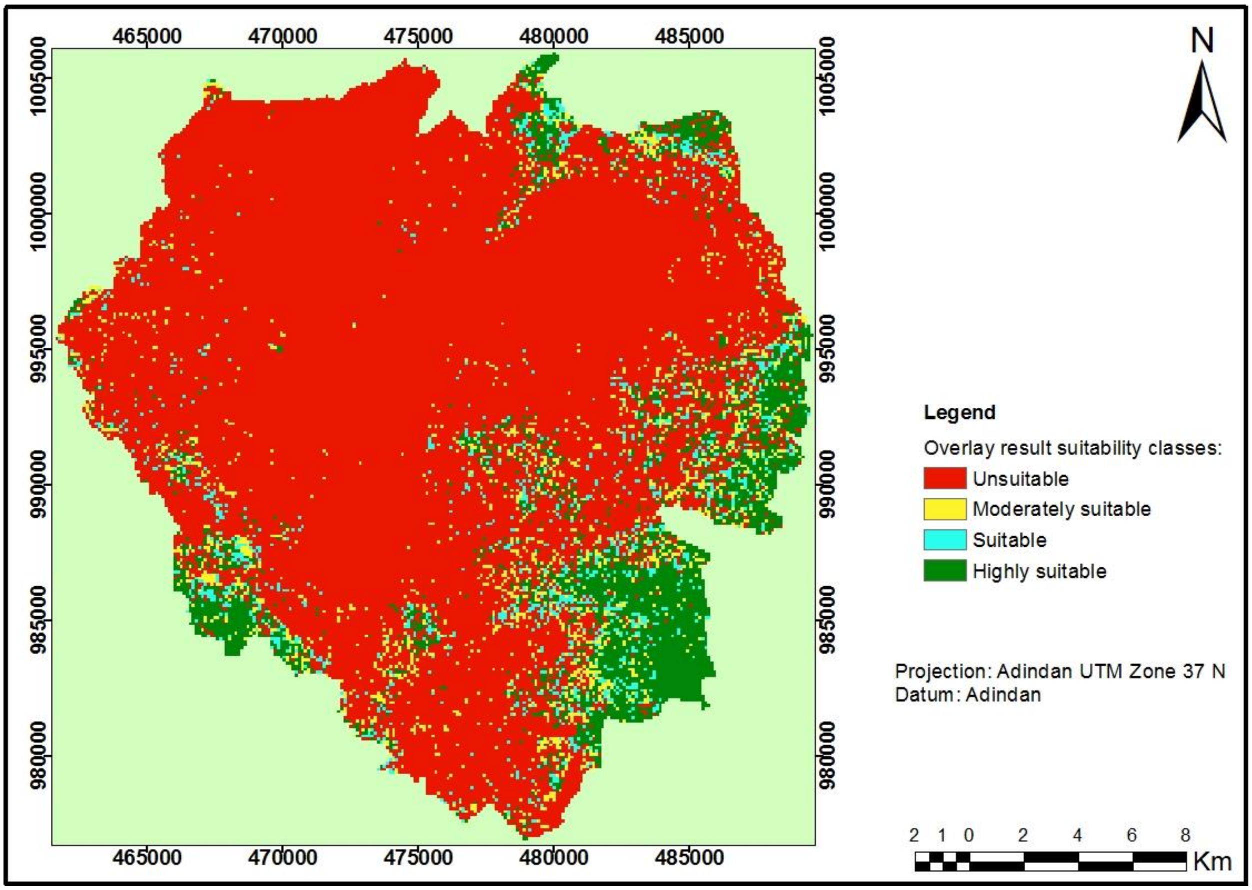


Figure 4.22 Weighted overlay result map of the study area.

4.11.3. Thematic mapping of the selected potential sites

The Weighted Linear Combination analysis result contains most suitable, suitable, moderately suitable and unsuitable areas for solid waste transfer stations. To produce the thematic map of the most suitable sites shape file was produced and all highly suitable areas were digitized in the Arc GIS environment. The final thematic map of the most suitable sites of the study area is clearly shown in the following (Figure 4.23):

Table 4.19: Potential sites and area coverage by Sub Cities:

No.	Sub-cities	Area in (hectares)	Area in (%)	Potential sites area in (ha.)	Potential sites in (%)
1	Addis Ketema	8,98	1.7	--	---
2	Akaki	12,614	23.4	5093.5	70.2
3	Arada	1,156	2.1	--	--
4	Bole	12,094	22.4	776.6	10.7
5	Gulele	3,273	6.1	--	--
6	Kirkos	1,626	3.0	--	--
7	Kolfe	6,510	12.0	315.7	4.4
8	Lideta	1,240	2.3	--	--
9	Nifasilk	6,359	11.8	460.7	6.4
10	Yeka	8,230	15.2	600.5	8.3
Total j 10		**54,000**	**100**	**7247**	**100**

Source: Extracted from reclassified Weighted overlay result map attribute table, 2015.

Based on the above potential sites area coverage (Table 4.19), most of the potential sites were found in Akaki sub-city (70.2%) and followed by Bole (10.7%) and Yeka (8.3%) Sub-cities respectively. From the total area of Akaki Sub- city 40.3% was found as highly suitable for stations. Out of the total size of Yeka and Nefasilk sub- cities about 7.3% and 7.2% were highly suitable respectively. The selected potential sites were bare lands and covered by agricultural activities.

The result of this study shows that areas in the remaining sub-cities like Addis Ketema, Arada, lideta, and Gulele sub cities were not suitable for the stations. Because these areas were unable to fulfill the social and environmental standards of the criteria used in this analysis. Therefore, the concerned body should give the appropriate solutions for sub cities which do not have potential sites for solid waste transfer stations like using the nearest potential sites etc.

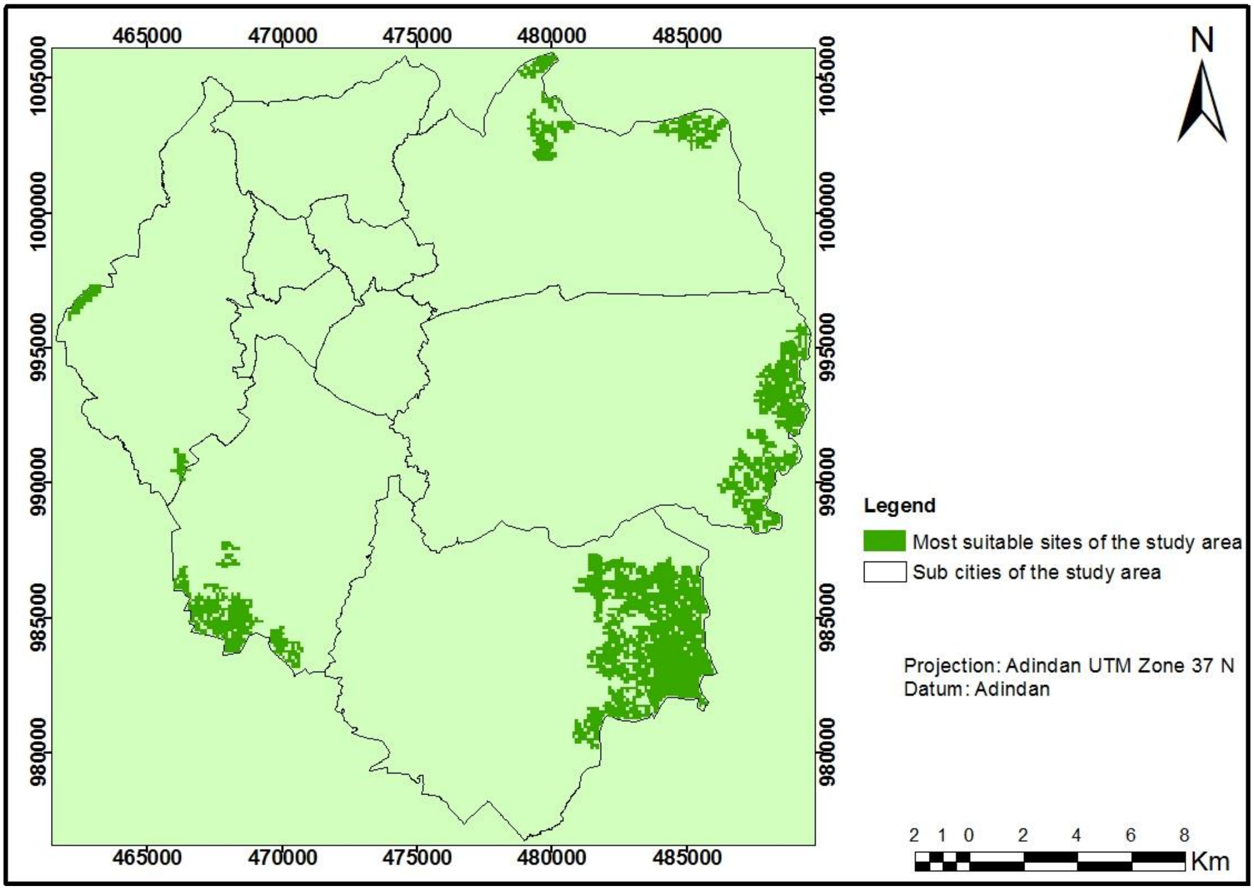


Figure 4.23 Thematic map of potential sites of the study area.

Chapter Five

5. Conclusions and Recommendations

5.1. Conclusions

In short, Solid waste management system is not well developed in the city of Addis Ababa because indiscriminate solid wastes are dumped in open areas around roads, streams, and near residential areas. It has been deteriorating the environment and the lives of the society at a large. Solid waste transfer station is a component of SWMS and needs to consider social, economic, and environmental factors.

Selection of potential sites for solid waste transfer station were a complex process that requires careful consideration of a number of environmental, social and economic factors of the study area. The researcher employed GIS based SMCE method to select the potential sites. Weights for each criterion were assigned based on AHP using pairwise comparison matrix. In this study, ten criteria namely physical factors (land use/cover, soil, geology, slope, drainage proximity, and socio-economic factors (like proximity to airport, health and educational centers, road network, residential etc.) were developed, standardized, weighted, and combined to select the potential sites in the study area.

All the standardized criteria were combined using Weighted Linear Combination (WLCM) method to integrate and transform geographic data to obtain potential sites for the stations. During the weight assigning process pairwise comparison matrices was used and the consistency ratio (CR) was calculated to determine the random value judgments. Therefore, based on the computed value the overall consistency ratio was 0.074/7.4% and found within acceptable limits.

The findings of this study have shown that 12.8% of the study areas were highly suitable and 73.3% were not suitable for solid waste transfer station potential sites. The selected most suitable potential sites were accessible to road networks, far away from streams, protected areas and fulfilled norms and standards employed in this analysis. Most of the identified potential sites were located in the eastern and south eastern parts of the study area. Specifically in south eastern parts of Akaki Sub city, east and south eastern parts of Bole (Bole Arabsa). These areas were covered by agricultural activities and bare lands. Based on the criteria employed in this analysis, the remaining sub-cities like Addis Ketema, Arada, Lideta etc. were not suitable for transfer stations. Finally, to facilitate SWMS in the City of Addis Ababa, researchers and stakeholders should give emphasis to social, economic, and environmental factors of the area.

5.2. Recommendations

Based on the research findings the following recommendations have been made:

- Decision makers should give a due attention to solid waste transfer stations because currently the container based stations placed without considering the environmental and social factors of the area and many people have been affected by the odor and other related factors of solid wastes.
- In this study ten social and physical criteria were used to select the potential sites, but factors like construction costs of the transfer stations were excluded due to time and financial constraints therefore, it is better to conduct further studies on this topic to improve solid waste management system in the city of Addis Ababa.
- As a result of population growth solid waste generation in the city has been increasing and becomes complex. On the other hand, the city doesn’t have norms and standards for solid waste transfer station sites selection. Therefore, the concerned body should formulate norms and standards for solid waste transfer stations by considering the social, economic, and environmental aspects to improve the status of solid waste management system of the city.
- Based on the findings of the study some sub cities like Addis Ketema, Arada, Lideta etc. of the study area do not have potential sites for solid waste transfer stations due to lack of open areas and low economic value lands. Therefore, the concerned body should find other alternative solutions like using the nearest sub cities potential sites to dispose solid wastes temporarily.

References

Abdulwahid, I., (2003). Solid waste management status report of Addis Ababa: The way forward. city government of Addis Ababa Sanitation, Beautification and Parks Development Agency, Addis Ababa, Ethiopia.

Addis Ababa City Administration, (1998). Improving urban environmental conditions in Addis Ababa, unpublished material, Addis Ababa, Ethiopia.

Addis Ababa City Sanitation, Beautification and Park Development Agency, (2014). Current status of dry waste management in Addis Ababa. Unpublished material, Addis Ababa Ethiopia.

Agunwamba, J.C., (1998). Solid waste management in Nigeria: Problems and issues. Environmental management, Vol. 25, Pp. 849-856.

Assiged Getahun, (2007). Geology of Addis Ababa city NC 37-10/ X and Y and NC 47-6/ E and F sub sheets, Geological Survey of Ethiopia. Addis Ababa, Ethiopia. Pp. 12-24.

Ayat, M., (1994). “The networks of collection and transfer stations of municipal solid waste management system”: Unpublished M.Sc. Thesis, University of Tehran, P. 137.

Bartone, C.R., (2001). The role of the private sector in municipal solid waste service delivery in developing countries: Keys to success. In: Challenge of urban government: Policies and practices, Freire, M. and R. Stren (Eds.). World Bank, Washington, DC., USA., Pp. 199-214.

Basagaoglu, H., (1997). Selection of waste disposal sites using GIS, *Journal of the American Water Resources Association,* 33(2), Pp. 455–464.

Berhanu Debele, (1985). The Vertisols of Ethiopia: Their properties, classification and management. In: Fifth meeting of the Eastern African sub-committee for soil correlation and land evaluation, Wad Medani, Sudan, 5-10 December 1983. World soil resources reports, No. 56. FAO, Rome. Pp. 31-54.

Bringi, S. D., (2007). “Application of 3D principles to solid waste management on the Asian Institute of Technology (Ait) Campus”. Unpublished M.Sc. Thesis. Indonsia, Pp. 45-80.

Brown, M. D. Vance, T.D. and Reilly, T.C., (1981). Solid waste transfer fundamental. An Arbor, MI, Ann Arbor Science Publisher.

Carver, S., (1991). Integrating multi-criteria evaluation with geographical information systems: *International Journal Geographical Information Science*, Vol. 5, Pp. 321–339.

Cointreau-Levine, S., (1994). Private sector participation in municipal solid waste services in developing countries, Volume 1: The formal sector. UNDP/UNCHS/World Bank urban management program, Washington, DC., USA., Pp. 1-68.

CSA, (2007). Population census of the Federal Democratic Republic of Ethiopia. Central Statistical Authority, Addis Ababa, Ethiopia.

Eastman, R. J., (2001). Idrisi 32, release 2. Tutorial. Clark university, USA. P. 237.

ENDA, (2006). Living healthily in a clean and green city. Habitat international coalition case study. Barcelona, Spain, p. 52

ENDA, (1999). The cycle of waste in Addis Ababa. ENDA, Addis Ababa, Ethiopia. Available at http://www.globenet.org/preceup/pages/ang/chapitre/capitali/transver/ethiopie.htlm released: 15/02/1999, accessed: 25/04/2014.

EPA, (1995). Decision maker's guide to solid waste management, Volume II, P. 58.

Erkut, E., Karagiannidis, A., Perkoulidis, G., and Tjandra, S. A., (2008). A multi-criteria facility location model for municipal waste management in North Greece: *European Journal Operational Search*, Vol. 167, No. 3, Pp. 1402–1421.

Ersoy H, Bulut F., (2009). Spatial and Multi-Criteria Decision Analysis-Based Methodology for Landfill Site Selection in Growing Urban Regions Karadeniz Technical University, Trabzon. Turk. Waste Manage. Res. 7(4), Pp. 56-67.

Eshet, Teshome, Baron, M., Shechter, M., and Ayalon, O., (2006). Measuring externalities of waste transfer station in Israel using hedonic pricing: waste management, Vol. 27, No. 5, Pp. 614–625.

FAO, (2013). Land potential data base, FAO Slope Class Codeset, Canada. Available at http://www.sis.gagr.ca/cansis/nsdb/lpdb/faoslcl.html released: 15/05/2013, accessed: 4/01/2015.

FAO, (2014). World reference base for soil resource, international soil classification system for naming soil and creating legend for soil map. Rome, Italy, Pp. 135 – 172.

Guerrero, L.A.,G. Maas and W. Hogland, (2013). Solid Waste Management Challenges for Cities in Developing Countries. Waste Manage., Vol. 33, Pp. 220-232

Henry, R.K., Z. Yongsheng and D. Jun, (2006). Municipal Solid Waste Management Challenges in Developing Countries-Kenyan Case Study. Waste Manage., Vol. 26, Pp. 92-100.

Herbert, F., Lund. Recycling Handbook. (2001). 2nd Edition Mc Graw Hill, U.S.A., Pp. 1-11.

Higgs, G. (2006). Integrating multi-criteria techniques with Geographical Information Systems in waste facility location to enhance public participation, waste management and research, Vol. 24, Pp. 1-105.

Jiang, H. and Eastman, J.R. (2000). Application of fuzzy measure in multi-criteria evaluation in GIS: *International Journal Geographical Information Science*, Vol. 14, No. 2, Pp. 173–184.

Joerin, F., Theriault, M., and Musy, A., (2001). Using GIS and out ranking multi-criteria analysis for land use suitability analysis: *International Journal Geographical Information Science*, Vol. 12, No. 2, Pp. 153–174.

Kao, J., Lin, H. Y., and Chen, W. Y., (1997). Network geographic information system for landfill siting: Waste Management Research, Vol. 15, Pp. 239–253.

Kebede Tsehayu and Tadesse Hailemariam, (1990). Engineering geological mapping of Addis Ababa. Ethiopian Institute of Geological Survey. Addis Ababa, Pp. 18-23

Khorasani, N. and Rafiee, (2007). Comparison between two methods of direct and indirect transfer of solid waste in Mashhad Municipal solid waste system (Abstract). In proceedings, urban planning & management conference. Mashhad City Council, Mashhad, Iran, Pp. 932.

Kontos, T., Komils, D. P., and Halvadakis, C. P., (2005). Siting MSW Landfills with a spatial multi-criteria analysis methodology: waste management, Vol. 25, Pp. 818–832.

Liu, D.H., Liptak, B.G. & Bouis, P.A. (1997). Environmental engineers handbook, second ed. Lewis Publishers, New York.

Makhdum, M., (1993). Fundamentals of land use planning: Tehran University Press, Tehran, Iran, P. 272.

Malczewski, J., (1999). GIS and multi-criteria decision analysis: John Wiley and Sons, Inc, New York, NY, P. 392.

Malczewski, J., (2004). GIS-based land use suitability analysis: a critical overview: progress planning, University of Western Ontario, London, Ont., Vol. 62, Pp. 3–65.

Municipal of Addis Ababa, (2002). Project proposal for Addis Ababa, Municipal proposal for Addis Ababa Municipal Solid Waste Management Program. Unpublished material.

Ministry of Agriculture, (2007). Soil Types of Addis Ababa, unpublished material, Addis Ababa, Ethiopia.

Moghadam, M., (2009). Municipal solid waste management in Rasht City, Iran. Waste Manage, Vol. 29, Pp. 485-489

Mohamed N. and Elsa, Z., (2003).Waste management program. UNIDO view document, No.3765. Tokyo, Japan.

Mohr P. A. (1967). The Ethiopian rift system. Bull. Geophysical observatory. Addis Ababa.31, Pp. 1-19.

National Meteorological Agency, (2014). Climate of Addis Ababa, unpublished material, Addis Ababa, Ethiopia.

Nilchiyan, S. (2002). “Site selection of transfer station and collection centers of municipal solid waste management system by using GIS”: Unpublished M.Sc. Thesis, University of Tehran, P. 187.

Rafiee, R. (2007). “Site selection for waste transfer station with regard to urban growth trend (Mashhad Case Study)”: Unpublished M.Sc. Thesis, University of Tehran, P. 105.

Rafiee, R., Syed, E., H., Afshin, D., and Nematolah, K., (2011). Siting transfer stations for municipal solid waste using a spatial multi-criteria analysis [illegible]XVII, No. 2, Pp. 46-48.

Saaty, T. L. (1980). The analytic hierarchy process: McGraw Hill, New York, P. 287.

Tchobanoglous, G., Theisen, H., and Vigil, S. A. (1993). Integrated solid waste management: engineering principles and management issues: McGraw Hill, New York, P. 978.

UNDP, (2004). Urban agriculture: food, jobs and sustainable Cities. New York: UNDP urban harvest working paper series, Paper No. 1.

UNEP, (2005). Solid waste management, Volume II: Regional overviews and information sources. USA, New York, P. 334.

US EPA, (1995). Collection and transfer: in decision maker’s guide to solid waste management. 2nd Edition, Washington DC. Available at http:/www.epa.gov/osw/nonhaz/municipal/pubs/dmg2.html released on 13/06/1995, accessed: 27/3/2015.

US EPA, (2002).Waste transfer stations: A manual for decision making. EPA530-K-01-005. Office of Solid Waste and Emergency Response, Washington. Available at http:/www.epa.gov/osw/nonhaz/municipal/pubs/ro2002.html released: 10/03/2002, accessed: 22/2/2015.

USEPA, (2004). Waste transfer stations: A manual for decision making, available at http://www.epa.gov/ebtpages/waste.html released: 05/01/2004, accessed: 20/01/2015.

Van De Klundert, A. and I. Lardinois, (1995). Community and private (formal and informal) sector involvement in municipal solid waste management in developing countries. background paper for the UMP Workshop in Ittingen. Available at http://www.gdrc.org/uem/waste/swm-finge1.htm released: 5/11/96, accessed: 12/9/2014.

World Bank, (1999). Technical guidance report on municipal solid waste incineration. The World Bank, Washington DC. Available at http://www.worldbank.org/urban/solid.../waste incineration.html released: 5/08/1999, accessed: 8/2/2015.

World Health Organization (WHO), 1996. Guides for municipal solid waste management in Pacific island countries, Healthy cities - healthy islands, Document series, no. 6, Pp.132.

Zake, J. (2007), A Base line survey report for sustainable neighbors' if focus cities project. Available at http://www.slideshave.net/joshuazake1/waste-is-wealth.html released: 10/04/2014, accessed: 18/3/2015.

Zanettine, B., Justine-Visentin, E**.** (1974). The volcanic succession in Central Ethiopia 2. The volcanic of the western Afar and Ethiopian rift margins, Mem. 1st Geol. Miner. Univ. Padova. 31, Pp 1-19.

Zhang, D.Q., S. K. Tan and R. M. Gersberg, (2010). Municipal solid waste management in China: status, problems and challenges. J. Environ. Manage., Vol. 91, Pp.1623-1633.

Appendix

Ground control Points of Health Centers (GCPs)

No	Name of health centers	X	Y
1.	Kidus Petros Tuberculos	473286.4	1003138.1
2.	Kidus Paulos	470021.4	999956.3
3.	Menilik	475211.9	998920.9
4.	Yekatit	473558.9	999464.8
5.	Ras Desta	471858.3	999592.2
6.	Tibebu	471726.1	999119.7
7.	Tikur Anbesa	472322.6	996859.8
8.	Zewditu	473134.9	996703.6
9.	Ghandi	473050.5	996384.3
10.	Police	471342.4	995893.2
11.	Dejach Balcha	141131.8	995927.4
12.	Armed Force	469533.3	995965.9
13.	Alert	468161.3	993122.7