JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCE AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Potential Landfill Site Selection in Gondar Town: A Decision Support System using GIS and Remote Sensing Technologies

By:

Getahun Sisay

Msc Thesis Submitted to the School of Graduate Studies of Jimma University Department of Geography and Environmental Studies, in Partial Fulfillment of the Requirement of Master of science in Geographic Information System and Remote Sensing.

June, 2017

Jimma, Ethiopia

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Declaration

I declare that the thesis entitled **Potential Landfill Site Selection in Gondar Town: A Decision Support System using GIS and Remote Sensing Technologies** has been carried out by me under the supervision of Dr. Ajay Babu (principal advisor) and Dr. Kefelegn Getahun (co-advisor) department of geography and environmental studies Jimma University during the year 2016-2017. It is submitted for the partial fulfillment of the requirement masters of Science in GIS and remote sensing. I further affirm that it has not been submitted for other Universities for the award of degree or diploma and all the sources that I have used have been indicated and dully acknowledged.

Signature --------------------------

Getahun Sisay Teshager

Place: Jimma University, Jimma

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Acronyms

AHP	Analytical Hierarchy Process
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EPA	Environmental Protection Authority
GIS	Geographic Information System
GPS	Global Positioning System
LULC	Land use and land cover
MCDA	Multi criteria Decision Analysis
MCE	Multi Criteria Evaluation
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MUDC	Ministry of Urban Development and Construction
OLI-TIRS	Operational Land imager and Thermal Infrared Sensor
SRTM	Shuttle Radar Topographic Mission
UNEP	United Nation Environmental Protection
WHO	World Health Organization
WLC	Weighted Linear Combination
^{0}c	Degree Celsius

Abstract

Selecting appropriate site for landfill is one of the major problems for most of towns and cities particularly in Ethiopia. This is due to the fact that the selection of suitable site requires the consideration of many environmental and socio economic variables. The study was initiated to map the potential suitable sites for solid waste landfill in Gondar town using GIS and remote sensing technologies. To achieve the objectives of the study GIS based multi criteria evaluation method was employed. To identify appropriate site for landfills 9 criterias were considered. All the input map layers were first geo-referenced and converted in raster format to make them ready for reclassification. Afterwards they were reclassified based on their suitability level according to the standards set by different researchers and the prevailing local conditions of the study area. After reclassification weights for each criteria was assigned by following AHP procedures using pairewise comparison matrix. After assigning weights for each criterion they were combined together using weighted overlay tools and highly suitable areas were identified. The final suitability map shows that about 4.5% of the study areas were found to be highly suitable and 39.5% was unsuitable for landfill site. The identified highly suitable sites were then reevaluated using criteria like distance from the center of the city, distance from the nearby settlement and size of the area. To assign weights for each candidate landfills Analytical Hierarchy Process was employed and highly suitable sites among the 7 sites were identified. Accordingly Landfill site 7 which is found in south east part of the town and landfill site 3 found in the north west of the town were selected as the first and second most highly suitable sites for landfill respectively. These sites were selected because they are large in size and are found in a compromise distance from the city center as well as from residential areas. This study showed that GIS and remote sensing technology are efficient and cost effective to select suitable sites for landfill in an attempt to facilitate decision making process.

Keywords: *multi-criteria evaluation, landfill, suitability*

CHAPTER ONE

1. INTRODUCTION

1.1. General Background

Waste is a useless material discharged from each daily human life activities which causes adverse impacts on human health and the environment (Bringi, 2007). Whereas solid waste is a non liquid and non gaseous useless products like food remnants, paper/carton, textile materials, bones, ash/dust/stones, dead animals, human and animal excreta, construction and demolishing debris, biomedical debris, household hard ware (electrical appliances, furniture etc) which can be produced from households, municipal, construction and industries (Sha'Ato et al., 2007; Babatunde et al., 2013).

Solid waste is a worldwide environmental dilemma in today's world both in developing and developed countries due to escalating growth of population, accelerated process of urbanization and industrialization, rapid economic growth and the rise in community living standards (Elmira et al., 2010).

Although solid waste management problem is facing both developing and developed countries the situation is particularly severe in developing countries where inadequate waste disposal can be very dangerous for environment and human health (Jilani et al., 2002). The most common problems is associated with inadequate collection, recycling or treatment and uncontrolled disposal of waste that causes severe hazards, such as disease transmission, fire hazard, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic loses (Jilani et al., 2002; Jayparakash et al., 2015). Visvanathan and Glawe, (2006) also noted that inappropriate disposal of solid waste can be manifested by contamination of surface and ground water through leachate, soil contamination through direct waste contact, air pollution by burning of wastes, distribution of diseases by different vectors and unrestrained release of methane by anaerobic decomposition of waste. For these and many other reasons, selecting appropriate landfill site far away from residential areas and environmentally sensitive areas is the main issue for management of solid waste (Tirusew & Amare, 2013).

Landfill is an important part of waste management system, which requires much attention to avoid environmental pollution and health problems. However, most landfill sites in many developing countries urban areas are found on the periphery of the urban areas where water bodies, crop filed, settlement, road, etc are available. These created suitable condition for the reproduction and propagation of vectors and transmit diseases that have an effect on human health (Abul, 2010).

The management of solid waste in Africa is often weak due to lack of appropriate planning, inadequate governance, poor technology, weak enforcement of existing legislation and the absence of economic and fiscal incentives to promote environmentally sound development. As a result of this nearly all nations applying open dumping for waste disposal without Leachate and gas management over ecologically or hydro-logically sensitive areas (Tirusew and Amare, 2013 ;Gizachew, 2011). This method of waste disposal is also more common in our country Ethiopia and is becoming a major public health and environmental concern (Degnet, 2008; Gennemo and Yohhanes, 2015). A survey conducted for fifteen randomly selected large and medium towns of Ethiopia about their status of solid waste management showed that 86% of them were used open dumping to dispose solid waste in a landfill site. From these towns Gondar town is among the one practicing open dumping for solid waste management (Gennemo and Yohhanes, 2015).

Like other towns of Ethiopia Gondar town is characterized by rapid population growth caused by natural increase and migration from rural area. Such rapid increase in population together with rapid development of the town has produced increasing volumes of solid waste generation and results solid waste management problem. Most of solid wastes that are generated in the town remain uncontrolled and simply dumped in open areas, road sides, river courses, gullies and etc which leads to disease transmission, atmospheric and water pollution and aesthetic problems. The disposal method that the town applying is open dumping (Mohammed, 2015; Gennemo and Yohannes, 2015) type which widely practiced in many developing countries and has hazardous effect on health and the environment.

The environmental and sanitary conditions of the town have become more serious from time to time and people are suffering from living in such conditions. Although most of the solid wastes are collected from the source using the method of door to door collection to transfer stations, there are no scientifically approved sites (Mohammed, 2015). The landfill site is not well planned, without principal concern for environmental protection and public health close to settlements and not at appropriate distance from the center of the town.

Many factors should be taken in to consideration during landfill site selection process and GIS is ideal for this kind of preliminary studies due to its ability to handle large volumes of spatial data from diversified sources (Sener et al., 2006). It handles and simulate the necessary economic, environmental, social and technical constraints while remote sensing provide information about a variety of spatial criteria such as land use/land cover, drainage density, slope, etc (Emun, 2010 and Oštir et al., 2003). The combination of GIS and MCE is also a powerful tool to solve landfill site selection problem because GIS provide efficient manipulation and presentation data and MCE supplies consistent ranking of the potential landfill areas based on a variety of criteria (Sener et al., 2006). Therefore, this study is aimed at providing potential landfill sites by using GIS and remote sensing techniques in order to minimize risk of ecological and human health problem in Gondar town.

1.2. Statement of the Problem

Solid waste management is one of the major problems for most developing countries like Ethiopia (Netsanet, 2015) because of its broader impact on socio-economic development and the environment. Level of municipalities solid waste management system in Ethiopia is low as a result of this, all urban areas indiscriminately disposes solid waste near ecologically and socially sensitive areas. This results environmental pollution and causes major threat for public health problem (ibid).

Genemo and Yohannes (2015) argued that the thriving growth of cities of the developing countries like Ethiopia has exceeded the financial and man power resources of municipalities to deal with the provision of services for management of solid wastes.

Lack of these services mainly affects the urban poor, women and children who are exposed to health hazards. Moreover, its effects are directly or indirectly reflected by reducing productivity, income, standard of life and physical environment (World Bank, 1999). With the current growth rate of urban population in Ethiopia, it is estimated that the population of most urban areas especially small urban centers is doubling every 15-25 years (Genemo and Yohannes, 2015). As solid waste generation increases with economic development and population growth, the amount in these urban areas will double within a similar time range and causes the problem to be more severe. Due to absence of landfill sites, people are forced to dispose the wastes from their home or other restricted areas haphazardly. These causes sanitary conditions of the area to depreciate and certainly will have high potential environmental and human health risk.

In Gondar town there are serious problems of solid waste management system. Institutions, industries and households dispose solid wastes without considering the topography, surface water, drainage, flora and fauna and its resulting social and ecological consequences (Mohammed, 2015). He also noted that municipalities of Gondar are using open dumping system and this in turn affects surface water, ground water, soil and natural environment as a whole. They are not taking the necessary care in selecting the site for collection and disposal solid wastes.

Previously, there were few researches which have been conducted on solid waste management in the study area. However, they didn't fully utilized GIS and remote sensing techniques as a decision making tool and were also unable to consider the very important criteria. For instance Mohammed by 2015 has conducted studies on assessment of the current status of solid waste management in Gondar town and tried to evaluate the current situation of solid waste management system but, he didn't apply GIS and remote sensing as a decision making tool. There was also another study carried out by Abel and Ebrahim in 2016 on determination of suitable solid waste disposal sites using GIS and remote sensing however, they were considered very few criteria. In addition to this the current landfill sites of the study area called *Ayira* is not on scientifically approved acceptable sites. The site is found very close to Gondar University, rivers, churches and residential areas without Leachate and gas management. Moreover, as a result of fast expansion of the town the landfill site is surrounded by settlements in almost all directions. When the site was selected they didn't consider social and environmental factors and even the future development of the town. Due to this the site is becoming in the center of the town and is causing environmental pollution and disease transmission. Therefore it is better to select another landfill site that considers social and environmental factors so as to preserve environmental health. By taking into account the sternness of the problem and all the above factors this study was conducted to select and map the potential landfill site for Gondar town.

1.3. Objectives of the Study

1.3.1. General Objective

The overall objective of this study was to determine the potential sites for landfill using GIS and remote sensing techniques by considering social and environmental factors.

1.3.2. Specific Objectives

Specifically this research is aimed at to:

- ❖ Identify important criteria that are necessary for selecting optimum landfill site
- ❖ Produce thematic map showing potential suitable landfill sites for the study area.
- ❖ Prioritize and rank the identified suitable candidate landfill sites based on their suitability level

1.4. Research Questions

- ❖ What are the important criteria for selecting suitable landfill site?
- ❖ What are the procedures used to produce thematic map of the identified landfill potential sites?
- ❖ How does the final selected candidate landfill sites prioritized and ranked?

1.5. Significance of the Study

Selecting potential site for landfill using GIS and remote sensing technique is one of the precise decision making tools to select and map suitable landfill sites in a manner that bearing in mind social and environmental factors. Therefore, the findings of this project will be significant for municipality of Gondar town as a basis for solid waste management decision making process. The suggestion and recommendation forwarded by this project will also be used as an input for decision makers to improve the existing solid waste management system of the town. Moreover, the information provided by this study may be used as a springboard for further studies related to solid waste management.

1.6. Scope and Limitation of the Study

The scope of this study was confined in terms of space and subject. Spatially this study was delimited to Gondar town comprising of 21 *kebeles.* The study was focused on selecting potential sites for landfill using GIS and remote sensing as a decision making in Gondar town. Its focus was only in the issue of solid waste landfill site selection in relation to different environmental and socio economic factors. The time for the study was until June 2017. During the course of preparing this thesis there were some limitations. These were absence of updated data, absence of secondary data from institutions and shortage of time.

1.7. Ethical Consideration

According to research code of ethics for GIS professionals prepared by institute for environmental studies at university of Wisconsin, (2001) the researcher tried to get informed consent from the town administrators and municipality workers by clearly stating the objective and relevance of undertaking the project. In the case of professional integrity the researcher was tried to be diligent enough to complete his duties. In addition to this the researcher was also tried to acknowledge other's contribution by properly citing scholarly literatures and data generated by other individuals or organizations.

1.8. Organization of the Study

This thesis has five chapters. Chapter one incorporates an introduction part which consists of the general background of the study, statement of the problem, objectives of the study, significance of the study, 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 include the analysis, results and discussion parts of the study and the last chapter presents conclusion and recommendations of the study.

CHAPTER TWO

2. Review of Related Literature

2.1. Definitions of Waste

It has been difficult to decide the exact definition of waste (Emeka, 2011). With individuals, community and nations, the meaning and interpretation differs greatly in all contexts. This complexity has led to a strict definition to ensure proper handling and disposal of waste types in accordance with laws and regulation. However, (Zake, 2007) defined it as a substance at a given times and places which in its actual structure and state is not valuable to the owner. It is also commonly referred to as rubbish, trash, garbage, refuse, effluents and unusable materials left over from a production process, or output which has no marketable value discharged to, deposited in, or emitted to environment in such amount or manner that causes a harmful change (ibid).

2.1.1. Solid Waste

Solid waste is a broad expression which includes all waste materials except hazardous waste, liquid waste, and atmospheric emissions (Liu et al., 1997). It is often used to explain non-liquid materials produced from domestic trade, commercial, agricultural, industrial activities and public services (Emeka, 2011). Solid waste can be categorized into three main categories based on its source namely: municipal, industrial and agricultural. Municipal solid waste has also several sources such as residential, commercial, institutional, construction and demolition and municipal services (Tchobanoglous et al., 1993). If solid waste is not properly handled and treated, it will have negative impacts on the sanitary conditions in urban areas and pollute air, surface and groundwater, as well as the soil and crops (World Bank, 1999).

2.2. Solid Waste Management

Solid waste Management comprises issues and processes related with controlling of waste generation, collection, transporting and disposal of solid wastes produced as a result of human related activities taking in to consideration social, economic and environmental conditions (Zake, 2007). The major types of solid waste management systems include, source reduction, recycling, waste transformation and land filling (Bagachi, 2004). Tchobanoglous and Kreith, (2002) also noted that solid waste management includes the selection and application of all suitable techniques, technologies and management programs to realize specific waste management objectives and goals. These goal and objectives of solid waste management is recovering of more valuable products from the waste with the use of less energy and minimizing the negative environmental impact (Bagachi, 2004).

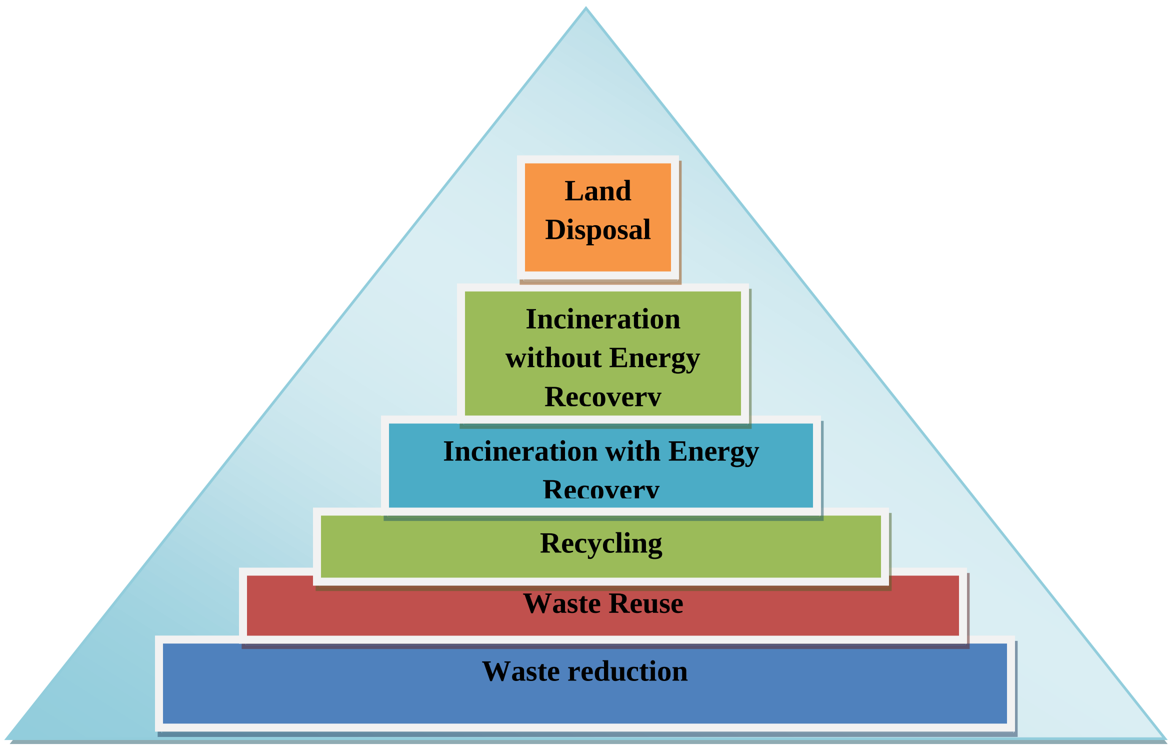


Figure 1: Pyramid showing waste management hierarchy (Bgachi, 2004)

2.3. Landfill Sitting

Landfill sitting is a method that solid waste which cannot be recycled or further used are placed in a landfill taking social, economic and environmental factors in to consideration (Emeka, 2011). It is a difficult, tiresome, and prolonged process requiring evaluation of several criteria (Chang et al., 2008) since it has to consider social, environmental, technical, and financial factors. Environmental factors are very important because the landfill may affect the biophysical environment and the ecology of the surrounding area (Siddiqui et al., 1996; Kontos et al., 2003; Erkut and Moran, 1991).

The location of landfill, without considering closeness of site to residential, river, water channel or other fragile ecosystem could lead to adverse environmental pollution and degradation as well as health hazards. However, many developing countries do not have a process and criteria or guidelines for landfill sitting and design, and in some areas, there have been inclinations to adopt guidelines or regulation of higher income countries without modifying or adapting them to local conditions. These create a problem because the developments of landfill require complex engineering design and construction techniques. In addition, complicated landfills normally have measures to control or use landfill gas, broad environmental monitoring points, leachate collection and treatment systems, and have need of a greatly qualified work force. As such, the implementation of complicated engineered landfills can only occur where the local economy can afforded the high level of expenses required for construction and operation of the landfill and where the technical resources to achieve high standards of construction and operation are made available (Laura, 2003).

2.4. Solid Waste Management System in Developing Countries

Solid waste management is becoming a serious confront for city 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 relied 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 different stages of waste management and linkages necessary to enable the entire handling system functioning (Mohghadam, 2009).

2.4.1. Solid Waste Management in Ethiopia

Solid waste management has been a major confront for most cities and towns of Ethiopia due to high rate of urbanization, escalating growth of population and limited financial and man power resources of municipalities. The Provision of municipal service for solid waste management lags behind the need and development of settlements (Gennemo and Yohannes, 2015). This increases deterioration of the immediate environment in the households and their environment.

An integrated rural and urban development study undertaken in 1988 indicates that among the eleven sample towns and cities only Addis Ababa had centralized solid waste disposal system (NUPI, 1989). Lack of manpower and technical skill remain the most important bottleneck in solving solid waste management problem for most towns in Ethiopia. Absence of waste segregation at its source, lack of standardized solid waste transfer stations, lack of collection from solid waste generation and poor landfill site management has also been observed in municipalities and is becoming a major challenge for town administrators (Global Methane Initiative, 2011).

Based on a survey conducted to assess the status of solid waste management for fifteen randomly selected large and medium towns of Ethiopia, 86% of them were using open dumping to dispose solid waste. From these towns Gondar was among the first to use this solid waste management system (Yami, 1999).

2.4.2. Solid Waste Management in Gondar Town

Gondar is the most populated zonal city with the population of above 200,000 (CSA, 2007) caused by natural increase and migration from rural area. Such rapid increase in population together with rapid development of the town has produced increasing volumes of solid waste and in turn it induced greater infrastructural demand, institutional setup and community participation for its management. The town sanitation and beautification which administers solid waste management activities of the town could not fulfill the necessary requirements for appropriate solid waste management (Mohammed, 2015). Most of solid wastes that are generated in the town simply dumped in open areas, road sides, river courses, gullies. The environmental and sanitary conditions of the town have become more serious from time to time, and people are suffering from living in such conditions.

Management of municipal solid waste in the town entirely relied on the municipality which provided the full range of waste collection, transportation and disposal service. But, the provision of this service is not kept in pace with the town solid waste generation. Majority of the household dominantly produced biodegradable solid wastes with generation rate of 0.21kg per person per day (Mohammed, 2015). This made the daily total solid waste generation of households to be 8,140 Kg. Together with other solid waste sources the total daily solid waste generation of the town is about 11,660 kg. Annually it reaches to 4, 197, 62, 90 Kg (ibid).

2.4.2.1. Preliminary Solid Waste Handling in Gondar Town

Solid waste storage facilities and their handling have significant impact for improvement of municipal solid waste management activity. This is from the point of identification of type and quantity of storage material to be used, appropriate location along with environmental and socioeconomic factors, deciding the collection method to be used, and avoidance of health, environment and aesthetic impacts of storage materials (Gebretsadkan, 2002 as cited in Mohammed, 2015). According to Mohammed (2015), waste handling and storage practice of Gondar town is grouped in to two categories. These are primary solid waste storage and handling and secondary solid waste storage and handling.

A. Primary Solid Waste Storage Facility and its Treatment

As explained by (Mohammed, 2015) the majority of the households of Gondar town have one storage materials to store solid waste while others have two storage materials. But, the types of storage materials used by households are different. This is mainly because of the nature of storage material of households that depends on the characteristics of solid wastes, collection frequency and types of collection equipment, space available for placement of the storage materials, and economic power of solid waste generators (Gebretsadkan, 2002).

B. Secondary Solid Waste Storage Facilities and its Treatment

Secondary storage facilities refers to different types of solid waste containers which involve keeping solid waste generated from different households at a common or central point from where collection vehicles can pick it and transport to final disposal site (Zebenay, 2010). These facilities are provided by municipality which is responsible for management of the town solid waste. Gondar town sanitation and beautification put public solid waste containers in different areas of the town where frequent illegal dumping of waste is mostly occurred, and in areas where high population density is assumed to exist (Mohammed, 2015).

2.4.2.2. Method of Solid Waste Collection and Transportation in Gondar Town

Collection and transportation of solid waste includes the process of gathering of waste from place of generation, taking it to nearby public solid waste containers and lastly dumping it to disposal site (UNEP, 1996). This functional element is very critical and necessary component of municipal solid waste management because efficiency of this service is highly determined by it. Currently, in Gondar town there are two methods of waste collection such as door to door and transfer stations collection.

A. Door to Door Solid Waste Collection and Transportation System

This technique is largely applied for collection of solid waste from households and is carried out by medium and small scale enterprises. 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 (Netsanet, 2015)**.** According to Gondar town sanitation office, (2017) there are 12 medium and small scale enterprises to involve in deliver of solid waste collection service to households, individuals, institutions and organizations. These enterprises take agreement to collect solid wastes and make it accessible for transportation to final disposal sites.

2.5. The Role of GIS and Remote Sensing for Landfill Site Selection

2.5.1. Geographic Information System (GIS)

The role of GIS in solid waste management is very large as many aspects of its planning and operations are highly dependent on spatial data (Emeka, 2011). GIS is a tool that not only reduces time and cost of site selection, but also provides a digital data bank for future monitoring programme of the site (Tomlison, 1990). It is a suitable tool for site selection since it has the capability to manage large amount of spatial data that comes from various sources. (Kao et al., 1996) also pointed out that large amount of spatial data can be processed using GIS and thus, it potentially saves time that would normally be spent in selecting an appropriate site. While, (Daneshvar et al., 2005) also claimed that GIS is an ultimate method for preliminary site selection as it efficiently stores, retrieves, analyzes and displays information according to user defined specification. It combines spatial data like maps, aerial photographs and satellite images with the other quantitative, qualitative and descriptive information databases (ibid).

As it is already described above landfill sitting is complex, tedious and costly as it requires multiple criterions from environment, social and economic point of view (Chang et al., 2008). It is a complicated process requiring a detailed assessment over a vast area to identify suitable location for constructing a landfill subject to many different criteria, but with the application of GIS, the task of finding potential suitable sites can be done efficiently and effectively. It is ideal for preliminary suitable solid dumping site selection because it can manage large volumes of spatially distributed data from a variety of sources, store, retrieve, analyze and display information for decision making by offering the spatial analytical capabilities to quickly eliminate parcel of land unsuitable for landfill site (Chang et al., 2007). In general, the major goal of landfill site selection is to ensure that a disposal facility is located at a potential site with minimal environmental and social impact (Bagchi, 2004; Vasilios, 2004) and GIS play an outstanding role in accordance with the technical requirements, with overlay the thematic map to get an appropriate landfill (Akbari et al., 2008).

2.5.2. Multi-Criteria Decision Analysis (MCDA) and GIS

Multi criteria decision analysis (MCDA) is a very valuable tool to solve problems that are characterized as a choice among alternatives. It makes the management of the large complex information easier (Khan and Samadder, 2014) and it is characterized by the ratings of each alternative with respect to each criterion and the weights given to each criterion. Multi criteria decision making provides a support for the identification of components of a decision making problem, organizing the elements into a hierarchical structure, understanding the relationships between components of the problem and stimulating communication among participants (Malczewski, 2006). The main goal of MCE analysis using GIS techniques is to examine a number of possible choices with reference to multiple criteria and conflicting objectives and takes in to account expert knowledge of decision making (Khan and Samadder, 2014). Integration of GIS and MCDA provides a more rational and impartial approach for decision making in land fill by analyzing the complex tradeoffs between alternative choices with different environmental and socio-economic impacts.

In the circumstance of integration of GIS and MCE, two procedures are commonly used (Jiang and Eastman, 2000; as cited in Netsanet, 2015). 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 after that the criteria maps are combined using logical operations: OR and AND, such that the resulting image simply has two classes indicating the suitable and unsuitable areas (Netsanet, 2015).

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 & Eastman, 2000). It allows the decision maker to assign weights according to the relative importance of each suitability map and combines the reclassified maps to obtain an overall suitability score (Malczewski, 2004).

Analytical Hierarchy Process (AHP) one of the methods of MCDA, is useful in estimating the weight coefficients for each criterion, which helps in structuring of multi-criteria in a decision hierarchy tree (Kontos et al., 2003). It assists the decision making process by allowing decision makers to organize the criteria and alternative solutions of a decision problem in a hierarchical decision model. It is considered as the most suitable method because it allows dividing the problem, and focuses on one smaller decision set at a time (Khan and Smadder, 2014).

2.5.3. Application of Remote Sensing for Landfill Site Selection

Remote sensing is defined as the science or art of obtaining information about an object, area or phenomenon through the analysis of the data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand et al., 2004). It serves as a tool for environmental resources assessment and monitoring. Nishanth et al., (2010) also states remote sensing as one of the excellent tools for inventory and analysis of environment and its resources, owing to its unique ability of providing the synoptic view of a large area of the earth’s surface and its capacity of repetitive coverage. The application of remote sensing is becoming gradually more frequent in environmental studies especially for solid waste landfill site selection where remote sensing data are used for extracting most of the site selection criteria used for sitting landfill (Oštir et al., 2003). It provides digital data as a source for GIS application.

2.6. Criteria used for Landfill Site Selection

Landfill should be selected through considering many criteria from environmental, social and economical point of view (Gizachew, 2011). This is because Landfill requires an extensive evaluation process in order to identify the optimum available disposal location. This location must fulfill with the requirements of the existing environmental, financial and infrastructural provisions (Baban and Flannagan, 1998) and at the same time must minimize economic, environmental, health, and social costs (Siddiqui et al., 1996).

Different researchers have used different criteria for landfill site selection purposes due mainly to the fact that different criteria applies to different region (Ayo et al., 2011). However, the following criteria are often used for landfill site selection process.

2.6.1. Distance from Settlement

The landfill site should not be placed close to a residential area to avoid adversely affecting land value and future development and to care for the general public from resulting environmental hazards released from landfill sites (Bilgehan et al., 2009). Therefore to minimize such problems the safe distances from settlements are determined as 700m for urban centers and 3000m for rural villages (Tirusew et al., 2013). Bilgehan et al., (2009) also suggested that landfill shall not be located within 1,000m distance of residential area.

2.6.2. Land Slope

The areas with high slopes are not ideal for landfill site and flat areas are not ideal either. This is because too steep of a slope would make it difficult to construct and sustain and too slope would affect the runoff drainage (Yeshdha & Karthihenyah, 2016). With higher runoff rate and decreased infiltration, contaminants are able to travel greater distances from the containment area. This matters a larger environment to the dangerous chemicals produced within the Leachate from the landfill, especially surface waters (Bilgehan et al., 2009). (Lin and Kao, 2005; MUDC, 2012; Tirusew et al., 2013 and Bilgehan et al., 2009) recommended that the appropriate slope for constructing a landfill is about 8 up to 12%.

2.6.3. Proximity to Water Bodies

Landfills should not be placed too close to streams and rivers that constitute the drainage system of an area in order to alleviate conflicts relating to the contamination of sources of water supply (Guiqin et al., 2009). This becomes very important in order to protect against health problems, noise complaints, odor complaints, decreased property values and animal perpetrated mischief due to scavenging creatures. To maintain the environmental health of water sources at least 500m buffered distance should be made (MUDC, 2012 & Guiqin et al., 2009).

2.6.4. Distance from Roads Network

A road is one of the criteria that should be considered from economic and social point of views during landfill site selection processes. This is because sitting landfill very close to roads may have public health problem as landfill can have hazardous effect to health. Moreover, landfill site very far from road network is also not recommended due to high transportation cost (Chang et al., 2007). Therefore, to minimize such problems, it must not be sited very close to and very far from roads. (Hasan et al., 2009) uses 50-100m buffer from road as a minimum distance. However, 100m buffer distance is mentioned as the safest distance (Map Asia, 2004; Zain, 2009; Yahaya, 2010; Ersoy & Bulut, 2009 & EPA, 1995).

2.6.5. Protected Areas

The landfill should not be located in close proximity to sensitive areas like churches, mosques, schools and hospitals to the limit of 3,000 m buffer surrounding and as distance increases the suitability also increases (Trusew et al., 2013). Similarly, the criteria of (Ersoy & Bulut 2009; Babalola & Busu 2010) show that the area located at the distance greater than 3000m from environmentally sensitive area were selected as highly suitable for landfill site.

2.6.6. Land Use and Land Cover Type

The land use land cover pattern is an outcome of both natural and socio-economic factors and their utilization by man in time and space (Yeshdha and Karthihenyah, 2016). The landfill site should not be selected close to the built up area to avoid adversely affecting land value and future development and to protect human being from environmental hazards created from dumping sites (ibid). Therefore it is recommended that low economic value lands like Scrub land and barren land are most suitable for the dumping site (Yeshdha and Karthihenyah, 2016; Trusew et al., 2013).

2.6.7. Soil Type

During landfill site selection it is recommendable that the soil of the selected site should have low permeability to significantly slow the passage of leachate from the site in order to reduce the possibility of aquifer contamination. Sites in clay rich environments are preferable, due to the low permeability, good workability and superior leachate retaining characteristics of these soils. Therefore, clay textured soil is more preferred for landfill as it is impermeable to leachate and also used for lining the base of sanitary landfill (MUDC, 2012).

CHAPTER THREE

3. Description of the Study Area and Methodology

3.1. Description of the Study Area

3.1.1. Location

Gondar is the capital city of North Gondar zone found in Amhara regional state north western Ethiopia founded by Emperor Fasilides around the year 1635. It is located 748 km North West of Addis Ababa and 180km North East of Bahir Dar. Astronomically it is located between 12^{0}30'0" and 12^{0}40'0"North of latitude and 37^{0}20'0" up to 37^{0}33'20" East of longitude. Part of the *Semien* Gondar zone in the Amhara region, Gondar is north of Lake Tana on the lesser Angereb river and southwest of the foothills of Simien Mountains.

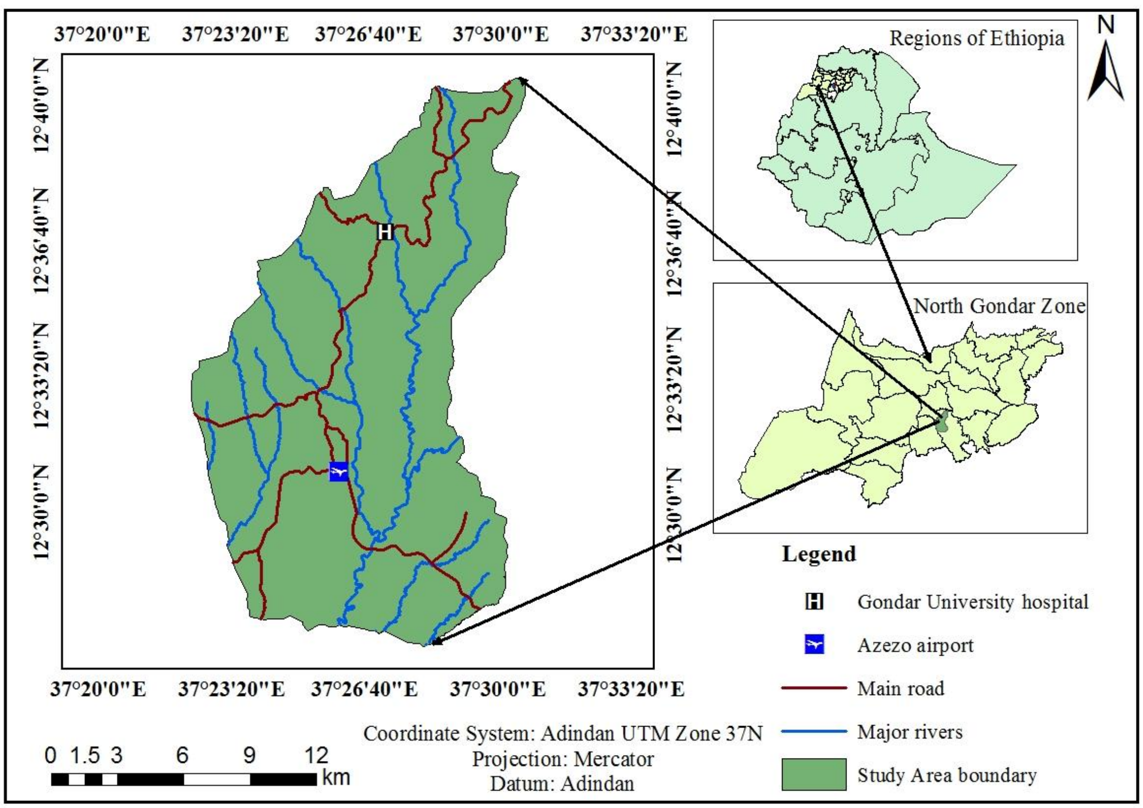


Figure 2: Location map of the study area

3.1.2. Topography

Gondar town is known by its rugged and mountainous topography with average elevation >2000 meter above mean sea level. The northern, north eastern and north western part of the town is characterized by very steep slopes. The steepness of the area decreases as we go from north to south along Azezo and *Teda*. The elevation map of the study area was extracted from SRTM (30m*30m) resolution DEM using GIS spatial analysis (surface) tools. Hence, elevation with in the town ranges from 1817 up to 2593 meter (Figure, 3).

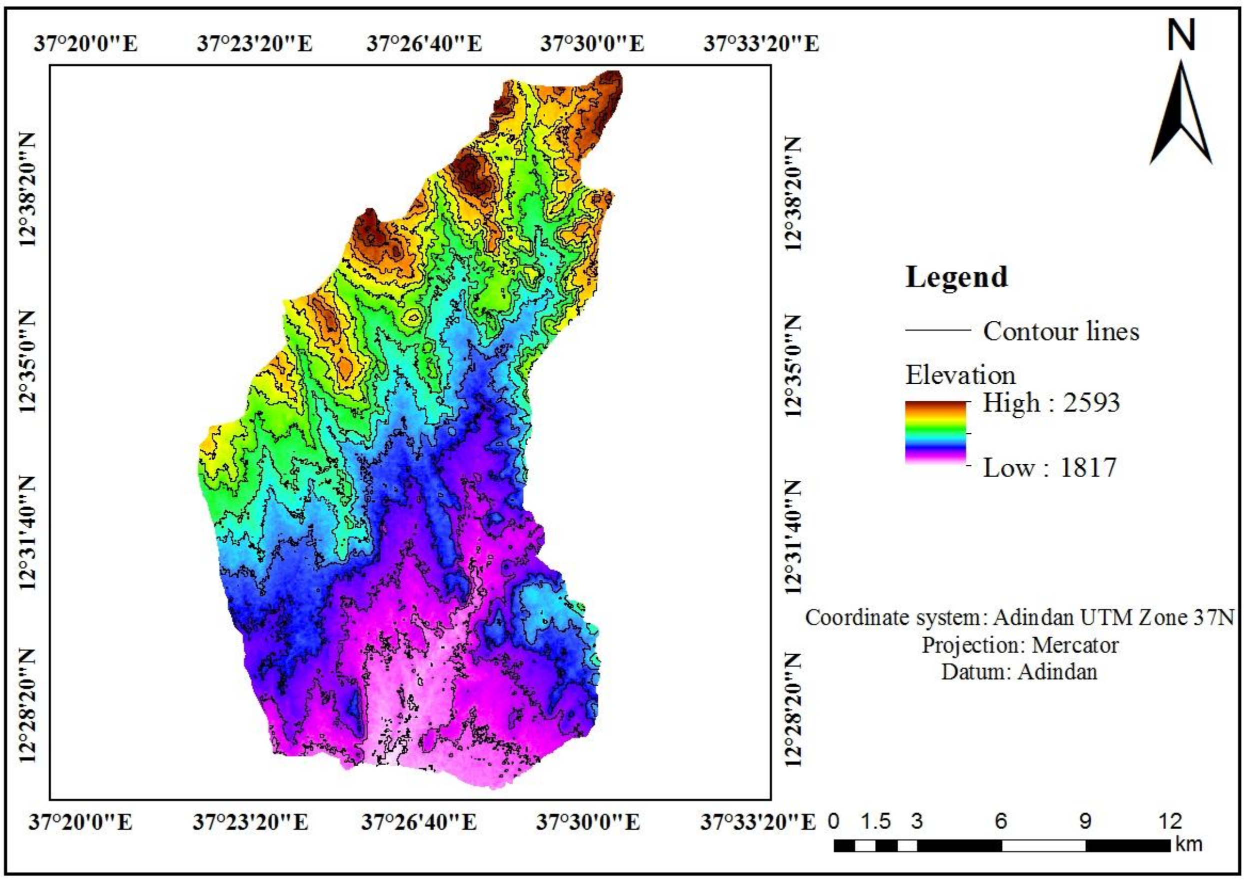


Figure 3: Elevation map of the study area (Source: Generated from DEM, 2017**)**

3.1.3. Climate

The agro ecological climate zone of Gondar is *weyina dega*, with a mean annual temperature ranging from 14.45^0C to 27.3^0C and average annual temperature of 20.8°C and mean annual rainfall 1427.8 mm (Ethiopian metrological service agency, 2016). The rainfall pattern of Gondar is characterized by a single maximum rainfall pattern with peaks in July and August. About 80%-90% of the mean annual rainfall falls in the main rainy summer season starts in June or July and extends up to August/September (Tewodross, 2011). Rainfall variability in time is more common especially at the start and end of the main rainy season. The average monthly temperature and rainfall data recorded from Gondar and nearby stations is clearly shown in the following figures (4&5).

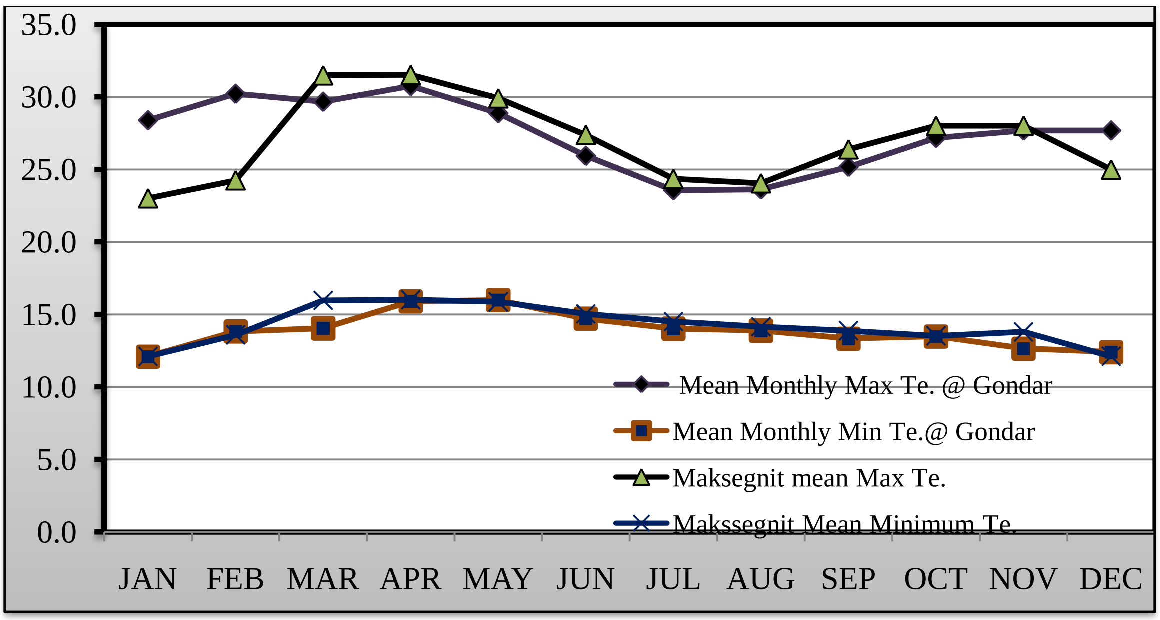


Figure 4: Mean monthly maximum & minimum temperature (in ºc) of the study area at two stations from 2006 up to 2016 (National Meteorological Agency of Ethiopia, 2017).

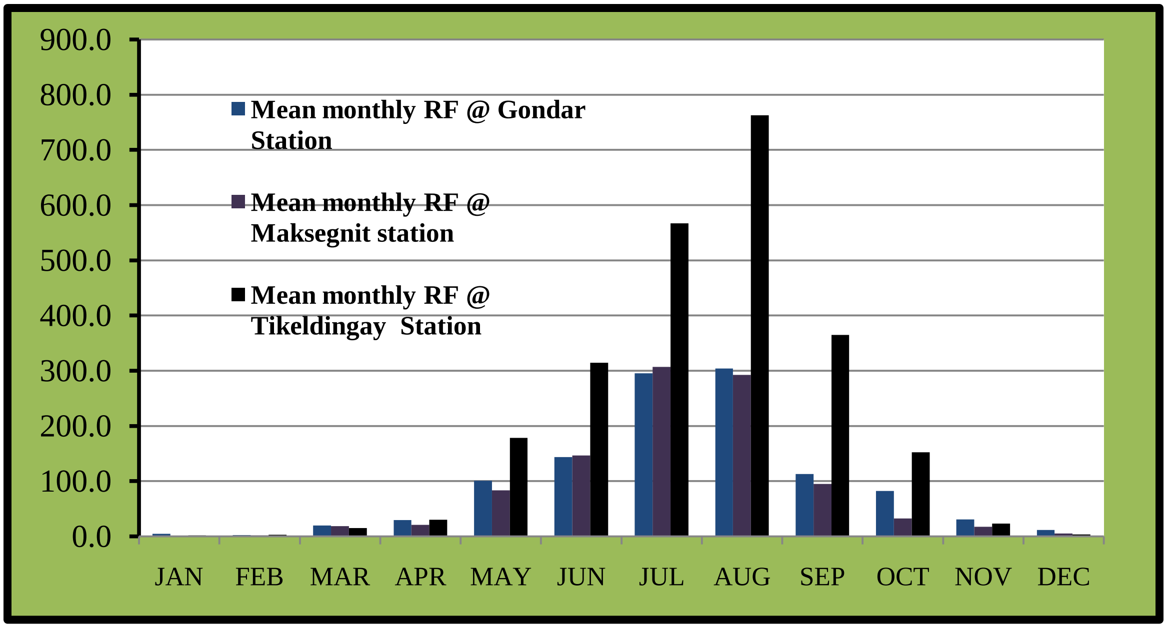


Figure 5: Mean monthly maximum & minimum rainfall (in mm) of the study area at three stations from 2006 up to 2016 (National Meteorological Agency of Ethiopia, 2017).

3.1.4. Soil

The type of soil can vary from place to place due to the fact that soil forming factors namely temperature, rainfall, topography, parent material, biological activities and time greatly determines the type of soil that are formed at a particular area. Accordingly the soil of Gondar town can be classified in to three categories namely: Eutric vertisol, Lithic leptosol and Haplic luvisol.

Eutric vertsol is predominantly found in the north western part of the town along *Dimaza* and *Shinta* River. Moreover this soil type is found in the southern tip of the town around *Teda* area. It is dominant soil type covering an area of 10189.26 hectare and characterized by its sticky nature during rainy season and forms crack during dry season (FAO, 2014). Lithic leptosol is the second dominant soil type which covers about 7999.9 hectare mostly found in the mountainous areas of the town around *Goha* ridge in the north eastern part and extends up to south eastern parts of the town along *Keha* and *Angereb* river. This soil type is known by its rocky nature with shallow depth by continuous hard rock within 25 cm from the soil (ibid).

Haplic luvisol is the least dominant soil type compared with others with an area of 6014.25 hectare. This soil type mostly found in the southern part of the city in some parts of *Azezo* sub city and mostly found on flat or gently sloping areas around Megech river and *Teda* town. It has higher clay content in the sub soil than in the top soil, as a result of pedogenetic processes or clay migration (FAO, 2014).

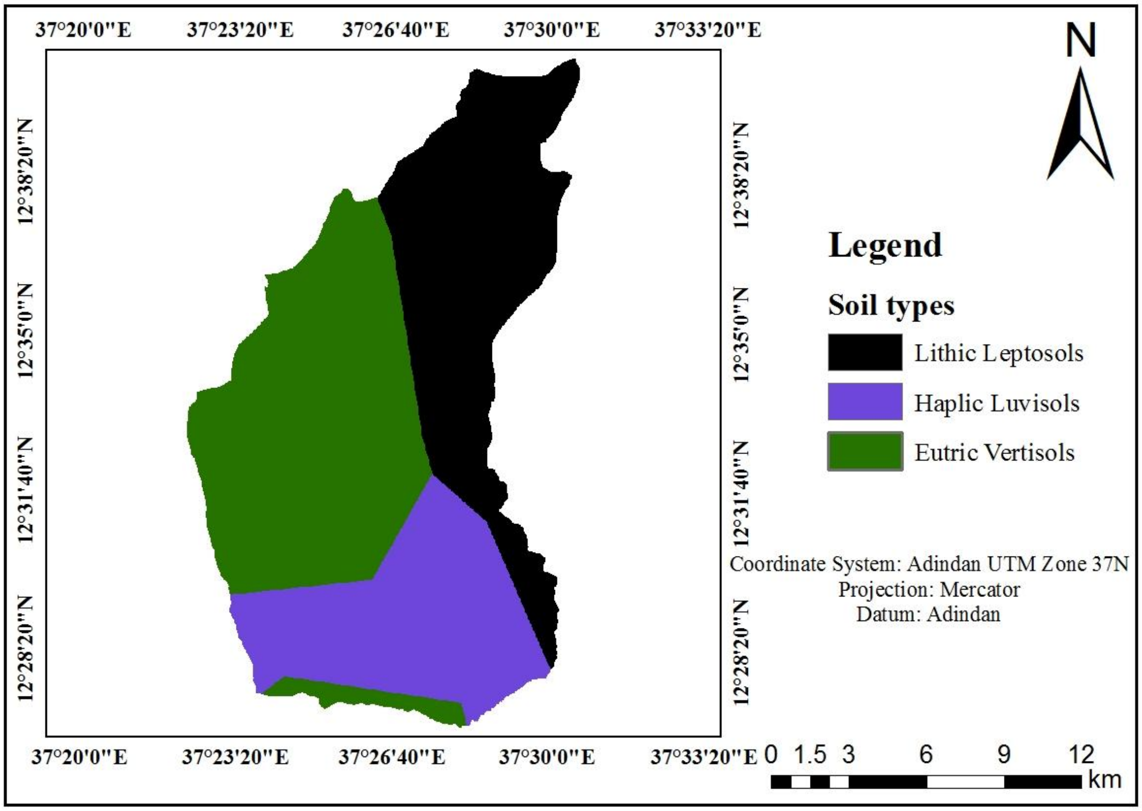


Figure 6: Soil map of the study area (Source: Amhara region water and irrigation office, 2017)

3.1.5. Drainage Network

There are a number of seasonal and perennial rivers that constitutes the drainage network of the study area. Some of the principal rivers are Keha, Dimaza, Angereb, Megech and Shinta River. Keha and Dimaza River dissects the town in nearly two equal parts and flows from North West to south east of the city and joins Megecch River. These rivers were extracted from SRTM DEM by using ArcGIS spatial analyst hydrology extension tools.

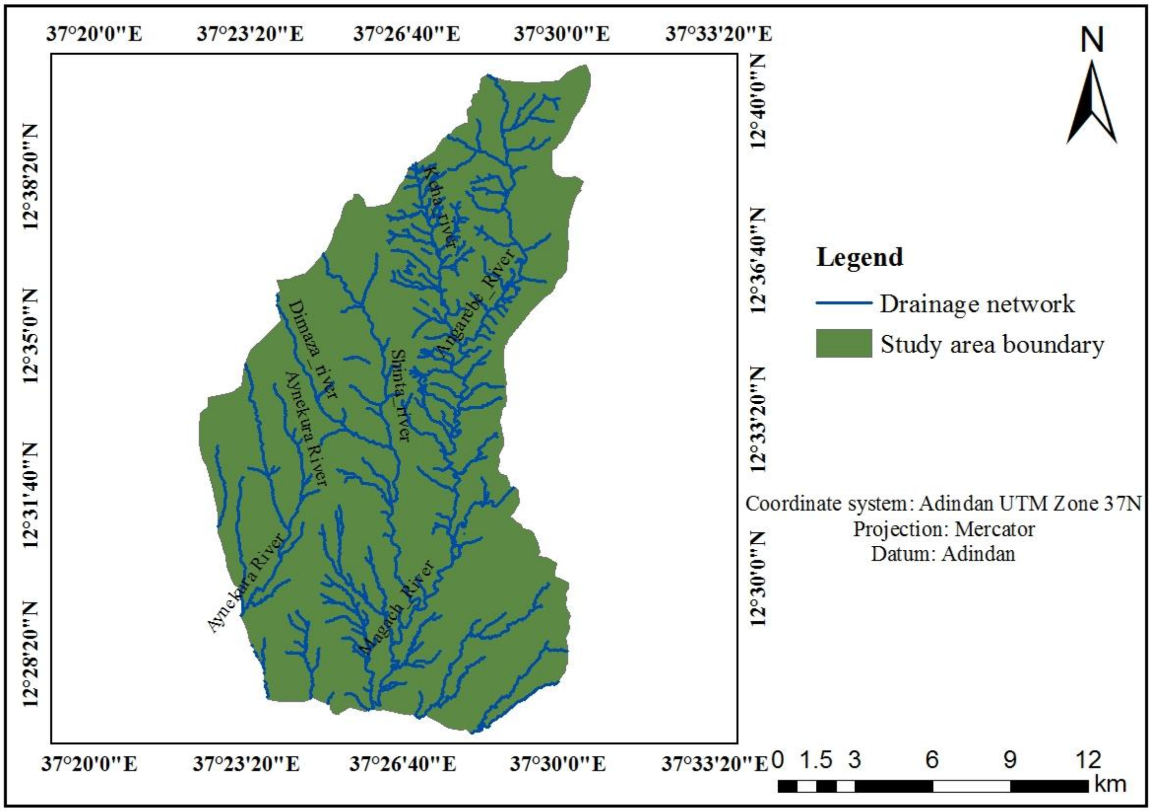


Figure 7: Drainage network of the study area

3.1.6. Population and Ethnic Composition

Gondar is the most populous town in Amhara regional state with the population of greater than 200,000 followed by Dessie and Bahir Dar. According to (CSA, 2007) demography survey report Gondar had a total population of 207,044, of whom 98,120 or 47.4 % were male and 108,924 or 52.6% were female. Based on the report there were three dominant ethnic groups namely Amhara comprising 89.9%, Tigrayan (6.7%), Qimant (2.4%) and others (1.98%). The majority of the inhabitants were follower of Ethiopian orthodox Christianity with 84% while 11.8% of the populations were Muslim and the remaining 1.1% was protestant.

3.2. Methods and Materials

3.2.1. Research Design

This study was based on partially mixed dominant status quantitative approach. It relied more on quantitative or technical logical procedures while concurrently recognizing qualitative procedures (Powell et al., 2008). Both quantitative and qualitative phases occur one after the other, with the quantitative phase being given higher precedence and mixing occurring at data interpretation stage. The technical phase of this research was associated with the identification of appropriate site for landfill related with different criteria. This was completed using software's like ArcGIS 10.3 (to screen out unsuitable areas based on standards), IDRISI version 17 (to derive weight for factors) and ERDAS imagine 2010 (for image preprocessing and classification).

3.2.2. Sources and Types of Data

The most important data for this research was soil type map, structural plan and administrative boundary, protected areas, SRTM DEM, aerial photograph, ground water well points and satellite image. To obtain these data both primary and secondary data sources were used. Primary sources of data were Garmin GPS to collect ground control truth points and field observation whereas secondary data sources was from, internet, reports, books, journals and governmental institutions. The following table clearly shows the types of data used and their respective sources.

Table 1: Summary of data types and their sources

No.	Types of data	Sources of data
1.	SRTM DEM (30*30m) resolution	Downloaded From global land cover facility through path 171 and row 051
3.	Master plan and Administrative boundary	Gondar town construction and land management office
4.	Soil type map	Amhara region water and irrigation bureau
5.	Ground water well point	Gondar town water and sanitation office
6.	Satellite image of landsat8 OLI-TIRS 2017	Freely downloaded from United States Geological Survey website
7.	Road network	Digitized from master plan of the town
	Residential areas	Digitized from aerial photograph
8.	Slope and contour	Generated from SRTM DEM of the study area
9.	Drainage network	Generated from SRTM DEM of the study area
10.	Protected areas	X,Y coordinates of protected areas were gathered using GPS during field survey
11.	Airport map	Digitized from aerial photo of the town
12.	Ground water well point data	XY coordinate of ground water well points were obtained from Gondar town water and sanitation office.

3.2.3. Data Collection Tools and Software used

The materials and software's that were used in this research include Garmin 72 GPS, to collect ground truth control points and digital camera. The software's that used for preparing and analysis of data include, ArcGIS 10.3 to perform spatial analysis and suitability modeling, ERDAS imagine 2010 for image preprocessing and classification. IDRISI selva version 17 was used for pair wise comparison and multi criteria evaluation.

3.3. Methods of Data Analyses

3.3.1. Analysis of Landfill Site Selection Criteria

To achieve the objective of this research different determinant factors that would affect the suitability of landfill sites were considered and analysis was made by using GIS procedure for suitability analysis with integration of multi criteria decision analysis. Accordingly, Land use/land cover, soil type, slope, proximity from road, proximity from rivers/streams, proximity from residential areas, proximity to protected areas, proximity from ground water well and airport were considered as criteria to select optimal landfill site for the study area.

A. Land Use/Land Cover Map

Satellite image of landsat8 OLI_TIRS 2017 image with spatial resolution of (15m*15m) panchromatic image was used to prepare Land use land cover of the study area. In order to enhance the visual interpretation of features and to improve the accuracy of image classification, Pre-processing operations like image fusion or pan-sharpening was done using ERDAS imagine 2010 software. In this process Landsat8 15m×15m resolution panchromatic image was merged with landsat8 multi-spectral image to get higher resolution multi-spectral image which is better for land use classification. Accordingly the output image, with spatial resolution of 15mx15m, was advantageous over both input images in having both high resolution and multispectral images (Sarup and Singhai, 2010).

During classification process aerial photograph of the town was used as reference to identify representative land cover classes. This was used for solving problems of identifying features of similar reflectance like green area with forest, open land with agricultural land. Hence, five land use land cover types were identified. Namely: built up area, agricultural land, open land, scrubland and green areas. After the preparation of land use/land cover map of the study area, accuracy assessment was done to know the accuracy of the classification by collecting 100 ground truth points using GPS. The kappa coefficient, which is a measure of agreement, was calculated assess the classification accuracy using equation 1(Congalton, 1991).

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$ Equation ………………. (1)

Where, ***r*** = the number of rows in the matrix; **X*ii***= is the number of observations in rows ***i*** and column ***i***; **X*i*+** = the total for column ***i*** and **X**+*i total for row i,* and **N** the total number of observations. Finally, the land use/cover map was imported to Arc GIS software and classified according to its suitability based on various reviews.

B. Slope

Slope is among the determinant criteria that should be considered during landfill site selection process. SRTM DEM with 30m*30m resolution was used to derive the slope of the study area. Based on Sener et al., (2011); Trusew, (2013) and Leao et al., (2001) the suitability of slope for landfill was decided. Hence areas with very steep and very flat were considered not preferable for landfill sitting. For this study slope of the study area was classified in to four classes: 0-2%, 2-12%, 12%-30% and >30%.

No	Slope in percent	Suitability index	Suitability score
1	0-2	Moderately Suitable	3
2	2-12	Highly suitable	4
3	12-30	Less suitable	2
4	>30	Unsuitable	1
Total			

C. Soil

The physical characteristics of soil are among the significant criteria during land fill site selection process. The soil of the study area that was obtained from Amhara regional state bureau of irrigation and water were grouped in to three categories namely: Eutric vertisol, Lithic leptosol, and Haplic luvisols. The suitability of each soil type for landfill was determined based on their permeability and clay composition. During reclassification in ArcGIS spatial analyst (re-class) tools, highest value (4) was given for soils which have low permeability and high clay composition while lowest value (1) was given to Lithic leptosol soil due to its high permeability, low clay composition, and shallow depth over hard rocks (FAO, 2014).

D. Drainage Network

To safeguard against contamination of surface water landfills should not be close to streams and rivers (Guiqin et al., 2009). Therefore, by using ArcGIS spatial analysis tools (proximity), buffering for streams and river networks with specified distance was created. Afterwards, reclassification was done using ArcGIS spatial analyst (re-class tool) and were reclassified according to their suitability level. Hence, buffering operation was done based on standards set by (MUDC, 2012; Guiquin, 2009). During reclassification in ArcGIS environment 300m distance was assigned as minimum buffer distance and the suitability a site for landfill increases with increasing distance to streams and rivers.

E. Road Network

The distance between roads and landfills is important criteria for landfill site selection processes. This is because, landfill site close to roads may have public health problem as landfill can have negative effect to health. In addition, landfill site very far from road network is also not suggested due to high transportation cost. To analyze the suitability of landfill sites from road networks geo processing operation like buffering was done with specified distance based literature values mainly used in landfill selection process. After buffering operation it was converted in to raster format to make it ready for reclassification and was reclassified according to its suitability classes.

F. Protected Areas

Protected areas in Gondar town include schools, churches, mosques, health centers and historical sites like Fasiledes castel (Appendix 1). To analyze the suitability of these protected areas, the collected GPS coordinates of protected areas were imported in to ArcGIS software and multiple ring buffer using analysis tools (proximity) was done. The analyses of protected areas were based on the standard set by Erosy and Bulut, (2009) and Bababola and Busu, (2010). Accordingly buffer of less than 1000 meter was considered as unsuitable and suitability increases with increasing in distance.

G. Boreholes

Proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection process so that wells can be protected from runoff and leaching of the landfill (Chang et al., 2007). Otherwise, it can have irreversible human and environmental impacts. Landfill very far from ground water well will have minimum effect and landfill very close to ground water well will have high effect. To determine the distance of areas between landfills proximity buffering using spatial analyst tool was done. Hence areas found within the distance of 500 m to boreholes were unsuitable, 500-1000m less suitable, 1000-1500m moderately suitable and above 1500m highly suitable.

H. Residential Areas

The residential area map was produced by Digitizing all pure and mixed residential sites from aerial photograph of the town in GIS environment. The extracted residential areas were first geo-referenced based on X and Y coordinates of the study area using ArcGIS geo-referencing tool. Proximity buffering using ArcGIS spatial analyst (proximity) tools was created in order to determine the minimum and maximum distance of areas from residential areas. Accordingly areas found within 1000m buffer distance to residential area was unsuitable assigned by (1), 1000-2000m less suitable, 2000-3000m moderately suitable and greater than 3000m highly suitable.

I. Airport

Azezo Airport was digitized from the aerial photograph of the town. Proximity buffering of the study area was produced in the ArcGIS environment using analysis tools (multiple ring buffer). To determine the proximity distance of airport the literature of Trusew, (2013) was used as reference. Hence, multiple ring buffer of 0-750m, 750-1500m, 1500-3000m and >3000m for Azezo airport was created. To sum up all the above criteria were first geo-referenced and converted in to raster format in GIS environment. After that they were reclassified using ArcGIS spatial analyst (re-class) tools based on their suitability level.

The level of suitability and values was determined based on various scientific published and unpublished documents (Table 2). Accordingly, all the factors and constraints were reclassified in to four suitability class namely, unsuitable, less suitable, moderately suitable and highly suitable with weight ranging from 1-4 where 1 for unsuitable 2 less suitable 3 moderately suitable and 4 for highly suitable. After reclassification process weight was assigned for each criteria using multi-criteria evaluation method using AHP procedures. Afterwards, all the standardized criteria were combined to perform weighted overlay analysis using ArcGIS spatial analyst (overlay) tools and thematic maps showing potential suitable site for landfill was prepared. Finally the highly suitable candidate sites for landfill were then evaluated and prioritized with different criteria like size, distance from the center of the city and distance from settlement. The following Figure 8 shows the major procedures to select potential suitable sites for landfill.

Figure 8: Model builder showing steps to select suitable site for landfill.

The determinant factors used to select the potential suitable sites, the suitability level, and standards was based on various reviews for each criterion and their respective sources are presented in (Table 2) below.

Table 2: Criteria considered for landfill site selection

No.	Criteria	Suitability Standard	Source
1.	Slope	❖ 0-12% as highly suitable, 10-15% as moderately suitable ❖ 15-20 as less suitable and >20% as unsuitable	Sener et al.,(2011); Trusew, (2013) and Leao et al., (2001)
2.	Settlement	❖ <500m as unsuitable ❖ 500-1000m as less suitable ❖ 1000-3000m as moderately suitable ❖ >3000m as highly suitable	Chang et al., (2007) Akbari (2011). Map Asia (2004), Yahaya (2010), Ersoy and Bulut (2009), EPA (1995) & UNEP (2005).
3.	LULC	❖ Low economic value lands like open land, & scrubland	(Yeshdha and Karthihenyah, 2016; Trusew et al., 2013).
4.	Soil	❖ Clay textured soil, low permeable soil	Fides and Edward, (2012) and Gizachew , (2011)
5.	Road Network	❖ <500m buffer unsuitable ❖ 500-1000m less suitable ❖ 1000-1500m buffer moderately suitable	(Babalola and Busu, 2010 and Trusew et al., 2013) (Erosy and Bulut, 2009; EPA, 1995)
6.	Protected areas	❖ <750m unsuitable, 750-1000less suitable, 1000-1500m suitable, >2500m highly suitable	Fides and Edward, (2012)
7.	Airport	❖ 3km highly suitable	Trusew, (2013)

8.	Borehole	❖ 0-500m unsuitable	Gizachew, (2011)
9.	Streams/ rivers	❖ >2000 meter highly suitable ❖ Moderately suitable from 1500-2000 meter ❖ Less suitable from1000-1500 meter ❖ Unsuitable <1000 meter	Sener et al., (2011)

3.3.2. Proximity Buffering

Proximity buffering is one of the spatial analyst tools used to determine the distance of factors like roads, drainage networks, residential areas, protected areas, airport and ground water wells to landfills. To do this proximity buffer of specified distance for the above criterias was done mainly based on literature values (Table 2).

3.3.3. Assigning Criteria Weights using Pairwise Comparison Matrix

In this study, all criterias considered were first converted in to raster with the same resolution. After reclassification process was done for all the factors, they were combined in order to find highly suitable sites. Since all the criteria can't have equal degree of importance, the importance of each criterion in relative to the other criteria was determined. This was done for the purpose of identifying the influence of each criterion relative to the other criteria for landfill site selection.

Weights for the criteria were assigned based on multi criteria evaluation in the AHP procedure developed by Saaty, (1980) using pairwise comparison matrix. Because this method is powerful to rank criterias according to their importance in meeting conflicting objectives and its ability to detect inconsistent judgments using consistency ratio. Accordingly, in IDRISI selva version 17 software pair wise comparison technique was developed so that weight for each criterion sums to 1. A pairewise matrix was constructed, where each criterion is compared with the other criteria, relative to its importance to the overall suitability map, on a scale from 1 to 9 and the higher the weight, the more important is the criterion. Each factor weights are calculated by comparing two factors at a time using a scale 5 to 1/5 or from 9 to 1/9. According to Saaty, (1980) a rating of 5 or 9 indicates that in relation to column factor the row factor is more important (Table 3).

Table 3: Scale for pairewise comparison (Saaty, 1980)

Degree of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to The objective.
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its importance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the adjacent judgments	When compromise is needed
Reciprocals	If activity ***i*** has one of the above numbers assigned to it when compared with activity ***j***, then ***j***, has the reciprocal value when compared with ***i***	

Based on the above scale pair wise comparison matrix was prepared. This was done by using IDRISI selva software decision support (weight) module. Accordingly, IDRISI weight module was utilized to prepare pair-wise comparison matrix to help develop a set of factor weights that will sum to 1. During the determination of values the upper triangle holds the importance level of the rows in the lower triangle.

Eigen vector weight derivation: to calculate the eigenvector weights for each criterion first we normalize the values i.e. we divide each cell for the column total finally we sum the rows and divide for number of criteria in our case 9.

Consistency ratio (CR): in AHP procedure developed by Saaty(1980) consistency ratio was calculated in order to determine whether the judgment was consistent or not during the comparison of criterion. Hence, it was calculated as:

CR= Consistency index (CI)/Random Consistency Index (RI)

CI = (λ_{max} – n) /n– 1, where λ_{max} is the Principal Eigen value and **n** is the number of factors

λ_{max} =∑ of the products between each element of the priority vector and column totals=9.60. Therefore CI= (9.60-9)/9-1, CI=0.075

CR=0.075/1.45=0.05<**0.1** which is within acceptable limit

According to Saaty (1908), if consistency ratio is less than **0.10** it is within acceptable limit. In our case the consistency ratio is **0.05**<**0.1** which is acceptable.

Note that: RI (1.45) = is the corresponding index of consistency for random judgments according to (Saaty, 1980) AHP model for 9 by 9 matrix **RI**, is **1.45**

3.3.4. Weighted Overlay Analysis

Weighted overlay is a method for applying a common measurement scale values of different inputs to create an integrated analysis. For this study, nine map layers were prepared with each of the nine layers were reclassified and standardized to determine their suitability level. The reclassified maps were combined using weighted overlay tool in GIS environment. The influence of each factor relative to the other factor was determined by referring different literatures and weight were assigned by following Saaty, (1980) in AHP procedures. Finally, the reclassified and weighted factor suitability maps were computed by weighted overlay tool of ArcGIS spatial analyst (weighted overlay) tools.

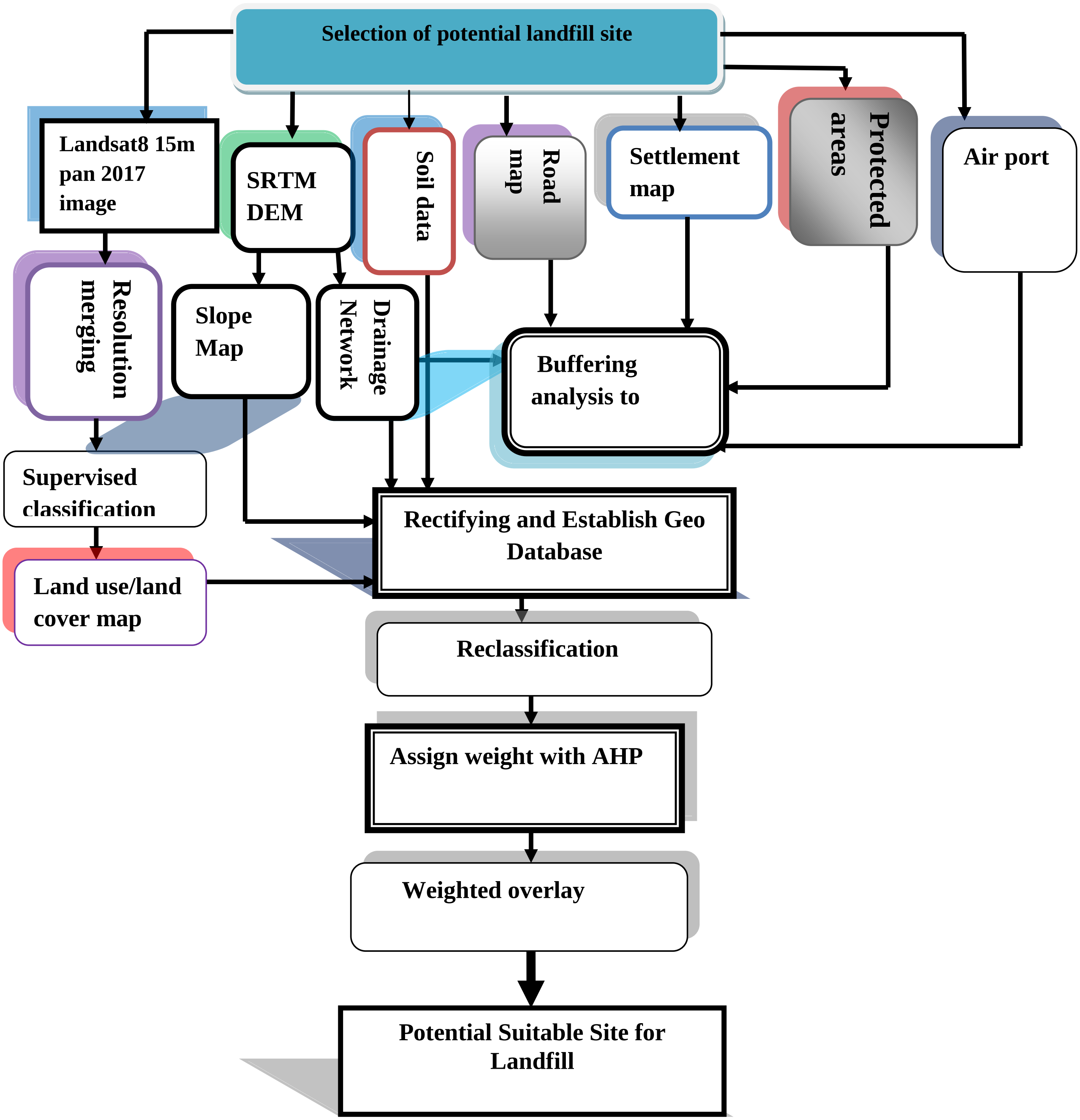


Figure 9: General work flow of the study.

CHAPTER FOUR

4. Result and Discussion

4.1. Determinant Factors to Select Potential Landfill for the Study Area

4.1.1. Slope

Slope is among the key criteria during landfill site selection process. This is because different slope type can increase or decrease the negative effect of landfill on the environment. In this study areas with high slopes and too flat slopes were taken as not suitable for landfill site allocation. This is because when the area becomes steep it may be vulnerable for erosion and results contamination of surface water through flooding. Moreover construction costs of excavation will increases in higher slopes. On the other hand too flat slope is not also recommended because of water logging problem and ground water pollution through leaching of polluted materials.

Different researchers set different slope type as suitable for landfill sitting. For instance Trusew (2011) take areas <10% as suitable area, Fides and Edward, (2012) used <12% as suitable while, Ersoy and Bulut, (2009) used areas with slope <20% as most favorable site for landfills. For this study, suitability of slope was determined based on Sener et al., (2011); Trusew, (2011) and Leao et al., (2001). Hence, areas between 0-2% was taken as moderately suitable, because areas in this slope range are vulnerable to water logging problem whereas areas found between 2% up to 12% was taken as highly suitable, because of its medium slope and are not vulnerable for water logging as well as erosion. Areas with 12% up to 30% were taken as less suitable and greater than 30% as unsuitable. This because as steepness increases it will incur high cost of excavation at the same time will increase transportation of polluted materials through erosion and flooding.

Table 4: Slope suitability and areal coverage of the study area

No	Slope in Percent	Suitability index	Area in hectare	Percent	Suitability score
1	0-2	Moderately Suitable	477.54	1.98	3
2	2-12	Highly suitable	8382.7	34.6	4
3	12-30	Less suitable	11456.8	47.3	2
4	>30	Unsuitable	3886.4	16.05	1
Total			24203.43	100	

During slope reclassification process the highest value (4) was assigned to highly suitable areas whereas, the lowest value (1) was assigned to areas which are steep slopes. As it is already mentioned above, areas with steep slopes are not suitable for solid waste landfill because of its difficulty to construct stations and high vulnerability of erosion. Therefore, the result of the analysis reveals that 1.98 % of the study area is found between 0 and 2% slope ranges taken as moderately suitable areas compared to steep slopes. On the other hand 34.6% of the study areas were highly suitable because areas in this slope range are not too steep and too flat while 47.3% and 16.6% of the study area were less suitable and unsuitable respectively. The suitability of slope is clearly shown on the following (Figure 10).

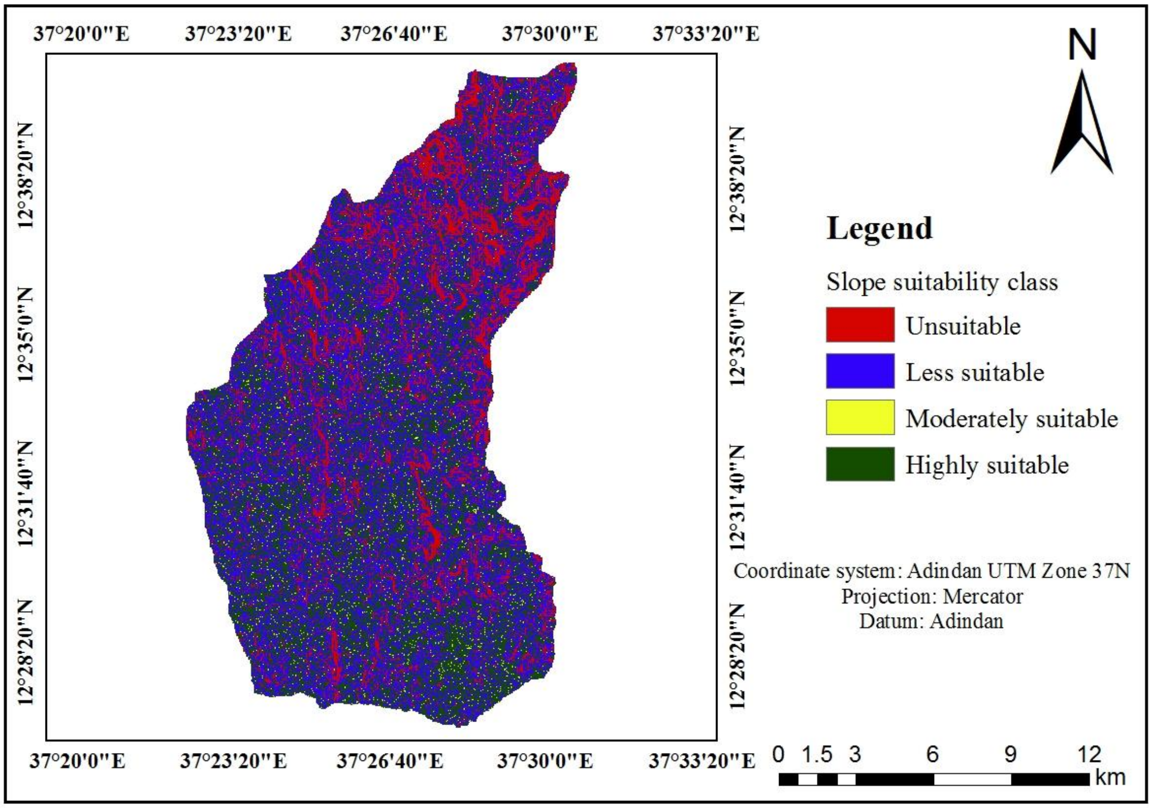


Figure 10: Slope suitability map

4.1.2. Soil Suitability Analysis Result

The majority of soil in the study area is dominated by Eutric vertisols (42.09%) which is found in north western and southern part of the city followed by lithic leptosols (33.05%) which is overriding in north eastern part of the city. The rest part of the city is covered by Haplic Luvisol (24.8%) predominantly found in southern part of the study area. To analyze the suitability level of each soil of the study area, the standard set by (Fides and Edward, 2012; Gizachew, (2011) was used as a reference. Therefore, the suitability level of each soil type was determined by their level of permeability and textural size. Soils with low permeability and high content of clay were selected as highly suitable. Because of the fact that low permeable soil has the capacity to prevent polluted materials not to pass through the ground and can control ground water pollution.

Table 5: Soil suitability class and areal coverage table of the study area

No	Soil type	Suitability index	Area in hectare	Percentage
1	Eutric Vertisol	Highly suitable	10189.26	42.09
2	Haplic luvisol	Moderately Suitable	6014.25	24.84
3	Lithic leptosol	Unsuitable	7999.9	33.05
Total			24203.43	100

As indicated in the (Table 5), high proportions of the study area (42.09%) were highly suitable. Because as explained by (Gizachew et al., 2011), vertisol soil has high content of clay and have low capacity to allow liquid pollutants like leachates to pass down to the ground. Therefore during suitability reclassification using ArcGIS analysis (re-class) tools value (4) was assigned for Eutric vertisol due to its high proportion of clay and low permeability. The second soil suitability value (3) was assigned to Haplic luvisols since, these types of soils are characterized by high immovability and less clay contents than Vertisols. Therefore hapalic luvisol was taken as moderately suitable for landfill. The least suitability level was assigned for lithic leptosol because this soil type is very shallow and its clay content is very low as compared to vertisol and luvisol having suitability score of (1).

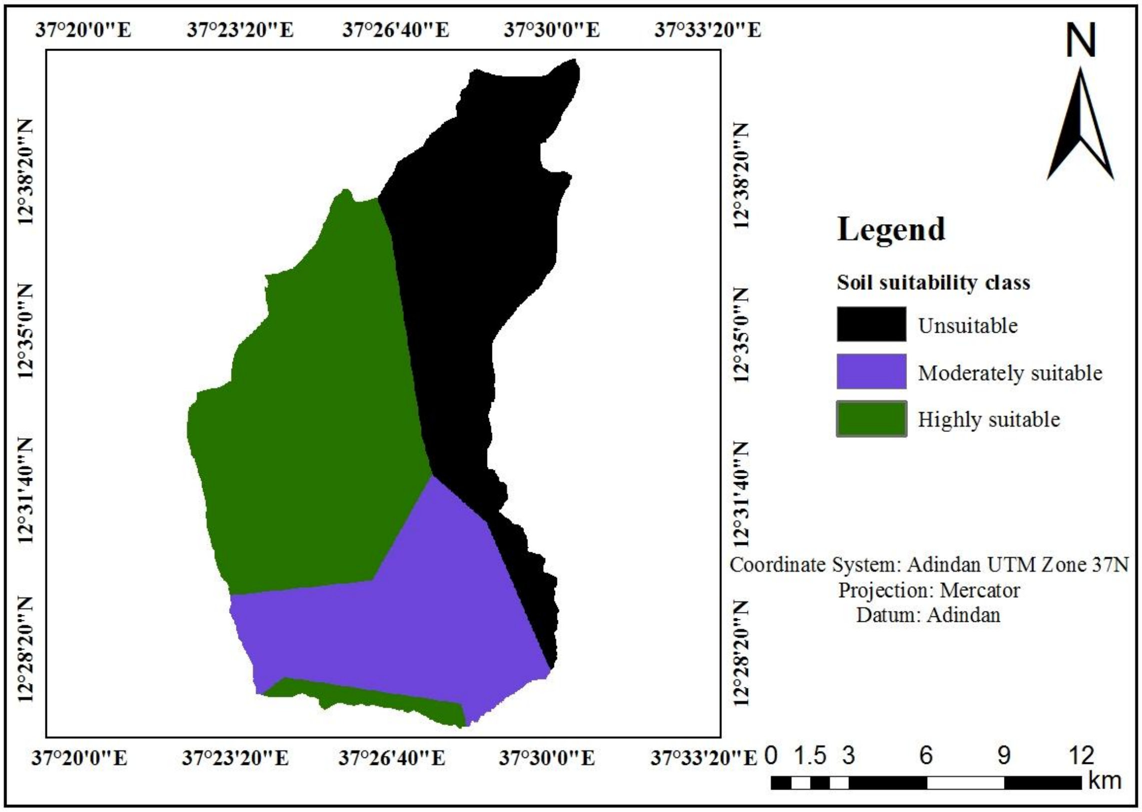


Figure 11: Soil suitability map of the study area

4.1.3. Land Use/Land Cover

Land use/ land cover of the study area was classified in to five LULC classes using supervised image classification. These LULC classes were water, built up area, open space land, green areas and agricultural land. Land use/ land cover classes and their areal coverage is clearly shown in the following table.

Table 6: LULC classes and areal coverage of the study area

No	Land use land cover type	Areal coverage in hectare	Percentage (%)
1	Water	22.3	0.09
2	Built up areas	6450.55	26.6
3	Open space land	11565.3	47.8
4	Green areas	4316.24	17.8
5	Agricultural land	1849.04	7.63
Total		24203.43	100

As shown above from the Table 6, large parts of the study area is covered by open space land which accounts about 47.8 percent followed by built up areas (26.6%), green area, water and agricultural land covers 17.8%, 0.09%, and 7.63% respectively.

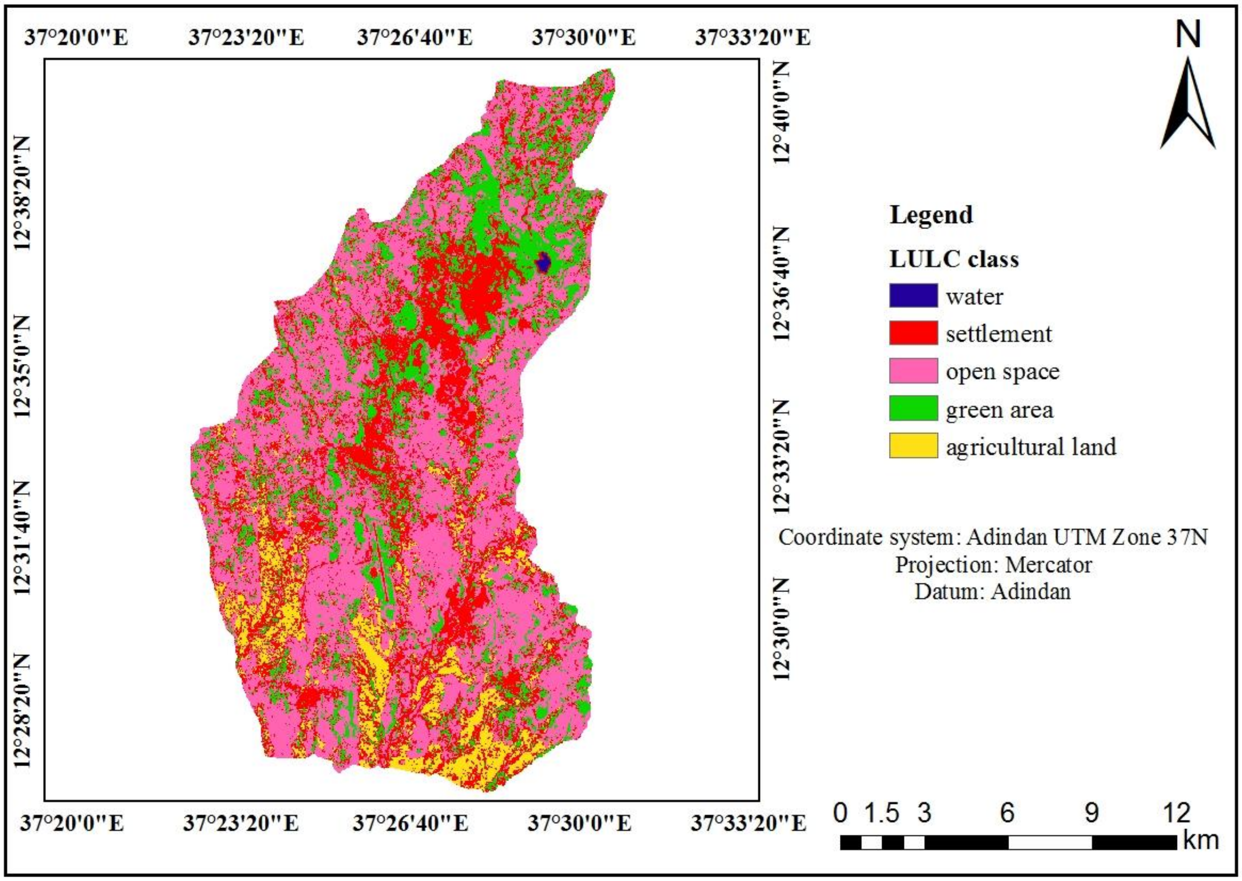


Figure 12: Land Use Land Cover Map of the study area.

The result of accuracy assessment for the above land use land cover class showed that overall accuracy of 85% and kappa coefficient of 81%. Of all land cover classification, water body was classified with hundred percent (100%) accuracy level.

Table 7: Confusion matrix of land cover classification

Class Name	Reference data					
	Water	GA	BA	OL	AG	RT
Water	**13**	0	0	0	0	13
GA	0	**16**	0	2	1	19
BA	0	1	**19**	2	1	23
OL	0	2	0	**19**	2	23
AG	0	1	0	3	**18**	22
CT	13	20	19	26	22	**100**

Where, GA= green area, BA= built up area OL= open land AG= agricultural land, RT= row total and CT= column total.

4.1.3.1. Land Use / Land Cover Suitability Result

The landfill site should not be selected close to the built up area to avoid adversely affecting land value and future development and to protect human being from environmental hazards created from landfill sites. For this study the suitability weight was assigned for each class based on literatures of (Yeshdha and Karthihenyah, 2016; Trusew et al., 2013). As a result low economic value land like open lands were selected as highly suitable compared to other land use types. During reclassification the highest value (4) was given to open space while, the lowest value (1) was assigned for high economic value land like built up areas and water body (Angereb dam). Accordingly, land use/land covers of the study area were reclassified in to four classes. Namely: unsuitable, less suitable, moderately suitable and highly suitable.

Table 8: Land use/land cover suitability level with their respective areal coverage

No	Land use/cover	Suitability class	Areal coverage (ha)	Rank/score	Percentage
1	Built up areas &Water body	Unsuitable	6472.85	1	26.75
2	Green areas	Less suitable	4316.24	2	17.8
3	Open space	Highly suitable	11565.3	4	47.8
4	Agricultural land	Moderately Suitable	1849.04	3	7.6
Total			24203.43		100

As it is indicated in the above Table 8, 26.7% of the study areas were unsuitable while 17.8%, 47.8% and 7.6% were less suitable, highly suitable and moderately suitable respectively from land use land cover point of view.

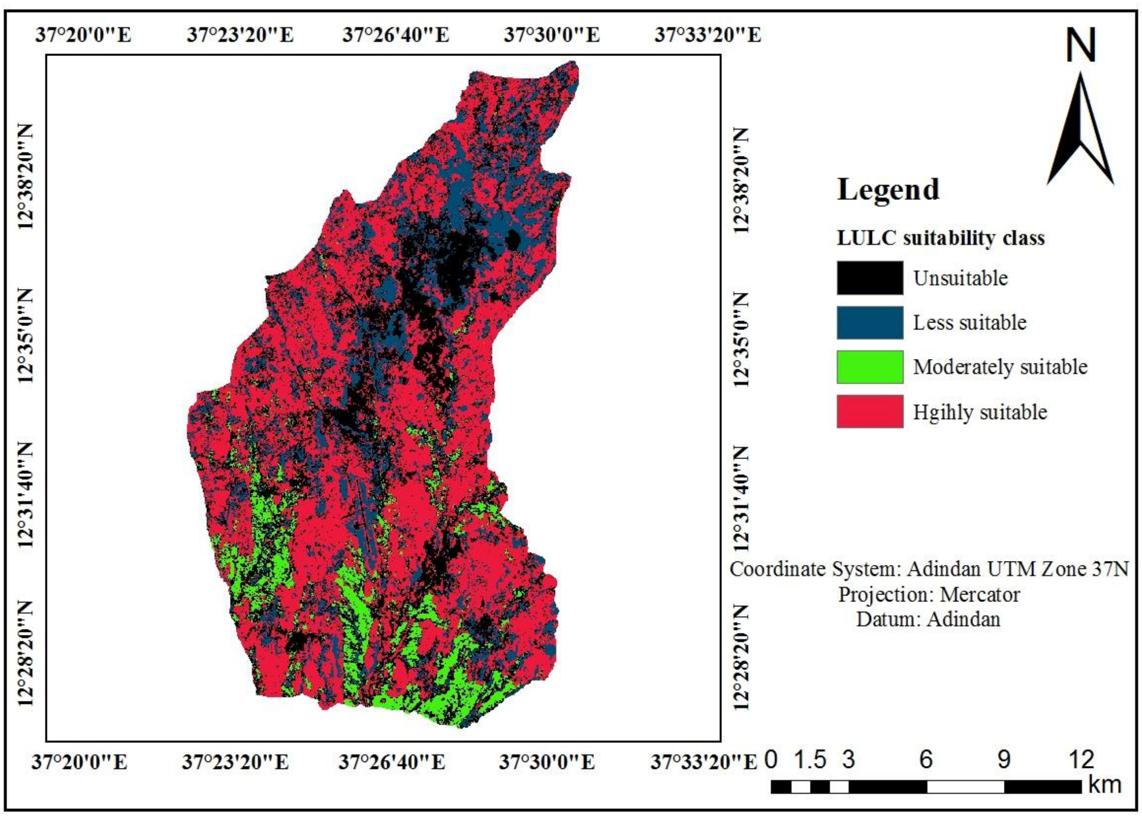


Figure 13: Reclassified Land Use Land cover suitability map

4.1.4. Proximity from Drainage Network

To determine the distance between drainage networks and landfill sites the literature values of (MUDC, 2012; Guiquin 2009) was used. During reclassification areas very far from drainage were given higher preference to be used as landfill site. Hence, sites within 300 meter distance were unsuitable; 300-500 were less suitable, 300-500 meter less suitable, 500-1000 meter moderately suitable and >1000 meter were highly suitable.

Table 9: Proximity distance suitability of drainage and areal coverage

No.	Distance in (m)	Suitability class	Area in hectare	Score/ rank	Percentage (%)
1	0-300	Unsuitable	14565.6	1	60.17
2	300-500	Less suitable	4842.63	2	20
3	500-1000	Moderately Suitable	3889.53	3	16.07
4	>1000	Highly suitable	905.6	4	3.74
Total			24203.43		100

As it is shown on the above Table 9, the majority of the study areas (60.17%) were unsuitable, 20 % less suitable, 16.07% moderately suitable and the rest 3.7% were highly suitable areas.

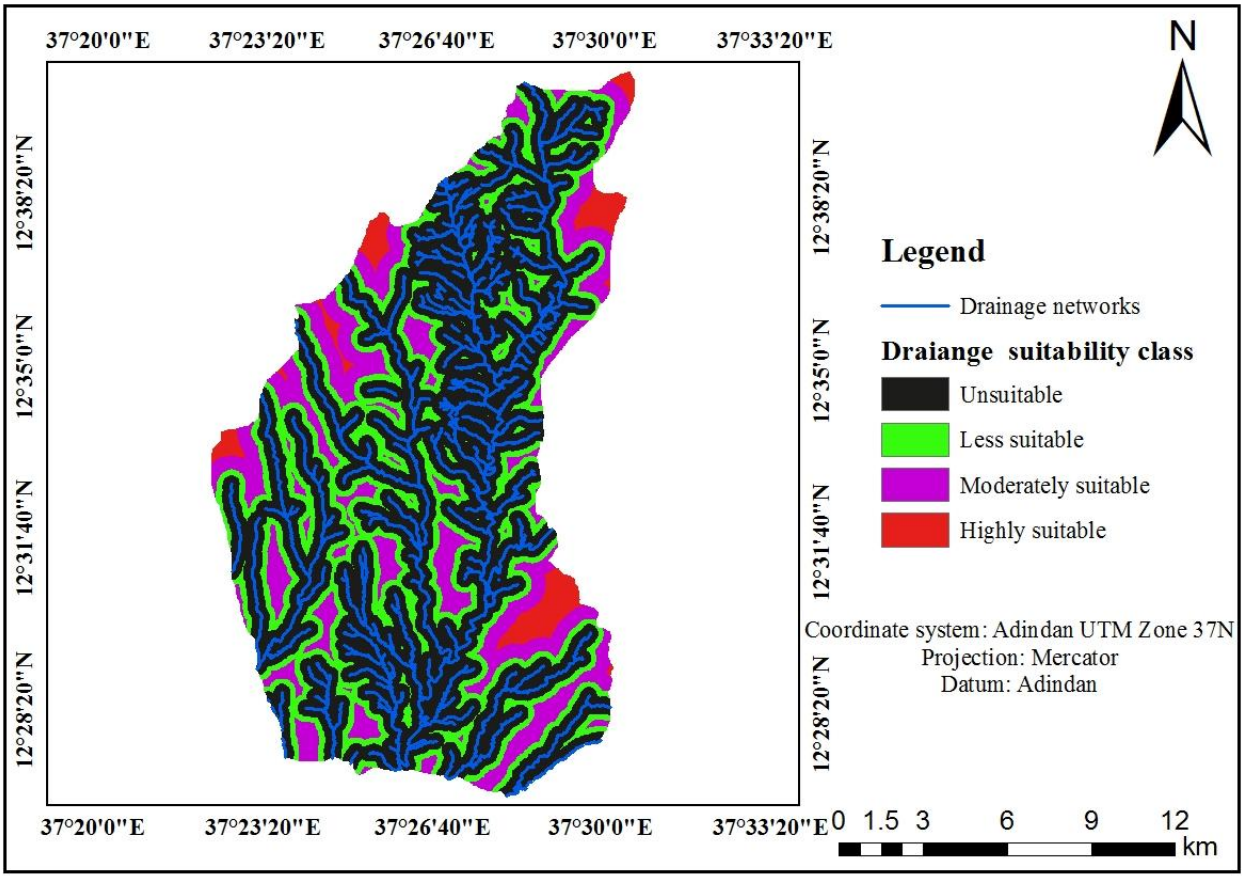


Figure 14: Reclassified Drainage suitability map

4.1.5. Proximity from Road Network

The selected suitable landfill site should not be too near and too far from road networks. Because areas too close to roads may create traffic congestion and will also bring aesthetic problems. On the other hand areas too far to road networks is not recommended because constructing roads for landfill access especially in long distances requires huge preliminary expenses. Therefore by taking this argument in to mind Proximity buffer was done based on the standard set by Babalola and Busu, (2010) and Trusew et al., (2013).

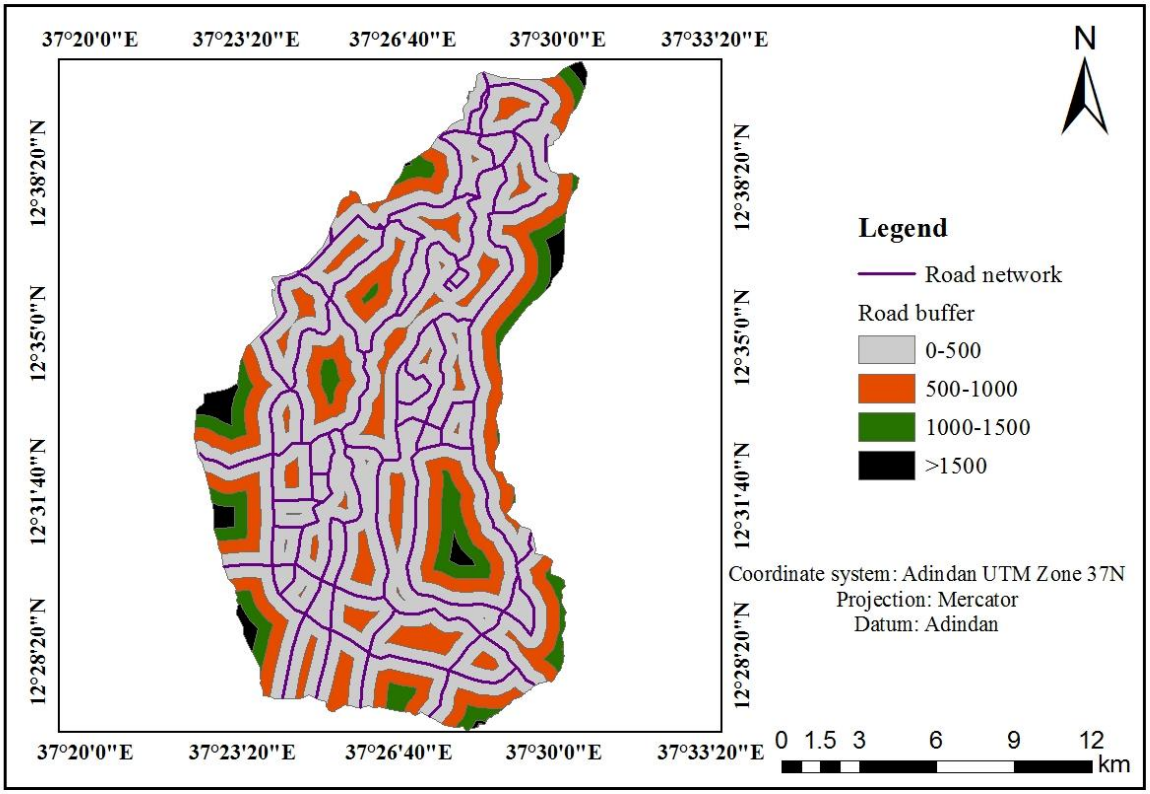


Figure 15: Road buffer map of the study area

During road network reclassification, areas very close and far to road network were reclassified as unsuitable and less suitable respectively. Hence areas within 500m to roads were classified as unsuitable, 500 up to 1000m as moderately suitable, 1000m up to 1500m as highly suitable and greater than 1500m as less suitable. Based on the above road network buffer result the suitability of roads to landfills were determined.

Table 10: Road proximity buffer suitability class and its areal coverage

No.	Suitability class	Buffer distance in meter	Suitability rank	Areal coverage in hectare	Percent (%)
1.	Unsuitable	0-500	1	16520.85	68.2
2.	Moderately Suitable	500-1000	3	5412.24	22.3
3.	Highly suitable	1000-1500	4	1807.2	7.5
4	less suitable	1500-300	2	463.14	1.91
Total				24203.43	100

As shown in the above (Table 10), 68.2% of the study areas were unsuitable because this area is found very close to road networks and will result traffic congestion as well as aesthetic problems. Moreover, 22.3%, and 7.5 % of the study areas were moderately suitable and highly suitable respectively because these areas are found not too near and too far from road networks. The remaining 1.9% of the study area is less suitable for landfill as it is found very far to roads and will incur high cost to transport solid wastes to landfill sites. The road network proximity suitability map of the study area is clearly shown in the following (Figure 16).

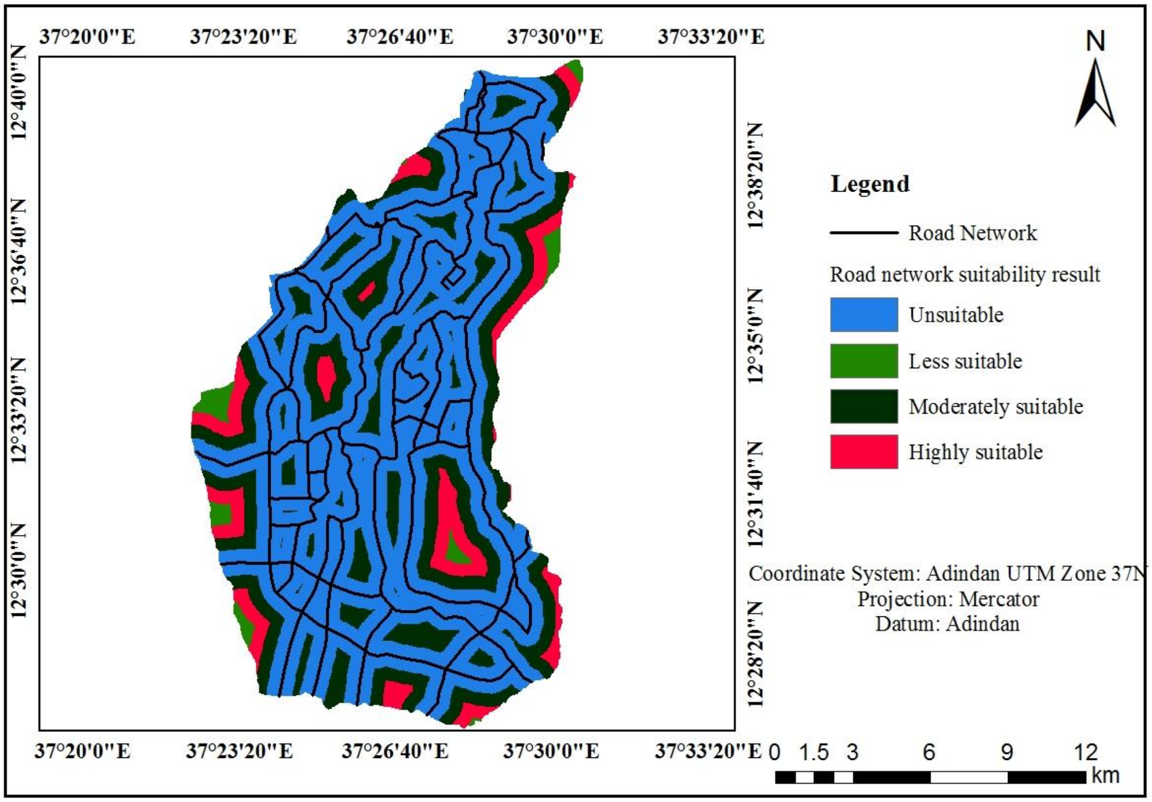


Figure 16: Road network suitability map

4.1.6. Protected Areas

For this study, areas far away from protected areas like churches, mosque, hospital, school, historical sites were suitable for landfill site selection. Based on buffering result four protected area suitability class was determined.

Table 11: Proximity distance of protected areas and their suitability class

No	Suitability class	Buffer distance in meter	Suitability weight	Area in hectare	Percentage
1.	Unsuitable	0-750	1	2287.9	9.45
2.	Less suitable	750-1500	2	3237.48	13.4
3.	Suitable	1500-2250	3	3792.87	15.6
4.	Highly suitable	>2250	4	14885.1	61.5
Total				24203.43	100

As shown on the above Table 11, the highest proportion of the study areas (61.5%) were highly suitable, because this area is far away from sensitive sites with the limit of above

2250 meter. Conversely the remaining 9.45%, 13.4%, and 15.6% of the study area were unsuitable, less suitable, and moderately suitable respectively. Because these areas were found in close distance from protected areas like schools, historical sites, mosques, churches and etc.

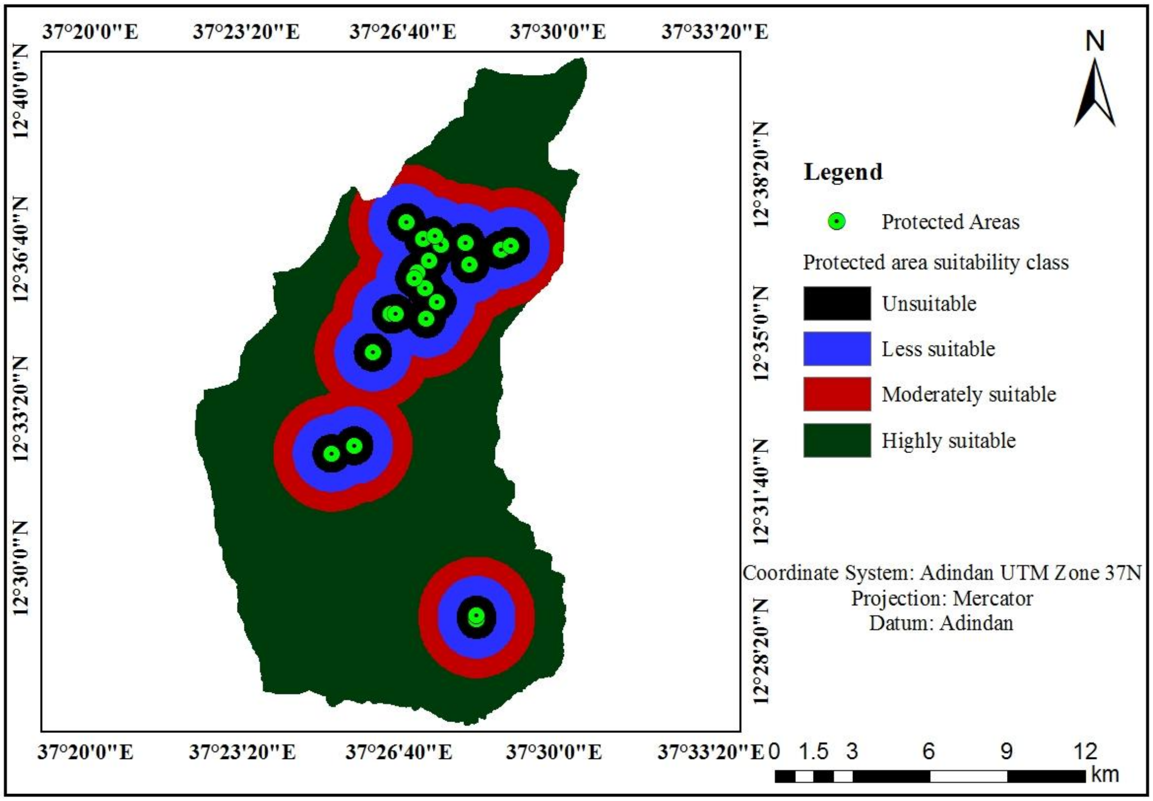


Figure 17: Reclassified protected area suitability map

4.1.7. Residential Area Suitability Evaluation

The land fill site should not be located near to residential areas in order not to affect land value and future development of the town and to protect environments from pollution released from land fill sites. Therefore to protect environments from such problems proximity buffer of specified distance was determined based on the standard set by (Bilgehan et al., 2009). Accordingly areas within 1000m buffer distance were taken as unsuitable areas for landfill sitting and suitability increases with increasing distance from residential areas. The proximity buffering result is shown in the following (Figure, 20).

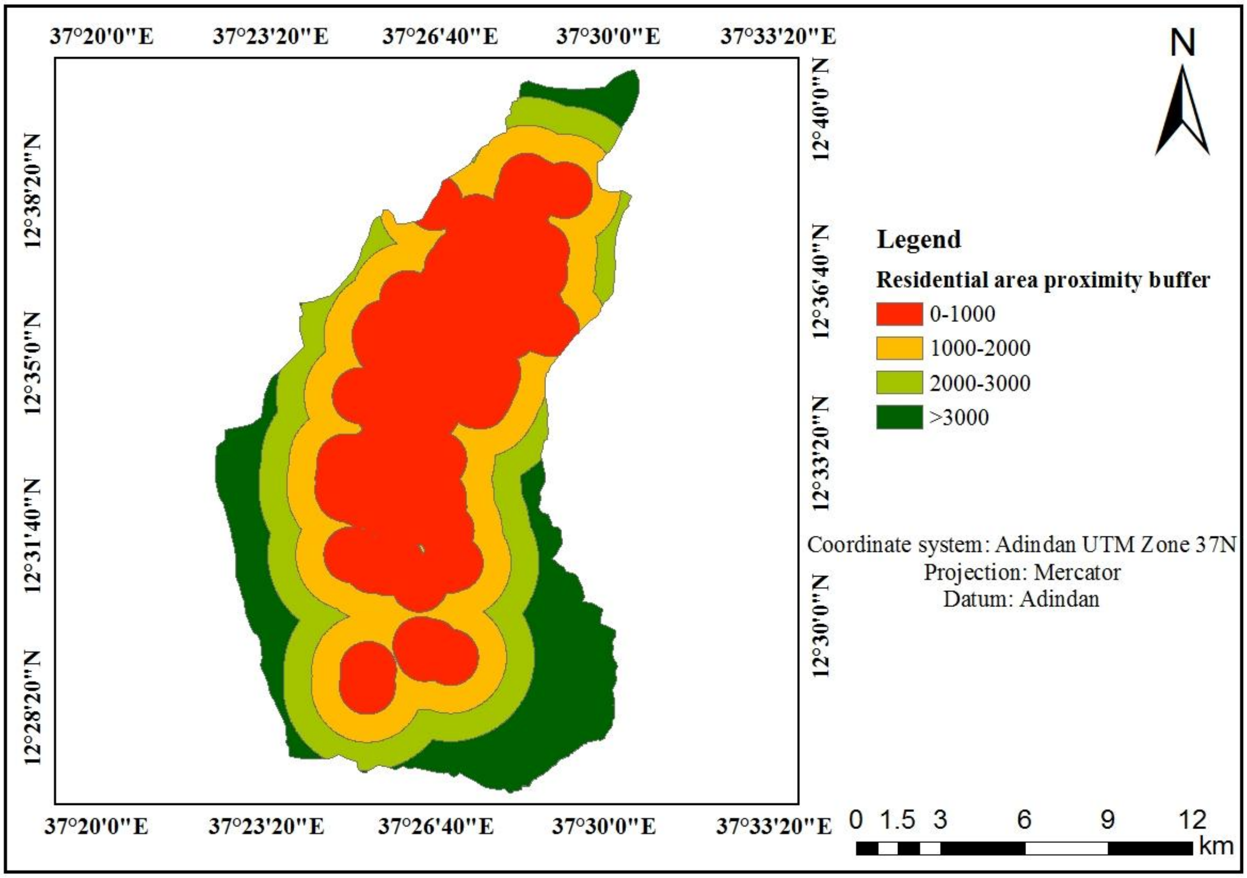


Figure 18: Residential area proximity map

Table 12: Proximity distance suitability of residential areas

No	Suitability class	Suitability range	Area in hectare	Percentage	Weight/score
1	Unsuitable	0-1000	9632.97	39.8	1
2	Less suitable	1000-2000	5774.31	23.8	2
3	Moderately Suitable	2000-3000	4247.28	17.54	3
4	Highly suitable	>3000	4548.87	18.8	4
Total			24203.43	100	

Based on the above (Table 12), the majority of the study areas (39.8%) were unsuitable for landfill site. Conversely, 18.8 % of the study area were highly suitable, because these areas are very far from residential areas found in the buffer distance of >3000 meter. The remaining areas 24.8% and 17.54% were less suitable and moderately suitable respectively. The residential area suitability map is shown in the following (Figure, 21).

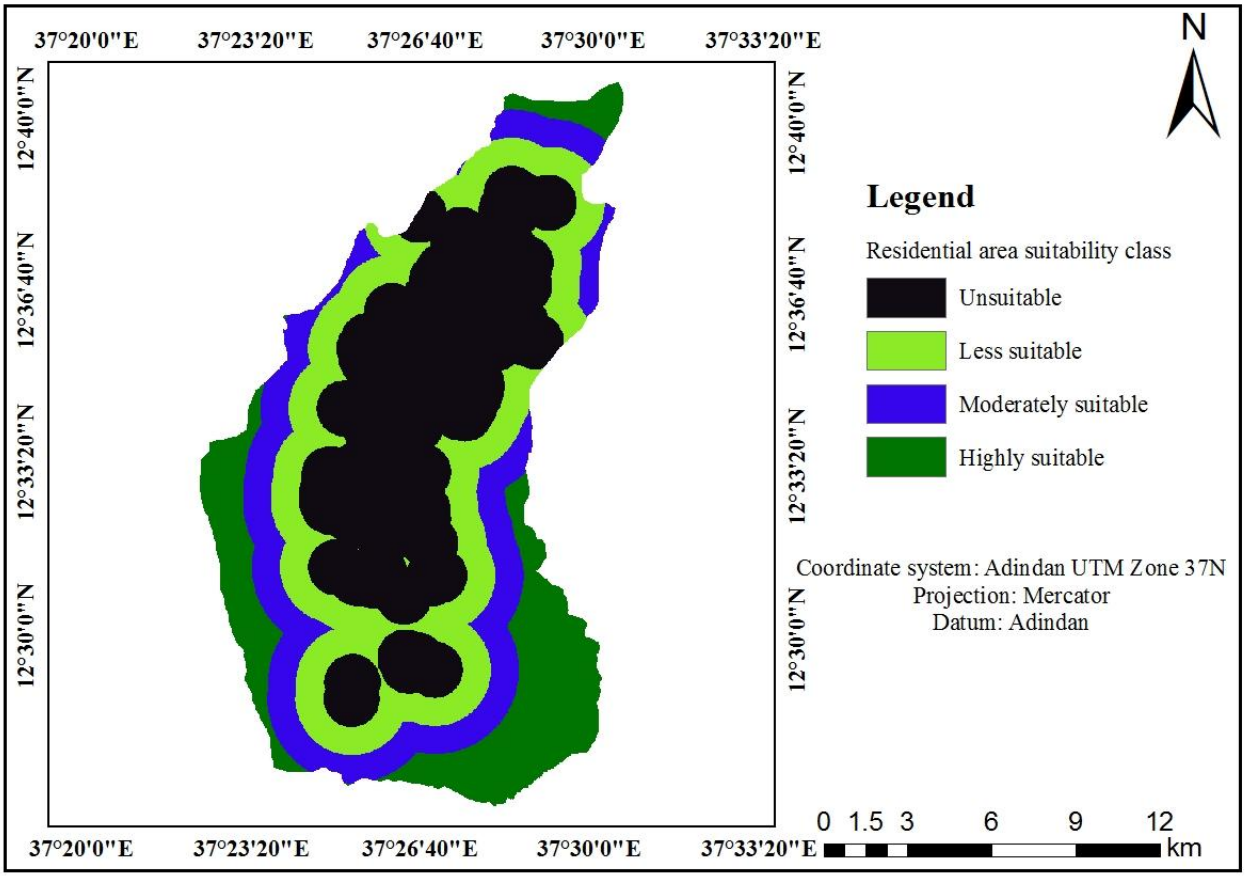


Figure 19: Residential area suitability map

4.1.8. Borehole Suitability Evaluation

According to Gondar town water supply and sanitation service bureau (2017), in the study area there were more than 15 ground water wells which were drilled in different years. However, currently only seven ground water wells are giving service. The remaining eight ground water wells are not functional because of their ground water table reduction. To analyze the suitability of ground water wells to landfills, proximity buffering was created based on Gizacheew, (2011).

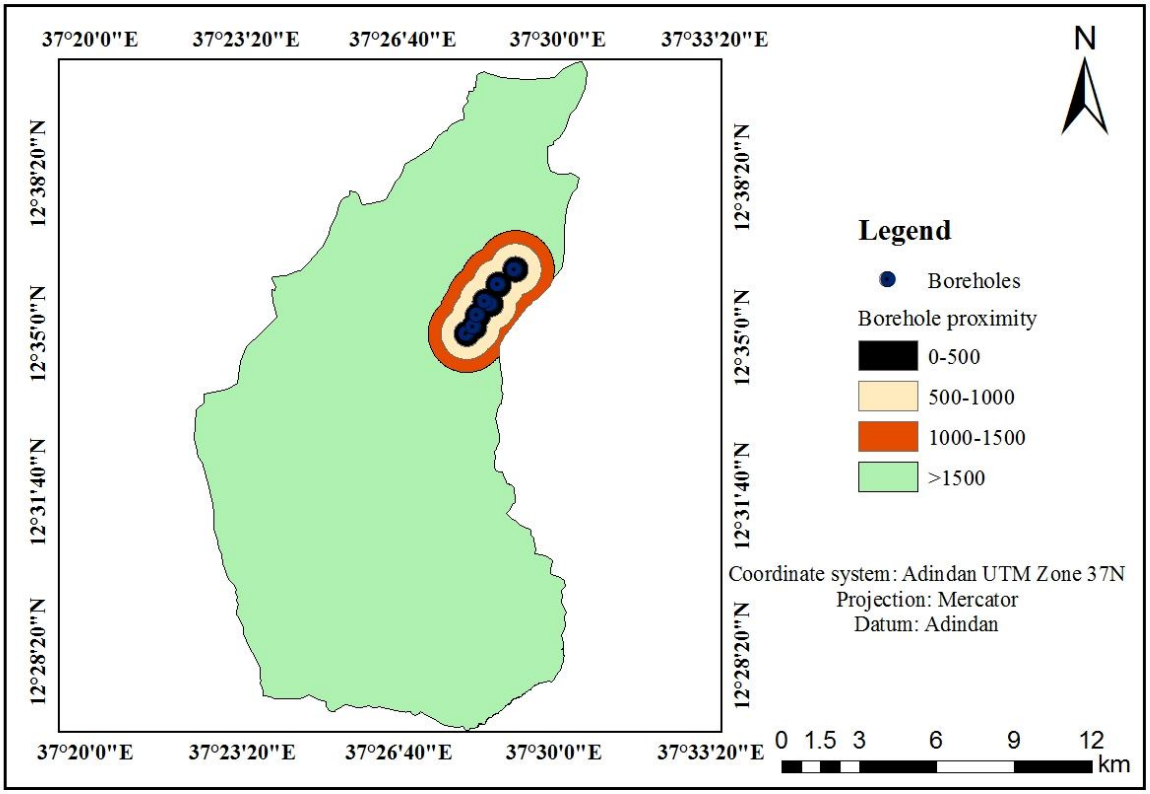


Figure 20: Borehole proximity map

Table 13: Proximity buffer distance of boreholes and their suitability

No	Suitability index	Suitability buffer	Area in hectare	Suitability score	Percentage
1	Unsuitable	0-500	380.7	1	1.57
2	Less suitable	500-1000	571.23	2	2.36
3	Moderately Suitable	1000-1500	649.8	3	2.68
4	Highly suitable	>1500	22601.7	4	93.38
Total			24203.43		100

As shown above from the Table 13, the majority of the study areas (93.38%) were highly suitable for landfill site. The remaining areas 1.57%, 2.36% and 2.68% were unsuitable, less suitable and moderately suitable respectively.

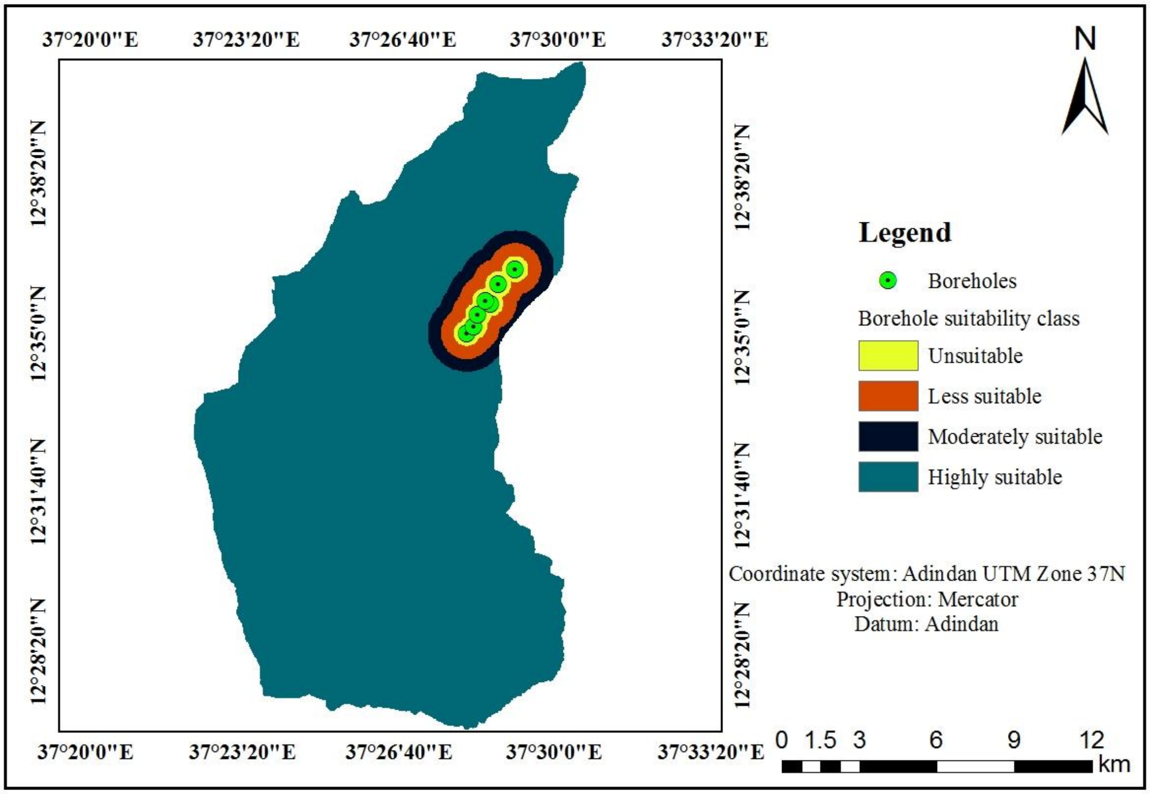


Figure 21: Reclassified borehole suitability map

4.1.9. Proximity from Airport

Distance from airport is one of the determinant criteria that should be considered during landfill site selection process. This is because landfill sites may attract birds that create danger to flight of aircrafts. Therefore to protect the safety of airports different researchers assign different proximity distances. In this study, the literature value of Trusew, (2013) was used as reference to determine the proximity distance of airport. Hence, multiple ring buffer of 0-750m, 750-1500m, 1500-3000m and >3000mfor Azezo airport was performed. The distance between 0-750m (2.9%) was taken as unsuitable, 750-1500m (4%) as less suitable, 1500-3000m (12.5%) as moderately suitable and >3000m (80.5%) as highly suitable areas. The airport proximity buffer distance map is clearly depicted in the following (Figure, 22).

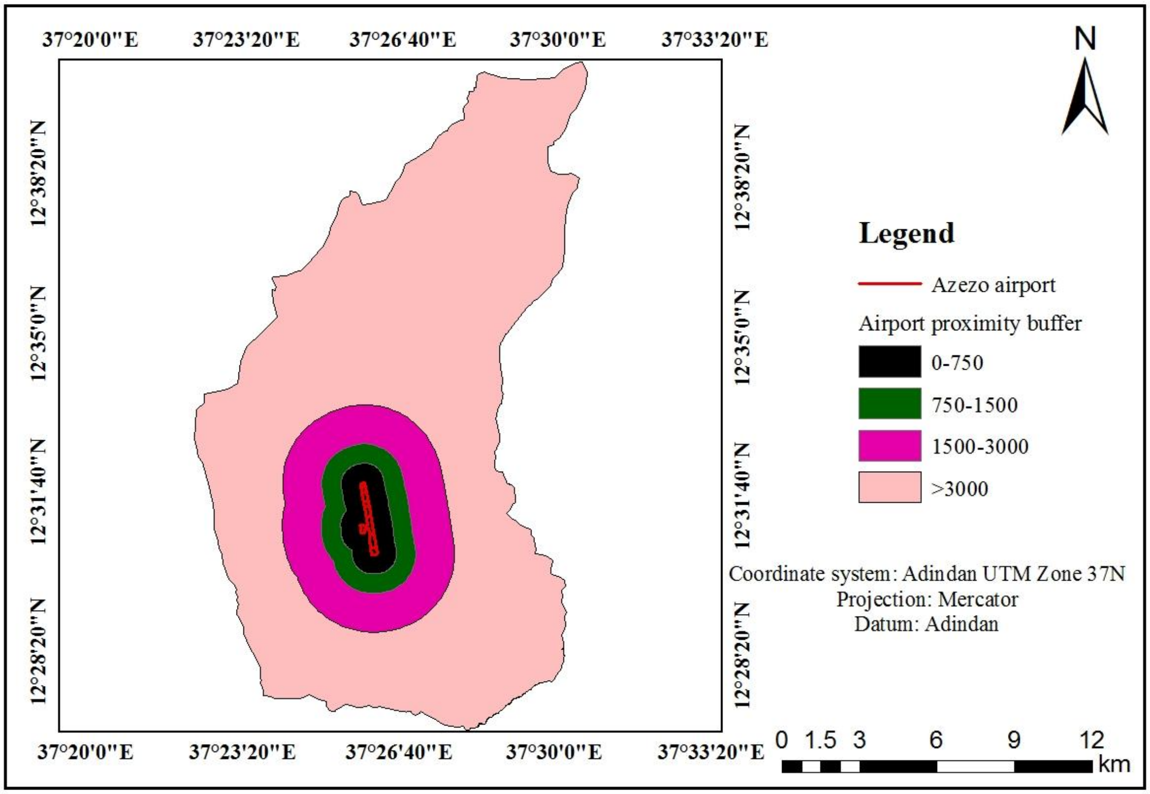


Figure 22: Airport proximity buffer map

Table 14: Airport Buffer distance suitability and its aerial converge

No	Suitability class	Buffer Distance	Area in hectare	Weight	Percent
1	Unsuitable	0-750	708.3	1	2.9
2	Less suitable	750-1500	985.77	2	4
3	Moderately Suitable	1500-3000	3026.52	3	12.5
4	Highly suitable	>3000	19482.8	4	80.5
Total			24203.43		100

As it is indicated in the above Table (14), 2.9% of the study area is found with the buffer limit of 0-750 meter and was unsuitable, 4% less suitable (750-1500m), 12.5% (1500-3000m) were moderately suitable and the majority of the study area (80.5%) found with buffer distance of >3000m was highly suitable from airport suitability point of.

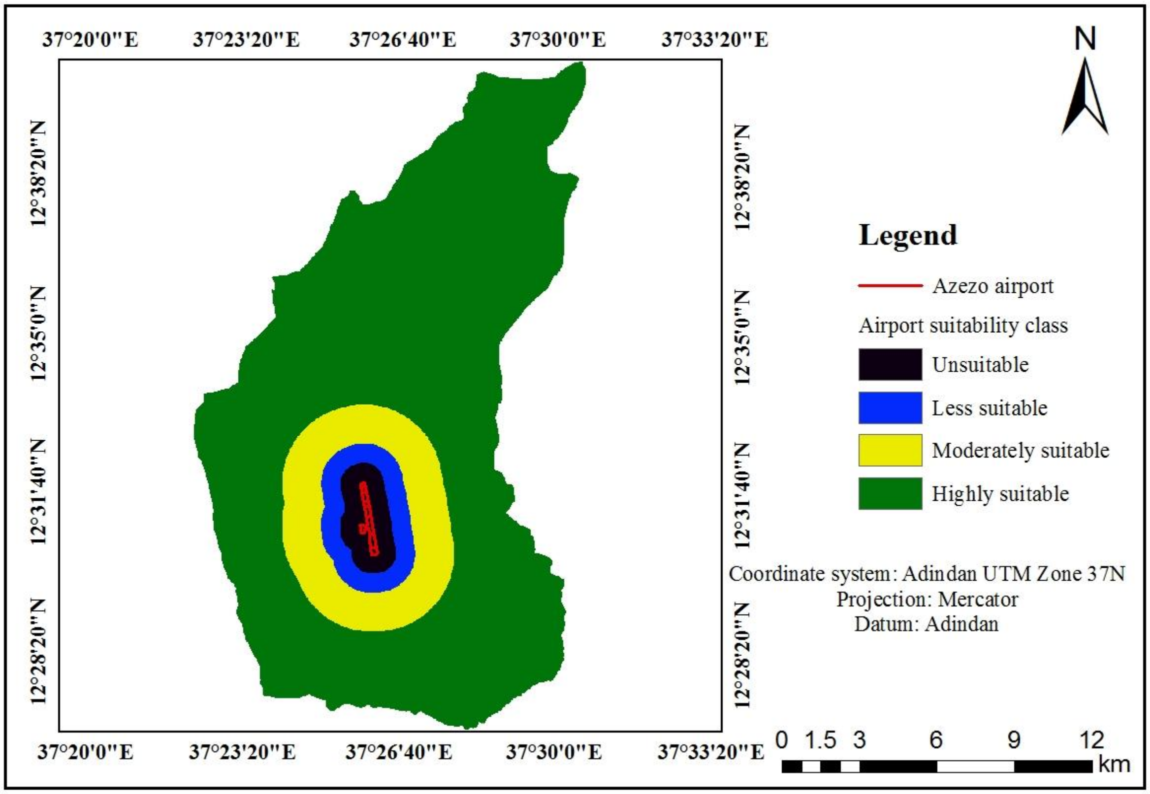
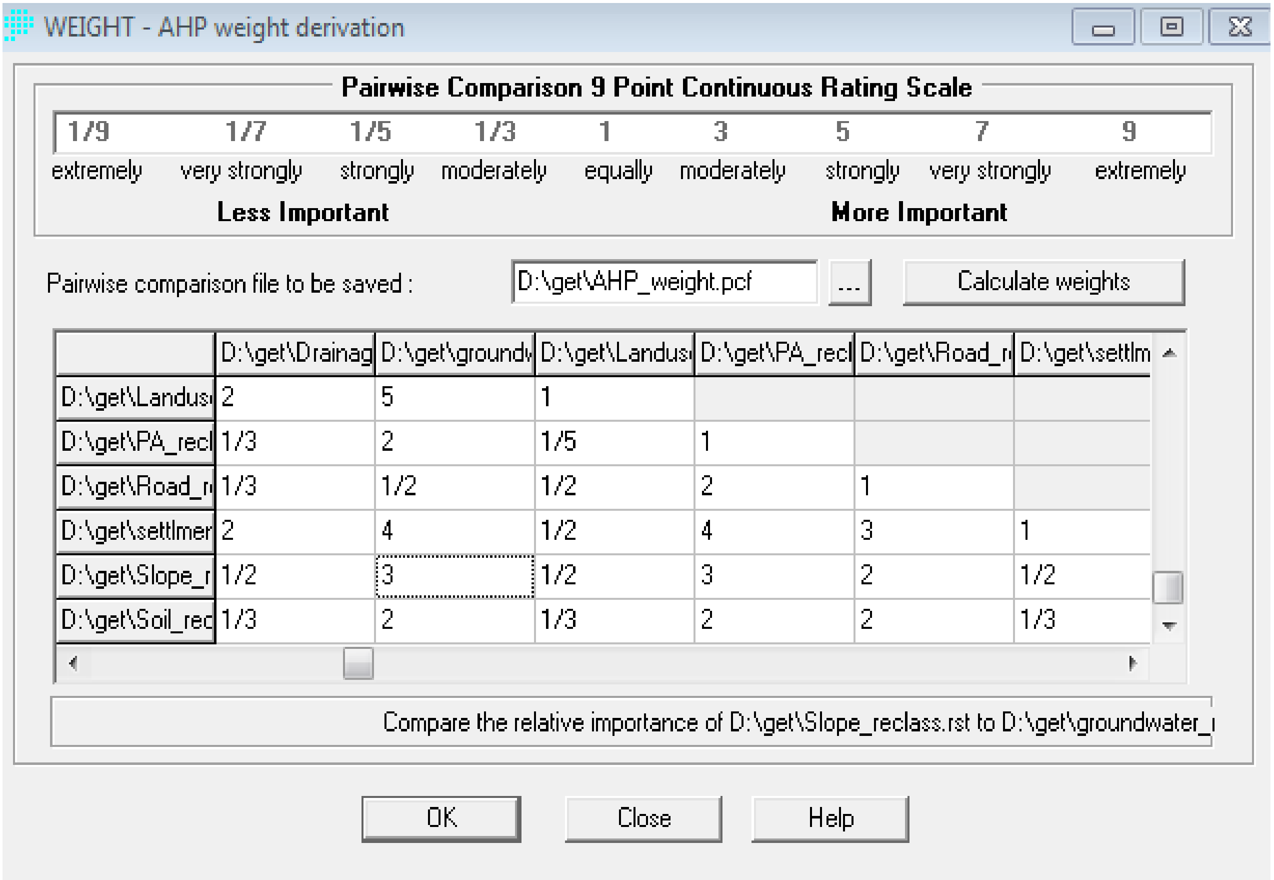


Figure 23: Airport suitability map

4.2. Pair wise Comparison Matrix Result

Based on IDRISI AHP weight module, pair wise comparison technique was used to calculate weights and its consistency ratio to select suitable site for landfill in the study area. Accordingly the relative weight of each criterion was assigned and consistency of judgment was determined by calculating consistency ratio. The result of the study indicated that consistency ratio was 0.05<0.1 which is acceptable (Saaty, 1980).

Table 15: Pairewise comparison of factors using IDRISI AHP weight module



	D:\get\Drainag	D:\get\groundw	D:\get\Landus	D:\get\PA_recl	D:\get\Road_r	D:\get\settlm
D:\get\Landus	2	5	1			
D:\get\PA_recl	1/3	2	1/5	1		
D:\get\Road_r	1/3	1/2	1/2	2	1	
D:\get\settlmer	2	4	1/2	4	3	1
D:\get\Slope_r	1/2	3	1/2	3	2	1/2
D:\get\Soil_rec	1/3	2	1/3	2	2	1/3

Based on the above IDIRISI AHP weight derivation module, the following eigenvector weights for all factors considered for landfill site selection were generated (Table 16)

Table 16: Criteria using pairwise comparison matrices

Criterias	AP	DR	GW	LULC	PA	Road	RA	Slope	Soil	Engine Vector Weight	%
AP	**1**	1/3	1	1/5	½	2	1/5	¼	½	0.0464	4.64
DR	3	**1**	4	½	3	3	½	2	3	0.1581	15.81
GW	1	¼	1	1/5	½	2	¼	1/3	½	0.0472	4.72
LULC	5	2	5	**1**	5	2	2	2	3	0.2381	23.81
PA	2	1/3	2	1/5	1	½	¼	1/3	½	0.0521	5.21
Road	½	1/3	½	½	2	1	1/3	½	½	0.0572	5.72
RA	5	2	4	½	4	3	**1**	2	3	0.2003	20.03
Slope	4	½	3	½	3	2	½	**1**	2	0.1228	12.28
Soil	2	1/3	2	1/3	2	2	1/3	½	**1**	0.0778	7.78
Total	23.5	7.08	22.5	3.9	21	17.5	5.3667	8.9	14	1	100

Note that: AP=Airport, DR= Drainage, GW=Ground water, LULC= land use land cover PA=Protected area and RA=Residential area

Finally, the result of AHP weight derivation indicates that, land use land cover, proximity from residential area and proximity from drainage network were found to be the most important factors to have overall suitability map with eigenvector weight of 23.81%, 20% and 16% respectively.

Proximity from airport, proximity from ground water well point and proximity from protected areas were found to be the least important criteria used in this study with engine vector weight of 4.6%, 4.7% and 5.2% respectively.

After assigning weights for all factors using pairewise comparison, they were combined using weighted overlay method in ArcGIS spatial analyst (overlay) tools. This was performed in order to find the most suitable sites for landfill sitting (Table 17).

Table 17: Weighted overlay result

No	Suitability class	Area in hectare	Percent
	Highly suitable	1110.105	4.58
	Moderately Suitable	13159.6	54.37
	Less suitable	354.7	1.46
	Unsuitable	9579.015	39.57
Total		24203.43	100

Based on weighted overlay result, only 4.58% of the study areas were found to be highly suitable for landfill site because these areas fulfill the previously considered environmental and socio economic criteria. Conversely 39.57%, 1.46%, and 54.3% of the study areas were unsuitable, less suitable and moderately suitable respectively because these areas were failed to fulfill the determinant criteria that were used in the previous analysis.

Generally, the north western and south eastern parts of the study area were found to be the most suitable areas for landfill sitting. The rest parts of the study area were inappropriate because they were unable to fulfill the physical and economic criteria and were excluded for further investigation.

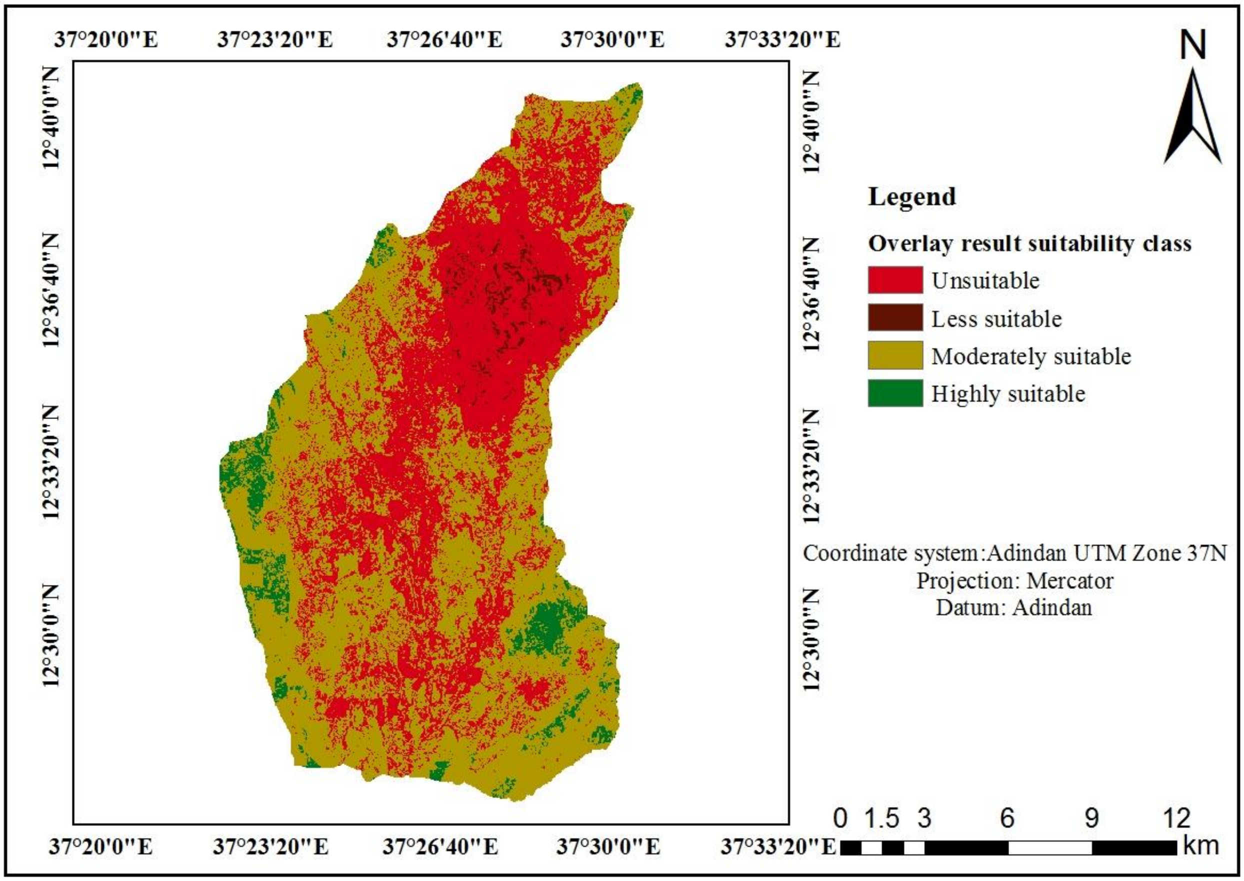


Figure 24: Weighted overlay suitability map

4.3. Thematic Maps Showing Highly Suitable Landfill Sites

After preparing weighted overlay suitability map, thematic map showing only highly suitable sites was prepared. To do so highly suitable areas were first converted in to shape file using ArcGIS analysis (conversion) tools. Finally thematic map showing merely highly suitable sites was prepared.

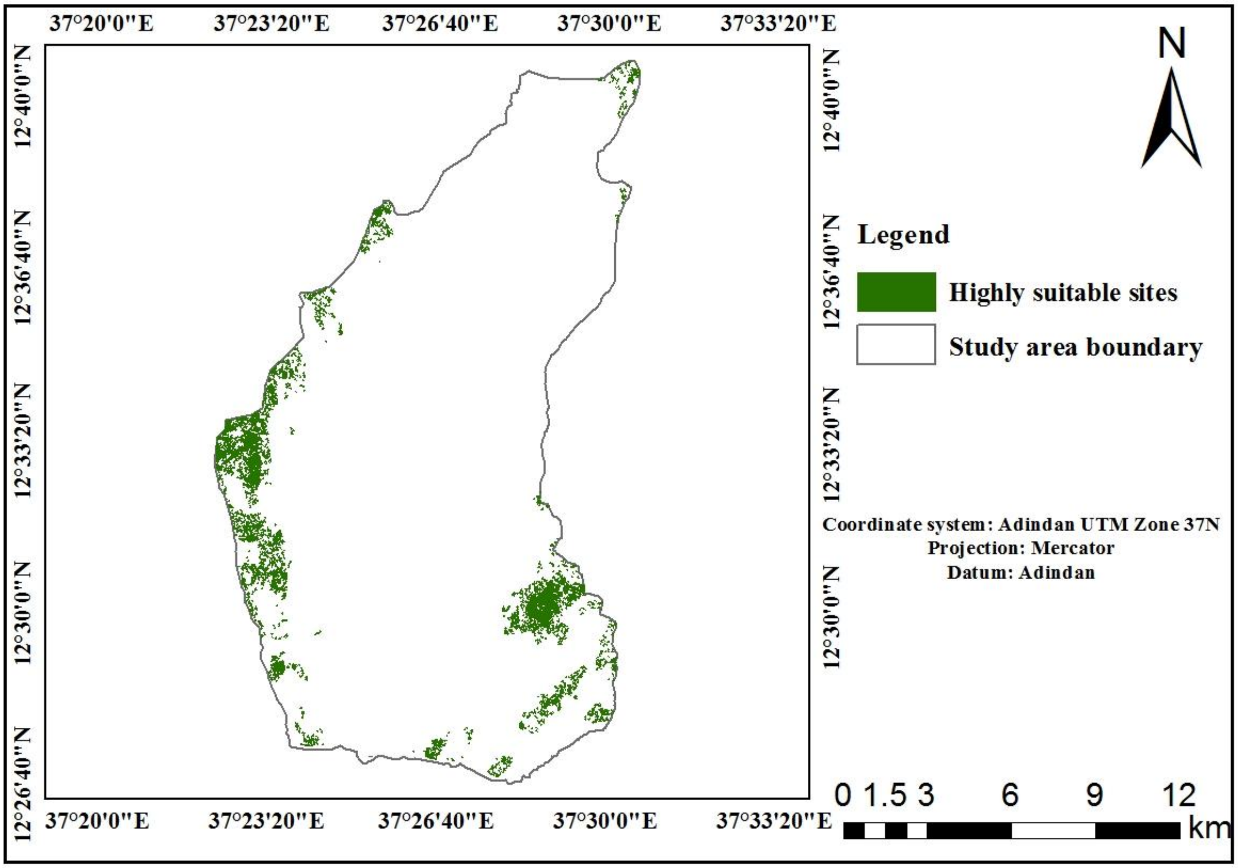


Figure 25: Thematic map showing highly suitable sites

4.4. Prioritizing Highly Suitable Candidate Landfill Sites

Though all the above areas (Figure 25) were selected as highly suitable areas they can be evaluated with each other based different criteria in order to give rank. This is because one landfill site selected as highly suitable may not be as suitable as others based on criteria like area, distance from the city center and distance from nearby settlements. Therefore, it is better to prioritize highly suitable areas based on these criteria. Larger size landfill is more preferable than small size landfill because large size landfill can serve for long years and can minimize the cost of reconstructing landfill. Hence, to determine the size of each site they were digitized using ArcGIS environment and their areal coverage was calculated. Thus, small and discontinuous sites were excluded for further analysis because they can be filled out within few years of service and will incur another cost to reconstruct sites. Consequently, the result of the analysis showed that seven candidate landfills were identified for further evaluations.

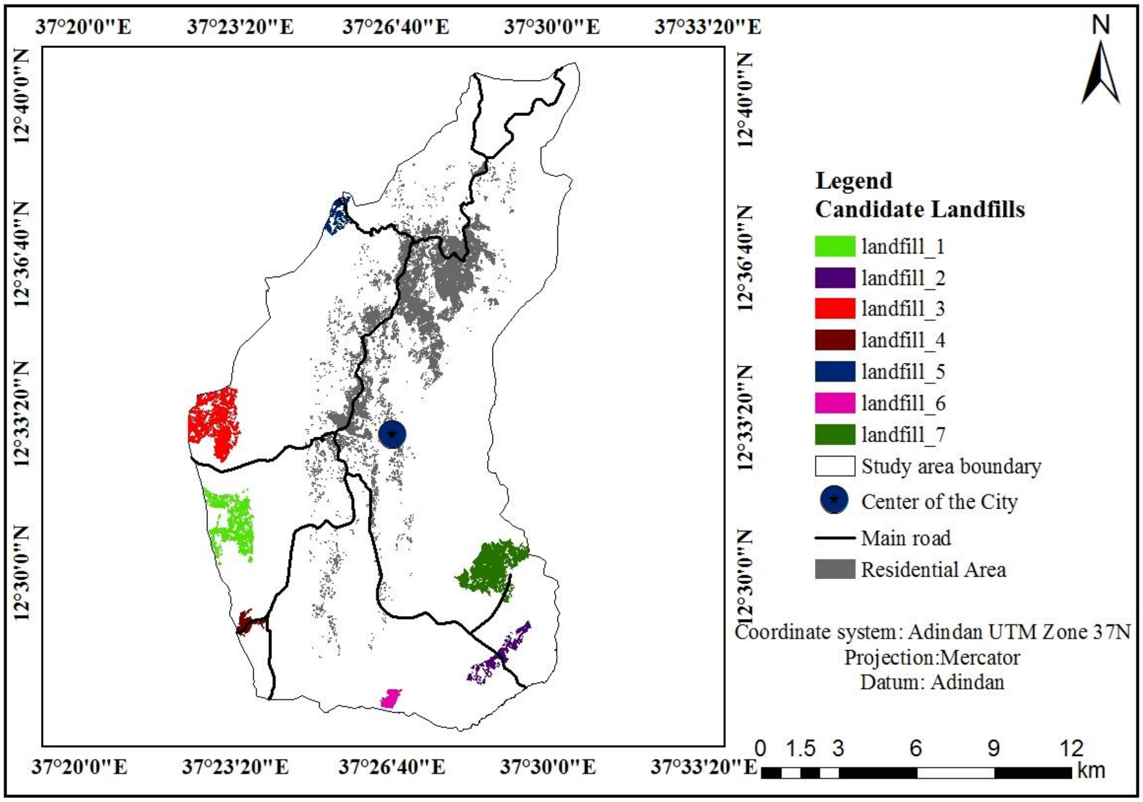


Figure 26: Candidate landfill sites from city center road and settlement

Landfills very far from the center of the city were considered unsuitable because of high transportation costs that will be incurred during its operation period. In addition to its cost, it should also be found on appropriate distance to be accessible for all parts of the city i.e. it should consider the distance of all parts of the city from landfills. Therefore, sites found in close distance from center were preferable than those too far from the center. Hence, the analysis of landfill sites from the center reveals that landfill 7 and 3 are close to the center of the town than other sites while landfill 2 and 6 are found far from the center of the city. Accordingly from economic feasibility point of view landfill 7 and 3 were highly suitable sites. However from environmental pollution and aesthetic value point of view landfills close to settlements is not preferable because it will result negative impact to human health. To prevent such problems landfill far from settlements were highly suitable. Analysis result of distance from settlements using ArcGIS environment reveals that landfill 2 and 7 are found on highly suitable site as they are far from the settlements with the limit of 10 and 7km distance respectively while landfill 5 and 6 are found in close distance and were not suitable compared to other sites.

Table 18: Candidate landfills size, proximity distance from center, and from settlement

Name	Area in hectare	Area in km^2	Distance from center (km)	Distance from settlement (km)
Landfill 1	158.4	1.58	7	2.8
Landfill 2	60.69	0.6	10	4.5
Landfill 3	221.4	2.2	6.8	3.3
Landfill 4	36.36	0.36	9	2.5
Landfill 5	37.89	0.37	8.5	2
Landfill 7	259.83	2.6	6	3.8
Landfill 6	30.43	0.343	9.5	2

As it is clearly shown in the Table 18, the criteria are inconsistent to each other. One criteria may be suitable from one dimension at the same time may not be suitable in another dimension (e.g. distance from city center and distance from nearby settlement). MCE solves such decision problems in order to choose the most suitable landfill sites by considering all the three criteria at a time for the all candidate landfill site. Therefore by using MCE in AHP procedure weights for each contradicting criteria were calculated. The result showed that size of landfill was the significant criteria to prioritize landfills with eigenvector weight of 0.5936 or 59.3%.

Table 19: AHP weight derivation for evaluation criteria.

Criteria	Settlement	size	Center	Weight	Influence (%)
Settlement	1	1/3	½	0.1571	15.7
Size	3	1	3	0.5936	59.3
Center	2	1/3	1	0.2493	24.9
∑	6	1.66667	4.5	1	100

Consistency ratio =0.05<0.1 which is within acceptable limit.

Based on the above parewise comparison matrix Table 19, landfills were prioritized and ranked based on their suitability in terms of their size, distance from settlement and distance from the center.

Table 20: Comparison of landfills by their size and distance to the center.

Size	LF1	LF2	LF3	LF4	LF5	LF6	LF7	WEIGHT	%
LF1	1	5	1/3	4	3	5	¼	0.1634	16.34
LF2	1/5	**1**	¼	3	2	4	7	0.0752	7.5
LF3	3	4	**1**	5	3	4	½	0.2317	23.17
LF4	¼	1/3	1/5	**1**	½	2	1/7	0.0410	4
LF5	1/3	½	1/3	2	**1**	2	1/7	0.0579	5.8
LF6	1/5	1/3	¼	½	½	**1**	1/7	0.0342	3.4
LF7	4	7	2	7	7	7	1	0.3966	39.6
Total								1	100
Center	FL1	LF2	LF3	LF4	LF5	LF6	LF7	Weight	%
LF1	**1**	3	½	2	2	2	½	0.159	15.9
LF2	1/3	**1**	1/3	½	1/3	½	1/3	0.0546	5.46
LF3	2	3	**1**	3	2	3	½	0.2193	21.93
LF4	½	2	1/3	**1**	½	2	½	0.0967	9.67
LF5	½	3	½	2	**1**	2	1/3	0.1248	12.48
LF6	½	2	1/3	½	½	**1**	1/3	0.0737	7.37
LF7	2	3	2	2	3	3	**1**	0.2719	27.37
Total								1	100

Note that: LF1=Landfill 1, LF2=landfill 2, LF3, 4, 5, and 7= Landfill 3, 4, 5, 6 and 7 respectively

Consistency ratio= 0.06 and 0.04 respectively (**acceptable**)

Table 21: Comparison landfills with their nearness to settlement

Settlement	LF1	LF2	LF3	LF4	LF5	LF6	LF7	Weight	**%**
LF1	**1**	½	2	3	4	½	3	0.1318	13.18
LF2	3	**1**	2	3	4	2	3	0.2986	29.86
LF3	2	½	**1**	2	½	2	2	0.1684	16.84
LF4	½	1/3	½	**1**	2	½	2	0.0933	9.33
LF5	1/3	¼	1/3	½	**1**	1/3	½	0.06	6
LF6	1/3	¼	1/3	½	1	**1**	2	0.06	6
LF7	2	½	2	2	2	2	**1**	0.188	18.8
Total								1	100

NOTE: LF1=Landfill 1, Landfill 2=Landfill 2, LF3, 4, 5, and 7= Landfill 3, 4, 5, 6 and 7 respectively. Consistency ratio**= 0.03**<**0.1** within acceptable limit.

As it is indicated in the above Tables 20 and 21 landfills were evaluated based on the above evaluation parameters. Accordingly landfill 7, 3 and 1 were found to be the most suitable site from size point of view compared with other sites with eigenvector weights of 0.3966, 0.2317and 0.1634 respectively while landfill 6 and 4 were the least suitable sites as they are small in size. The analysis result of landfills with distance from the center of the town also shows that landfill **7** with eigenvector weight of 0.2719 is the most suitable site while landfill 2 with eigenvector of 0.0546 is the least suitable site compared to other sites. From proximity to settlements point of view landfill 2 is highly suitable site with eigenvector weight of 0.2986 while landfill 5 and 6 are the least suitable sites because these sites are found very close to settlements and can pose health and aesthetic problem.

As we seen all the above analysis result there is inconsistent decisions. To solve such contradicting decisions to select the most suitable landfill site, all the evaluating criteria were considered at a time in MCE methods. Therefore, weights for all candidate landfills were derived by multiplying criteria weight and landfill site weight finally summing the equivalent products.

Table 22: Weight score of the candidate sites and their rank

Landfills	Size of the site	Distance from center	Distance from settlement	Weight score	Weight score in %	Rank
	0.5936	**0.2493**	**0.1571**			
LF1	0.1634×**0.5936**	0.159×**0.2493**	0.1318×**0.1571**	0.157	15.7	3
LF2	0.0752×**0.5936**	0.0546×**0.2493**	0.2986×**0.1571**	0.105	10.5	4
LF3	0.2317×**0.5936**	0.2193×**0.2493**	0.1684×**0.1571**	0.2186	21.86	2
LF4	0.0410×**0.5936**	0.0967×**0.2493**	0.0933×**0.1571**	0.0631	6.31	6
LF5	0.0579×**0.5936**	0.1248×**0.2493**	0.06×**0**.1571	0.0749	7.49	5
LF6	0.0342×**0.5936**	0.0737×**0.2493**	0.06×**0.1571**	0.0481	4.81	7
LF7	0.3966×**0.5936**	0.2719×**0.2493**	0.188×**0.1571**	0.3327	33.27	1
Total				1	100	

As shown above from the Table 22, all the candidate landfills were prioritized by considering their size, distance from the center of the city and distance to settlements using MCE techniques following AHP procedure. Finally the result of the analysis reveals that landfill 7 and landfill 3 were selected as highly suitable site with eigenvector weight of 0.3327and 0.2186 and ranked as first and second respectively. These sites were selected because from economic point of view they are large in size and can serve for long period of years. In addition to this, since they are found far from the nearby settlements can not pose health related problems as well aesthetic problems. On the contrary, landfill 6 and 4 are found to be unsuitable according to the criteria considered and are the last option to be used as landfill site. Because these sites are small in size and also are not on appropriate distance from the city center as well as settlements.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Selection of suitable site for landfill is a complex task which requires a careful consideration of many factors like environmental and socio economic factors. In this regard application of GIS and remote sensing data is very crucial to identify potential landfill site. This study was conducted to assess the potential suitable landfill sites in Gondar town by considering the physical and socio-economic factors using GIS and remote sensing techniques as a decision making tool. The study also used multi-criteria evaluation method to assign weight for all criteria considered and to handle large and conflicting criteria in landfill site selection processes. This method used various geographical data with GIS spatial analysis tools. Accordingly, site suitability maps for each of the factors considered were combined using weighted overlay tools in a GIS environment.

The result of the final suitability map showed that 4.58% of the study area is highly suitable for landfill. Moreover, 54.3%, 1.46% and 39.5% of the study area is moderately suitable, poorly suitable and unsuitable respectively. From the highly suitable areas **7** candidate landfill were selected each with an area greater than $0.3km^2$. In this case candidate landfill sites were prioritized based on their size, distance from the center of the city and distance from settlement. To do so AHP procedure using parewise comparison was applied to assign weight based on their importance. Accordingly, weight was computed for each criteria to candidate landfill sites in relation to the criteria. The final result showed that landfill **7** with eigenvector weight of 0.3327 and landfill 3 with eigenvector weight of 0.2186 were found to be the two most highly suitable sites while landfill 6 was selected as the last option to be used as landfill site with weight of 0.0481. The first ranked highly suitable area (landfill 7) is found in the south eastern part of the town. This place is large in size, easily accessible for road and is found where environmental and health risk is minimized.

5.2. RECOMMENDATION

The findings of this study come up with the following recommendation:

- The current landfill site called ***Ayira*** is found on unsuitable sites and is becoming a cause for health and environmental problem. Therefore the concerned body should give due attention and the suggested selected sites should be used as landfill site.
- In this study 9 social and physical criteria were used to select suitable landfill sites, but factors like geology and construction costs of landfill site were excluded due to shortage of time and absence of updated geological maps. Therefore, it is better to conduct further studies on this topic to fill this research gap by incorporating these criteria.
- The suggested candidate landfills are for only non hazardous wastes, hazardous wastes generated from hospitals and factories should not be disposed on these sites. This is because of the fact that the criteria used for hazardous waste and non hazardous waste is quite different. Therefore, the concerned body should take due consideration and separate landfills should be constructed for hazardous wastes.
- To safeguard downstream surface water pollution runoff must not flow in to and out of the landfill site. Due to this reason, drainage should be constructed around the landfill sites.
- Detailed ground water level analysis should be done for the selected candidate landfills in order to further determine the effects that will result from the landfills.
- In order to safeguard ground water pollution resulted from leaching, the municipality should construct Leachate treatment facility for landfill sites.

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Appendix 1

Latitude and longitude of protected areas

No	Name of protected areas	x-coordinate	y-coordinate	Elevation
1	Alnejash Mosque	331930	13920654	2092
2	Fasil Castle	333679	11394035	2226
3	Debrebrhan Silassie	334861	1394577	2272
4	Angereb Dam	335259	1394741	2142
5	St. Gebriel Church	333509	1394880	2210
6	Fasildes Preparatory School	332546	1394768	2130
7	Gondar College of Teachers Education	331940	1393114	2095
8	St. Yohhanes Church	332091	1394174	2122
9	Felege Abyot Primary School	331646	1393730	2124
10	Lideta Mariam Church	331536	1393499	2120
11	Dashin Brewery Factory	329920	1390629	2113
12	Kings Academy School	330629	1392105	2155
13	Gondar University Referral Hospital	331859	1399022	2172
14	Kusquam Mariam Church	331236	1395644	2254
15	Abora Giyorgis Church	332399	1392592	2078
16	Maraki Clinic	331990	1391917	2080
17	Loza Mariam Church	328324	1386729	2158
18	Azezo Primary School	329201	1387029	2036
19	Teda Health Science College	333935	1380303	1944

20	Hidassie Teda High School	333930	1380491	1944
21	University of Gondar	330789	1395135	2153
22	Fasiledes Bath	332332	1395118	2137

Appendix 2

Ground truth points for different types of land use

No	**X-coordinate**	**y-coordinate**	**Land use type**
1	0329246	1383990	Open land
2	0329158	1383997	Open land
3	0329174	1384149	Open land
4	0329402	1384482	Open land
5	0329325	1385431	Agricultural land
6	0329254	1385427	Agricultural land
7	0329250	1385489	Agricultural land
8	0329215	1385545	Agricultural land
9	0329180	1385642	Agricultural land
10	0329005	1386125	Green area
11	0329056	1386129	Open land
12	0329124	1386371	Agricultural land
13	0329236	1386460	Agricultural land
14	0329147	1386783	Green area
15	0329209	1386888	Open land
16	0329280	1387087	Green area
17	0330789	1392135	Open land
18	0330909	1392113	Green area
19	0331957	1394751	Green area
20	0332984	1394766	Settlement
21	0333254	1394849	Settlement
22	0333390	1394777	Settlement
23	0333486	1394761	Settlement
24	0333618	1394583	Settlement
25	0333609	1394526	Settlement
26	0333584	1394406	Settlement

27	0333664	1394325	Settlement
28	0333418	1394406	Settlement
29	0332723	1394881	Settlement
30	0332521	1395242	Settlement
31	0332292	1395083	Settlement
32	0332288	1395214	Settlement
33	0332756	1394850	Settlement
34	0332648	1394770	Open land
35	0332594	1394712	Open land
36	0332571	1394644	Green area
37	0332622	1394642	Green area
38	0332658	1394690	Green area
39	0332694	1394728	Green area
40	0332280	1394866	Settlement
41	0332297	1394902	Open land
42	0332313	1394813	Open land
43	0332395	1394957	Open land
44	0331539	1393259	Settlement
45	0331908	1394993	Settlement
46	0331835	1394871	Settlement
47	0331795	1394848	Green area
48	0331872	1394911	Settlement
49	0330958	1391710	Open land
50	335259	1394741	Open land
51	328324	1386729	Open land

Appendix 3

Photos

Plate 1: Settlements found very close to Ayira landfill site in south (Photo by author, 02/03/2017).

Plate 2: Settlements found very close to ***Ayira*** landfill site in west (Photo by author, 02/03/2017).

Plate 3: Uncontrolled solid waste disposal on steep areas.

Plate 3: Uncontrolled solid waste disposal near to settlements

Plate 4: The author during field GPS data collection