JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING MASTER PROGRAM

SUITABILITY ANALYSIS OF SOLID WASTE DISPOSAL SITE USING GEOGRAPHICAL INFORMATION SYSTEM TOOL: (THE CASE OF GONDAR TOWN, ETHIOPIA)

By: Tigist Birhanu

A Thesis Submitted to the Faculty of Civil and Environmental Engineering of Jimma Institute of Technology in Partial Fulfilment of the Requirements for the Degree of Masters of Science in Environmental Engineering.

April, 2019

Jimma, Ethiopia

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Main Advisor: Dr.-Ing. Fekadu Fufa (Asso. Prof.)

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April, 2019

Jimma, Ethiopia

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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ABSTRACT

*The problem of environmental pollution and health hazards due to inappropriate solid waste disposal is critical in developing countries like Ethiopia, Gondar town is one of the town in Ethiopia facing from environmental pollution due to lack of appropriate dumping site and solid wastes are not dumped in suitable area which leads pollution of environment in and around dumping area. Therefore, the main objective of this study is selection of suitable site for disposal of solid waste using Geographic Information System (GIS) tools. The data used for this study were a spatial resolution of (DEM 20m*20m), satellite map (landsat 8) to generate current LULC of the town, geological map, soil map and structural map of the study area which was collected from different governmental organization. Selection of the most suitable landfill site was determined through the integration of geographic information system (GIS) tools, multi criteria decision analysis (MCDA) and remote sensing techniques. To select suitable landfill site several parameters were considered such as slope, built up area, historical site, main road, surface water, land use/land cover, geology, ground water depth, groundwater well and soil. For each parameter map layer was prepared using GIS tools. The weight of each parameter was assigned based on their importance using pairwise comparison method in AHP. After the prepared map layer was standardized and weighted. Suitability map was prepared by overlay analyses on GIS based Weighted Linear Combination (WLC) analysis to select the suitable solid waste disposal sites and ranked as the value given 1; unsuitable, 2; low suitable 3; moderately suitable and 4; highly suitable were determined. Result shows that 9.1% of the study area is highly suitable, 21.1% is moderately suitable, 42.1% is low suitable and 27.7% is Unsuitable. The most suitable disposal site area from the town result shows that eastern direction 4.97% (12.1 km^2), western direction 0.43% (1km^2), north eastern direction 0.83% (2km^2) and the south east direction 0.43% (1km^2). These most suitable disposal sites were free from environmental, social and public health risks.*

Key words: *Geographical Information System, Landfill, Multi criteria Decision Analysis, Site selection.*

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ACRONYMS

AHP	Analytical Hierarchy Process
CSA	Central Statistics Agency
DEM	Digital Elevation Model
EPA	Environmental Protection Authority
GIS	Geographical Information System
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
LULC	Land Use Land Cover
MCDM	Multi-Criteria Decision Making
MSW	Municipal Solid Waste
MUDH	Ministry of Urban Development and Housing
OLI	Operational Land Image
SWM	Solid Waste Management
UNEP	United Nation Environment Program.
USGS	United State Geological Survey
WLC	Weighted Linear Combination

CHAPTER ONE

INTRODUCTION

1.1 Background

Solid waste is the term used to describe non-liquid waste materials arising from domestic, trade, commercial, agricultural, industrial activities and from public services (Aibor and Olorunda, 2006). It is one of the global environmental problems in the world in both developing and developed countries. Population growth, rapid urbanization, booming economy the increase standard of living in a community enhance solid waste generation in the world (Tirusew and Amare 2013)

Solid waste management is a big challenge in the world because of population growth and rapid urbanization especially in urban areas. In developed country identifying and managing best solid waste disposal site is difficult Mcfaden (2003) states that lack of land for waste disposal and unsuitable landfill site are the major problems in most of large urban areas in the world which has a negative impact on human and environment.

Selecting and managing appropriate solid waste disposal site also is a big challenge in developing country. Most developing countries do not have any organized means of controlling solid waste. The lack of status and poor salary associated with the profession discourage qualified employees and they have also lack of human resource that have enough experience to handle solid waste efficiently. On the top of that there are limited opportunities to learn about solid waste in education and on job training program. In low income country over 90% of wastes is often disposed in unregulated dumps and openly burned (World Bank, 2018). This practise leads serious health, safety and environmental consequence. Globally, urbanization and rapid population growth can lead to an enormous increase of solid waste generation per unit area (Peter, 2015).

Inappropriate SWM can result in environmental health hazards and has negative impact on the environment (Birhanu and Berisa , 2015). On other hand uncollected wastes, which are dumped inappropriately, in turn can either produce insects, parasites and bacteria that spread diseases such as cholera and dysentery, or block the drainage channels as well as pollute the surface groundwater and both inadequate collection and unmanaged disposal, therefore, bears several adverse consequences on human health and environment (Peter, 2015). Therefore, selecting proper sites for solid waste disposal far from residential areas, environmental resources and settlement is the main issue in the management of solid waste.

In Africa most developing countries have no effective solid waste management system cause of lack of good governance, public commitment, planning and technology. Several studies show that in developing countries much of municipal solid waste is generated in from household (55% - 80%), market area (10% - 30%) and the other from institutions (Nabegu, 2010). In Ghana the rate of waste generation is 0.47kg/person/day and throughout the country only 10% of solid wastes generated are properly disposed and 30- 50% of residential waste are not disposed properly that are dumped near the street, in drain and in stream (Mensha and Labri, 2005)

As a result of rapid urbanization and population growth in the town of the study area, the solid wastes are increasing from time to time. The appropriate site for these solid wastes is not selected due to this reasons the community of the town are dumping their waste around their homes and near to the street (unsuitable area). The Solid waste disposal site suitability analysis using Geographic information system (GIS) tools is very important to solve that all problems discussed above and in complex decision making processes involving multi thematic layers and their pair wise comparison, Analytic Hierarchy process (AHP) has proved to be a very useful decision making tool. Though the problem is increasing time to time there is no any research done on this area. So this study will fill gap to develop socio economic wellbeing of the community of the town.

1.2 Statement of problem

Solid waste management has been a big challenge in all over the world. The amount of volume of solid waste generation is increased cause of rapid population and development activities. Due to improper management and disposal of solid waste urban cities facing various problems like diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic loses (Jayprakash, *et al.*, 2015). In Gondar town rapid increase in population together with rapid development of the town has produced increasing volumes of solid waste and rapid population growth caused by natural increase and migration from rural area. The current sources of solid wastes in the town are residential area, commercial area street sweeping, institutions and small scale industries. Most of solid wastes that are generated in the town remain uncollected and simply dumped in open area, around the homes, near to street, in drain, burning and the town is facing problem in dumping the wastes in unsuitable area that have direct effect in polluting environments and human health. To eliminate the existing problem suitable site selection of solid waste disposal using GIS technique is very important.

1.3 Objective

1.3.1 General objective

The main objective of the study is to identify suitable site for solid waste disposal in Gondar town using Geographic Information System (GIS) tools.

1.3.2 Specific objectives

The specific objectives of study are

1. To identify important parameters for selecting solid waste disposal site in Gondar town and prepare their map using GIS.
2. To evaluate the current landfill site in Gondar town.
3. To develop a map of suitable disposal site for thestudy area.

1.4 Research questions

1. What are the important parameters for selecting solid waste disposal site?
2. How to evaluate the current landfill site in Gondar town?
3. How to develop a map for suitable solid waste disposal site?

1.5 Significance of the study

This study is essential to protect environmental safety of Gondar town by selecting suitable site for waste disposal using different parameters. This study will reduce surface and ground water, air, and soil pollution due to solid waste management system in the town. It will help Gondar Town community of the town to solve problem face with landfill suitability. To improve the existing solid waste management system of the town selecting suitable site for solid waste disposal using Geographic information system is very important.

1.6 Scope of the study

This study focused on identify suitable site for solid waste disposal using GIS and AHP method in Gondar town by considering environmental, social and economic factors.

1.7 Limitation of the study

The site selection criteria were stated based on local legislation and literatures. Because of the specific features of the study area, some of the criteria are not incorporated in the solid waste disposal site suitability due to lack of data.

1.8 Organization of the thesis

This research has five chapters. Chapter one is an introduction part which consists of the introduction, statement of the problem, the objectives, research equations, significance, scope of the study, and the organization of the study. The second chapter deals with review of related literature obtained from various published and unpublished reference materials. Chapter three describes the study area and the research methodology. Chapter four contains the analysis, results and discussion parts of the study and the fifth chapter presents the conclusion and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Solid wastes are all those wastes that are useless, unwanted and cast off materials arising from production and consumption or from human and animal activities (Arifur and Tanisa, 2013). The municipal solid waste landfill is defined as a method of disposing without any negative effect on public health and environments. Landfill site selection is complex and time consuming process. To identify landfill site without the risk of public health and environment, the process of landfill sitting considers environmental, ecological, and technical parameters and also must fullfill legislative guidelines.

2.2 Solid waste management

Waste management is monitoring, collection, transportation, processing or disposal of waste. As urbanization increase, solid waste management (SWM) becomes a major public health and environmental threat in urban areas (Mohammad, *et al*., 2016). In most developing countries in the world use inappropriate handling and disposal of municipal solid waste that leads environmental degradation, i.e., air pollution, soil contamination, surface and ground water pollution (WHO, 1996). To control the generation, storage, collection, transfer and transport, processing and recovery, and final disposal of solid wastes in a manner that the term usually relates to materials produced by human activity and to reduce its effect on health, the environment or aesthetics SWM is needed (Jaya, 2004).

2.2.1 Solid waste management in world wide

In worldwide an estimated 11.2 billion tonnes of solid waste is collected in and decay of organic proportion of solid waste is contributing about 5% of global greenhouse gas emission (UNEP, 2005). These wastes are from electrical and electronic equipment which having a new and hazardous substance presents a fastest growing challenge in both developing and developed country. Around the world waste generation rates are increasing. In 2016 the worlds' cities generated 2.01 billion tonnes of solid waste and it is 0.74 kilogram per person per day. With increase population growth and urbanization annual waste generation is expected3.4 billion tonnes in 2050 (World Bank, 2018).

According to PPCB (2007), increment of municipal solid waste generation has been recorded worldwide in major cities Because of urbanization growth, population growth, industrialization, and economic growth. Improper waste disposal is a serious issue for environmental problems all over the world therefore accumulation of solid waste and its subsequent management has become an adverse impact on the environment and public health and safety all over the world especially in urban area of developing country (UNEP, 2005).

Rathore *et al.* (2016), said that because of the degree of rapid urbanization and increasing number of population growth, solid waste management is a big challenge for the cities administrations in many developing countries. The amount of solid waste generation increased cause of this population growth. In most of developing countries, municipal solid waste management (MSWM) is inadequate and beyond the capabilities of their economic setup for handling and disposal (WorldBank, 1999).

2.2.2 Solid waste management in Ethiopia

Solid waste generation in Ethiopia has negative effects on environment and public health. Rapid expansion of urbanization, industrial activities, agriculture and population growth produced large amount of solid waste that pollute environment and has an effect on public health problem. The disposal of MSW in developing countries has a challenge due to changing economic trends and rapid urbanization (Peter, 2015). On the top of that for municipalities and urban governments in the developing countries, urban waste management has been a challenge, due to poor infrastructure, bureaucratic competence and limited institutional capacity of the municipalities (Birhanu and Berisa, 2015).

In Ethiopia, rapid urbanization with increased urban population in the last decade has an effect on increasing solid waste amount that brought enormous pressure on municipal services, mainly in the management of solid waste (Hailemariam and Ajeme, 2014). Degenet (2008), said that, like in many other developing countries, the majority of inhabitants in most towns of Ethiopia often use unsafe solid waste disposal practices, such as open dumping, burning and burying.

In Ethiopia most of the solid wastes are dumped in drainage lines, open space, near to the street and informally burned. Open dumps pollute surface and ground water, soil and the natural environment as a whole. Generally according to (Birhanu and Berisa, 2015), 43% of wastes are collected in country are properly collected and dumped in open landfill. Worldbank (2004), stated that study conducted in per capita amount of waste generated in Ethiopia range from 0.17 to 0.48 kg/person/day for urban area to about 0.11 to 0.35 kg/capita/day for rural area. Generally, in Ethiopia solid waste generated in most of cities are not correctly managed.

2.2.3 Waste Disposal status of Gondar Town

In Gondar town there are two methods of waste collection such as door to door and transfer stations collection (Gedefaw, 2015). But presently, only doo-to-door collection method is practiced. Collection carried out by 5 small scale enterprises. Under these 5 enterprises 64 male and 177 females totally 241 members are collecting wastes and the equipment that they use sack and 16 push carts for collection of solid waste **(**Ministry of Urban Development and Housing, 2016).

Non-degradable components are plastics, textiles glass, metals and the construction and demolition. Construction and demolition activities consisting of sands, soil stones, metal, cement concrete and wood are also observed in the town. Such wastes are not properly managed that is disposed within their compounds, outside in streets and open areas **(**MUDH, 2016). And Bio medical wastes such as syringes, gloves, glucose materials from hospitals, clinics, and other health care wastes are dumped in different areas of the town (Gedefaw, 2015). As it is hazardous waste it should be dumped in different area and managed carefully. In Gondar town the daily total solid waste generation from different sources are around 11660kg and annually it reaches to 419762kg.

Table 2-1: Solid waste sources and their generation rate per day in Gondar town.

Source of solid waste	Solid waste generation rate per day (quantity by ton)	Solid waste generation rate (by %)
From household	48.8 ton	55
From business	22.2 ton	25
From industry	4.4ton	5
From institution	8.9ton	10
From agricultural	2.7 ton	3
From other sources	1.8 ton	2

Source: Ministry of Urban Development and Housing (2016)

2.3 Landfill suitability

Landfill is an engineered physical facility used for the disposal of Solid Waste and Solid Waste residuals in the surface soils of Earth. According to the United States Environmental Protection Agency (EPA, 1995), a landfill is a large area of land or an excavated site that is specifically designed and built to receive wastes. It is the most common type of waste disposal facilities and is an integral part of an integrated waste management system.

According to Sener (2004), the methodology for a landfill site selection should have the following: A systematic and impartial way of evaluation and assessment of sites that can be reasonably considered available for landfill, a mechanism for the comparison of potential sites based on their suitability and then ranking them based on suitable and unsuitable, it should be easy to implement in a computerize system and it should be able to produce and present self-explanatory results in format that is easily understood by all stakeholders. Hakan and Fikri (2009), states that a GIS and AHP-based methodology that was carried out with the aim of identifying and ranking the candidate landfill sites.

According to EPA (1995), leachate describes any liquid percolating through the deposited wastes and emitted from or contained within a landfill. The composition and characteristics of leachate depends on factors such as: the type of the wastes deposited, rainfall and other climatic factors, the degree of surface and groundwater ingress, the age of deposited waste, degree of compaction and cover, capping and restoration. Landfill gas is the mixture of gases; it mainly consists of methane (CH_4) and carbon dioxide (CO_2). These are the main products of the anaerobic decomposition of the biodegradable organic fraction of the municipal solid waste in the landfill. Other components of landfill gas include atmospheric nitrogen and oxygen, ammonia, and trace organic compounds (Samuthi, *et al*., 2007).

2.4 Site selection criteria

Suitable landfill siting requires an extensive evaluation process in order to identify the optimum available disposal location. This location must full-fill with the requirements of the existing governmental regulations and at the same time must minimize economic, environmental, health, and social costs (Siddiqui *et al*., 1996). Factors that should be considered for selection of landfill disposal sites: Soils that have low permeability, No environmentally significant wetlands of important biodiversity, there should be placed away from private or public drinking, irrigation or livestock water supply wells down-gradient of the landfill boundaries to minimize the risk of contamination of ground water and leachate movement, No residential development is adjacent to the perimeter of the site boundary, No fault lines or significantly fractured geological structure that would allow unpredictable movement of gas or leachate, The site is not within 3 km of an airport and the site should not be placed within 1 km of socio politically sensitive sites (Philip and Michael, 1999).

When assessing suitability of landfill site, landfill site criteria are key issue that needs to be considered. To be commercially and environmentally acceptable, a landfill must be constructed in accordance with specific rules, regulations, factors and constraints which vary from place to place or from country to country (Olusina and Shyllon, 2014). The specific rules, regulations, factors, and constraints must cover: geomorphology, land value, slope and proximity to recreational areas (Kao and Lin, 1996). Generally Kontos *et al*. (2005), gave the following criteria's for specifying the best Site for landfill these are water sources, surface water, sensitive ecosystem, urban centre, slope, cultural area, road and land use land cover. On the other hand, landfill site is a complex process that needs consideration of many criteria which are environmental, social and economic criteria to select the best site (Kabite, *et al*., 2012). Kabite *et al*. (2012), gave the following criteria for select the best site for landfill these are river/ stream, geology, slope, airport, fault, road, bore hole, land use/ land cover, soil, ground water depth.

In order to minimize future risk to the environment from landfill activities, Environmental, technical, economic and social factors influence the suitability of a site, and so achieving a balance among all these factors is very important (EPA, 2002). Baban and Flannagan (1998), states that there are a number of criteria for landfill site selection these are environmental, political, financial and economic, hydrologic and hydro-geologic, topographical, geological, availability of construction materials, built up area, climatic, and difficult infrastructural provisions.

2.4.1 Geological criteria

Solid waste becomes a part of the geologic environment, however, when it is deposited in the earth materials of a sanitary landfill, and it is then subject to such normal geologic processes as weathering and movement of water through waste. As a result of these natural processes, hidden and irreversible groundwater contamination or surface water contamination may result. Low permeability of rocks such as shale, marl clay stone and schist are suitable for landfill. While rocks like limestone, sandstone, dolomite, alluvium and terraces are high permeability and has low suitable for solid waste disposal site (Kontos *et al*., 2005). Generally, areas with low permeability material are preferred.

2.4.2 Soil

Soils with a high percentage of clay particles (but which are workable in wet conditions) are generally the preferred soil type, suitability for on-site disposal of leachate by surface or subsurface irrigation and the potential effects of failure of leachate containment and collection systems (land fill guideline, 2000).Impermeable strata and consolidated material are suitable for landfill site as they do not allow movement of leachate and hence minimize the risk of groundwater contamination from landfill leachate (Hakan and Fikri, 2009). According to Sener (2004) and Ismail *et al*. (2016), soil with high rate of permeability (Sand, Sandstones, Gravel, Limestone) are considered unsuitable for solid waste disposal/landfills while soils with medium rate of permeability (Silt, Granites, Siltstones) and low rate permeability (clay, mudstones, gneisses, pebbly clay) are considered suitable.The soil type that have less porous, less infiltration into ground like clay soil types are the most preferred for landfill site to control pollution of environment (Ismail, *et al*., 2016).

2.4.3 Hydrological criteria

There are risks of surface water pollution if landfills are sited in close proximity to waterways.When landfill sited near to waterways can be a source of water pollution by leakage of leachate and runoff. It is generally undesirable to site a landfill in the following areas like land that is designated as a water supply catchment or reserves for public water supply, water courses and locations requiring culverts through the site and beneath the landfill and estuaries, marshes and wetlands (Kontos, *et al*., 2005). Ground water contamination if once it is contaminated it is difficult to restore the original water, degrades water quality producing an objectionable taste, odour and excessive hardness so it is irreversible (Gawsia, *et al*., 2014). Ground water is one of the main sources of drinking water so it should be better to control ground water from any contamination. Factors affecting groundwater are nature of bedrock geology, depth from surface soil, vegetation, climatic variation, permeability of sediments, and topography, while anthropogenic are nature of human activities, urbanization, industrialization and waste management disposal, amongst others (Ifeoma, 2014). To control pollution of leachate into the ground landfill site should be placed away from ground water wells and in deep depth of ground water table because such pollution of groundwater results in a substantial risk to local groundwater resource user and to the natural environment.

2.4.4 Topographical criteria

In considering potential landfill sites an assessment of the potential for existing topographical features to assist in minimizing impacts should be made. (Hasan, *et al*., 2009) Set areas with slope <15-20% as the best site for landfill, while (Chang, *et al*., 2007) describe slope <12% as the best site and slope >12% unsuitable for landfill. Akbari *et al*. (2008), stated that modest slopes enable easier storm water control, leachate control and site stability measures, as well as facilitating the operation of the site.

2.4.5 Environmentally Sensitive Areas

According to Kontos *et al*. (2005), landfills should generally be located to avoid areas where sensitive natural ecosystems would be adversely affected, such as: significant wetlands, inter-tidal areas, significant areas of native bush including the Forest, recognized wildlife habitats, national/regional and local parks and reserve lands (for example, cemeteries); and any areas where release of contaminants from the site could severely affect fish/wildlife/aquatic resources and sites of historical or cultural significance.

2.4.6 Land use

Land cover describes the physical state of the earth's surface and immediate subsurface in terms of the natural environment (such as vegetation, soils, and surfaces and ground water) and the man-made structures (e.g. buildings) and the term Land use itself is the human employment of a land-cover type (Malczewski, 2006). Aim of site selection analysis is to identify the best site for some activity given the set of potential (feasible) sites therefore land-use suitability analysis aims are to identify the most appropriate spatial pattern for future land uses according to specified requirements, preferences, or predictors of some activity (Collins *et al*., 2001). To identify the best landfill disposal site according to prevent the public health and odour, disease outbreak, noise complaints, scavenging, rodents and other animals' complaints, and decreased property value landfill site should be implemented far away from built up area. And also landfill sites should not be located too far away from road causes that will increase costs significantly and the site locating nearby the road might cause odour and environmental pollution (Goskel *et al*., 2016).

2.5 Application of GIS and remote sensing

According to Whitach (1977), Remote Sensing includes all methods of obtaining pictures or other forms of electromagnetic records of Earth's surface from a distance, and the treatment and Processing of the picture data, Remote Sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. And its multispectral capability provides appropriate contrast between various natural features where as its repetitive coverage provides information on the dynamic changes taking place over the earth surface and the natural environment (Adeofun *et al*., 2011).

GIS is a powerful tool that can integrate driven types of spatial data and perform a variety of spatial analysis and it is used as a tool to find solid waste and land fill sites, which are environmentally safe and acceptable to people. Particularly GIS is used to view, understand, question, interpret and visualize huge amount of spatial and non-spatial data in many ways that reveals relationships, patterns and trends in the form of maps, reports and charts, which will be important for critical decision making (Malczewski, 2006)

GIS plays a considerable role in the selection of landfill sites. The application of GIS in the selection of a potential landfill site reduce time and enhance accuracy, it easily helps to capture, store, and manage spatially referenced data, it helps to perform analysis of spatially referenced input data, it helps to extract or classify spatial features while searching suitable sites, it helps to communicate model results and used in selection of solid waste site (Jayprakash *et al*., 2015). In GIS-based land-use suitability analysis, it is always assumed that the study area is partitioned into sets of polygons or raster data sets which are the basic units of observations (Malczewski, 2006).Satellite remote sensing data and Geographical Information system (GIS), is an intelligent system providing more realistic analysis and models based on different criteria to convert spatial and non-spatial data into useful information which helps the decision maker to make critical decisions for landfill site selection (Rathore *et al*., 2016).

2.6 Multi criteria decision making analysis

MCDA is a process that transforms and integrates spatial data and the decision maker's preferences to obtain information for decision making(Malczewski, 2006).GIS-based MCDA can be thought of as a process that combines and transforms spatial and non-spatial data (input) into a resultant decision (output)(Malczewski, 2006).The main objective of MCDA is the design of mathematical tools to support the subjective evaluation of a finite number of decision alternatives under a finite number of criteria in order to find the best choice (Pournamdarian, 2010).

According to Malczewski (2006) and Sener (2004), Steps in solving problems with MCDA: A specific or a set of goals that the decision maker wants to achieve, The decision maker or a group of decision makers involved in the decision making, process with their preferences on the evaluation criteria, a set of evaluation criteria, a set of decision alternatives, a set of uncontrollable (independent) variables or states of nature and a set of results corresponding to each alternative.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study area

3.1.1 Location

The city of Gondar; Founded by Emperor Fasiledas in 1636 A.D is also the current capital of the Administrative Zone. It was the capital of Ethiopia for more than 100 years. Currently Gondar town is the capital city of North Gondar zone and it is located 747km North West of Addis Ababa and 180km North East of Bahir Dar. It is located at 332805.00m E to 327314.00m E and 1394441.00m N to 1397208.00m N. The town limits of Gondar enclose an area of 242km^2 and standard altitude is 2133m above sea level**.** Gondar is one of the well-known cities in Ethiopia and the fast destination of tourists.

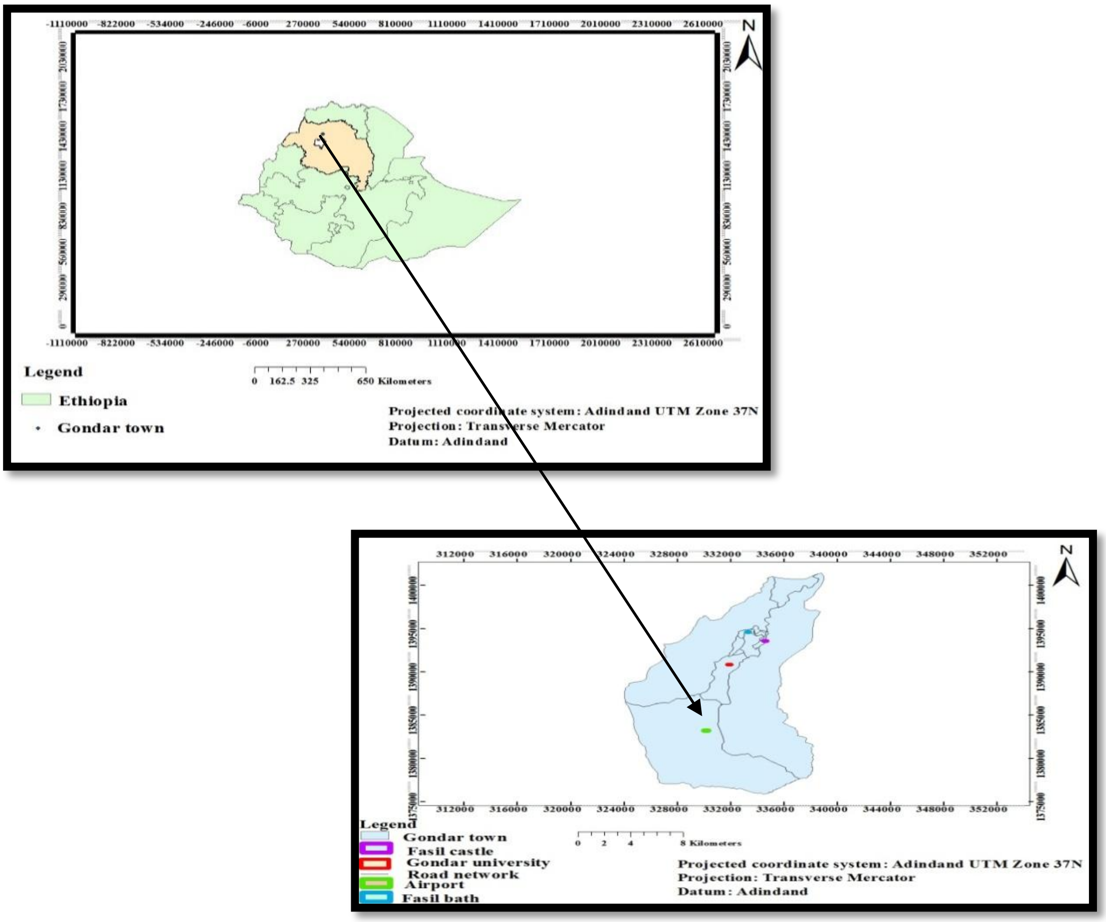

Figure 3-1: Map of study area

3.1.2 Population

Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA, 2007) Gondar had a total population of 207,044, of whom 98,120were men and 108,924 women. According to MUDH (2016), total population of Gondar city was 355,857.

3.1.3 Topography

Gondar is located in the northern highlands of Ethiopia. The topography of the town is undulating and consists of hills, sloppy areas, gentle slope areas, rivers and streams. Elevation of the town ranges between 1850-2752.5m above sea level. Elevation of the town decreases from north to the south and then rises again in the eastern part of Teda town. the northern part of the town has the highest elevation 2292-2752.5m above sea level and falls down to the south and south east 1852m above sea level.

The town has eight hills in the west, north and east and also in the south namely: Genet, Mushira Dingay and Wenfit in the north; Ambasoni, AmbaTerara, Bilajig, AnchiDuba, Maraki in the west and Genfo Kuch in the south. In between there are areas with undulating slopes that continue to gentle slope areas to the south in Azezo and also it is dissected by the three rivers Keha, Shinta and Dimaza (Gondar Town Structure Plan, 2014).

3.1.4 Climate

The mean annual temperature in Gondar town varies between 16^0C and 20^0C. Similar to other parts of Ethiopia, maximum temperature occurs in March-May and minimum temperatures are observed in January and December. The average maximum temperature is 29^0C and the average minimum temperature is 10^0C and the mean annual temperature is 20^0C (Ethiopian Meteorological Services, 2011). According to Ethiopian local climate classification the town falls within Weina Dega climatic condition.

Gondar has one main rainfall season and small showers of rain in other seasons. Long-term distribution of rainfall data indicates that most of the rain occurs in July followed by August, June and September. The annual rainfall varies from 712 to 1823mm with a mean annual rainfall of 1200mm.

3.1.5 Soil

According to FAO classification the soil units of this town is classified into three classes these are cambisols, regosols and vertisols. The soils have brown colour on the hills and sloppy areas and dark to gray colour in parts of the town with gentle slopes including in Azezo. In Azezo the soil is clay. The dominant textures identified in this area are silt clay loam and silt clay

Cambisols are a medium and fine texture material derived from a wide range of rock, mostly in alluvial and collivial deposit. They are found in northern and eastern part of the town. It is widely used variety of agriculture and in steep land mainly used for grazing and forestry. Most Cambisols are medium texture and have good structural stability, good water holding capacity and drainage.

Vertisols are heavy clay soil with high proportion of swelling clays and it is hard in dry season and sticky in wet season. It has high water holding capacity. They are found in the southern part of the town. It has 2.5mm/hr infiltration capacity (Mangal, *et al.*, 2016)

Regosols are unconsolidated and finely grained weathering material and they are found in the western part of the town. It is common in arid area, dry tropic and mountainous region and used for capital intensive irrigated farming.

3.1.6 Geology

Termaber basalt is the dominant basalt in Gondar town (Amhara Design and Supervision Works Enterprise). (Gondar tourist master plan study, 2012) shows that the town is sitting on a volcanic plateau of Tertiary Age, mainly basaltic flows which have been deeply eroded to rounded hills except for higher elevations where outcrops of resistant basalt may be seen. According to Amhara Design and Supervision Works Enterprise, Layers of volcanic flows make up the mountains and very few areas are covered by agglomerates and younger tertiary basaltic flows. Alluvial and lacustrine deposits cover the plain areas to the north of Lake Tana including southern parts of Gondar. Volcanic rocks of different nature and condition are observed in the town. Some are massive, mixed with scoria and weathered in some cases. The geology of the town consists of basalts which are black and massive, greenish-brown vascular basalts, boulders and in few areas scoria.

3.2 Study design

The study was done by applied study design. This study was analysed using GIS based MCDA to select suitable solid waste disposal site in the study area. Different data that are used for this study were collected from different organization and satellite image. Different criteria were applied for selecting appropriate solid waste disposal site, in this study slope, geology, soil, ground water depth, LULC of the town and distance to ground water well, surface water, road, airport, fault, historical site and built up area. For each parameter buffer zone has been done and then reclassified map, lists of weight for each criteria and weighted linear combination has been done for locating suitable site for solid waste disposal in Gondar town and the research objective methodology outlined in figure 3-2 below.

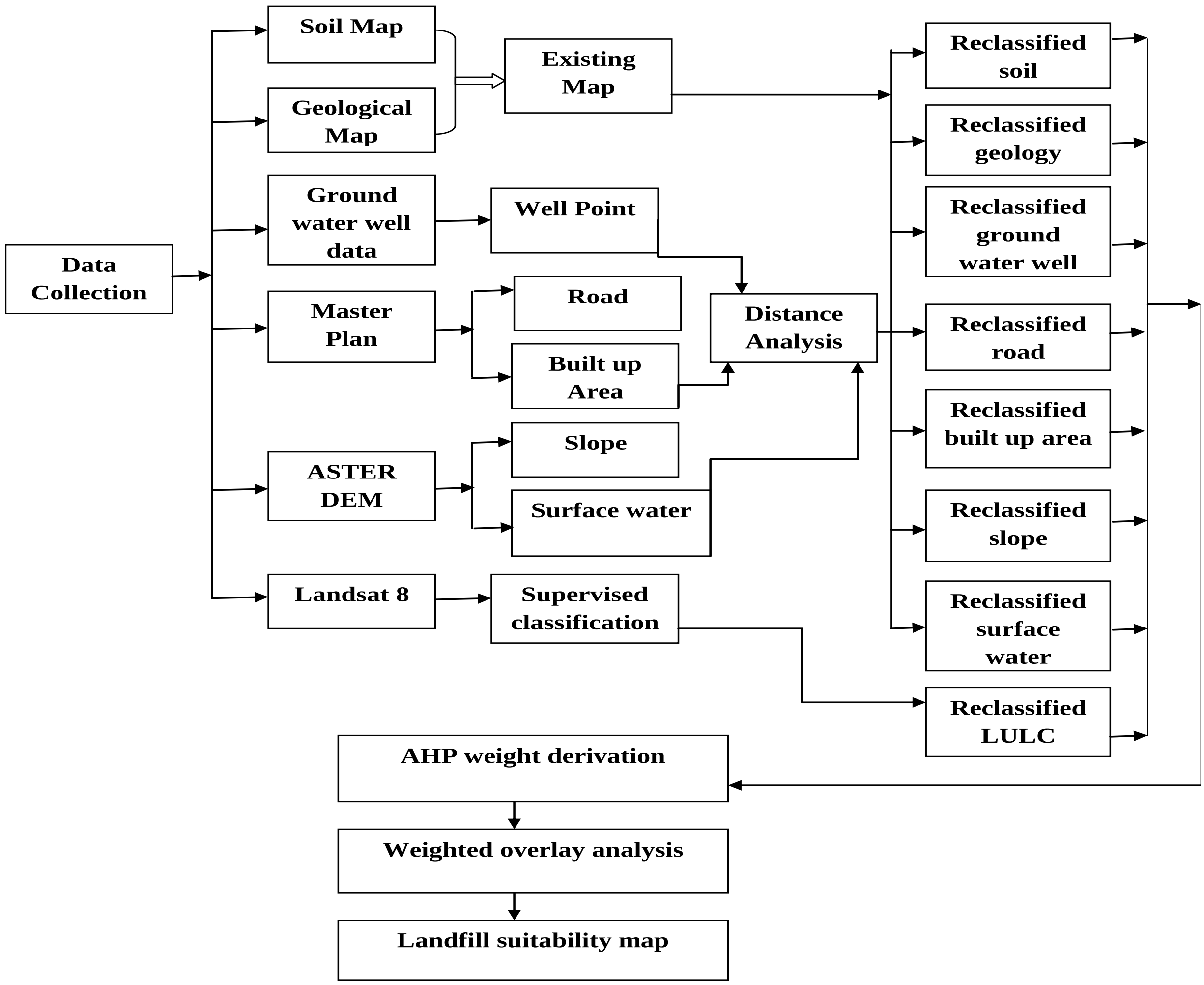

Figure 3-2: Flow chart method

3.3 Study variables

3.3.1 Dependent variable

The dependent variable was response variable or output and which is considered dependent because its value depends upon the value of the independent variable and that directly related on general objective of the study. Therefore, dependent variable of this study was identifying suitable solid waste disposal site.

3.3.2 Independent variable

The independent variable is the variable that is changed or controlled in a scientific experiment to test the effect on the dependent variable that related on specific objective of the study.

Therefore, the independent variables were distance to road, soil, land use land cover, geology, distance to built-up area, distance to historical site, distance to surface water, distance to airport, distance to fault, distance to ground water well, ground water depth and slope.

3.4 Data collection

To perform the objectives primary and secondary data were used Primary data were collected by field survey of study area using GPS and Secondary data was acquired from satellite images and governmental institutions. The data used for this study were Borehole data like ground water well points were collected from urban Water supply, Geological map (2008 G.C) were collected from Geological survey of Ethiopia, Soil map (2013 G.C) were collected from Ethiopia mapping agency, structural plan of study were collected from Gondar zone urban development office. Landsat 8 Operational Land Image (OLI) of February 2018 was acquired for land cover/land-use map of Gondar town and its WRS path was 170, sensor was OLI-TIRS, Cloud 0.59 and totally it had 11 bands. The OLI image is used to determine the available area that can be used as a potential site for sitting the disposal landfill. Likewise, ASTER data was acquired for generating slope of the study area. Both Landsat 8 OLI image and ASTER data (DEM 20x20m resolution) of the study area are acquired from US Geological Survey (USGS).

3.5 Materials and Tools used

Tools/software’s used for this study are ArcGIS 10.4.1 used for digitizing, buffering, reclassifying, overlaying and identifying suitable disposal site, GPS GERMI used for acquire coordinates for LULC map verification and for current landfill site, AHP used for pairwise comparison of matrix and ERDAS imagine 2015 used for classification of LULC map.

3.6 Data analysis and presentation

In this study, an integration of GIS and MCDM method was used to identify appropriate solid waste disposal site areas at Gondar town. GIS and MCDM methods are recommended for siting landfills because they are powerful and integrated tools that are able to solve the problems that arise in landfill site selection (Chabuk, *et al*., 2017).

3.6.1 Criteria for selecting potential landfill site

To identify the best available disposal location, that is a location which meets the requirements of government regulations and minimizes economic, environmental, health, and social cost. Literatures directly related the study along with local regulation for selecting the criteria namely; surface water, slope, geology, built up area, main road, ground water wells, soil, faults, land use land cover, ground water depth, historical site and airport to determine the appropriate location of solid waste landfill site. The above mentioned criteria were classified into two which are environmental criteria (surface water, ground water wells, ground water depth, soil and geology) and socio economic criteria (slope, road, land use, built-up area, historical site and airport). Classifications were carried out on various layers with the assigned value ranging from most suitable to unsuitable and the reclassification were signed 1's, 2's, 3's and 4's ranking system, where 1 refers to unsuitable, 2 low suitable, 3 moderate suitable and 4 highly suitable. These criteria were selected by referring different sources from the literature as indicated above.

3.6.2 Buffering

A buffer is useful for proximity analysis. Buffer is a zone that is drowns around any point, line or polygon that encompasses all of the area within the specified distance of the feature. In landfill site selection it was carried out for generating areas in a given distance around the specified criteria. By referring different researcher, the buffering analysis was carried out for faults, surface water, road networks, airport, built up area, historical site and ground water well.

Table 3-1: Buffering distance for different parameter from different sources

Parameter	Proximity to standard	Sources
Soil type	Clay textured soil (low permeability rate)	Senser (2004) and Ismail *et al*., (2016)
Geology	Impermeable strata and consolidated material (low permeable rate)	Erosy and bulut(2009)
Fault	200m 500m >60m 60-2000m	Eskandari *et al.*,(2015) Sumathi *et al.,(*2008) Erosy and bulut (2009) Allen *et al.*,(2003)
Ground water well	300 – 1000m 400m	Allen *et al.*,(2003) Akbari *et al.,*(2008)
Ground water depth	< 50 m not suitable >50 m most suitable	Ahmad *et al*., (2011) Sumaiya *et al.,(*2014)
Surface water	300-1000m 300m 200m	Allen *et al.*, (2003) EPA (2007) Akbari *et al*., (2008)
Road	300m 500m 60-600m	Akbari *et al.*, (2008) EPA (2007) Allen *et al.*,(2003)
Built up area	500m 500 – 2000m	EPA (2007) Hasan *et al*., (2009)
Historical site	1000 m	Ersoy and Bulut (2009)
Airport	3000m	Kontos *et al*., (2005), World bank (2004) and UNEP (2005)
Slope	> 20 % not suitable > 20 % not suitable	Akbari *et al.*, (2008) Senser *et al.*, (2011)

3.6.3 Assigning weight to evaluation criteria

A weight can be defined as a value assigned to an evaluation criterion indicative of its importance relative to other criteria under consideration (Drobne and Anka, 2009).

AHP is one of the types of MCDM process which was developed by Thomas Saaty in 1980 to standardize the multi-criteria decision-making process. AHP is a multi-objective, multi criteria decision-making technique which was used to assigning weights to all the factors (Olusina and Shyllon, 2014). And it is widely accepted decision making method to assign weights of the selected criteria, which is one of the problems faced during multi-criteria decision analysis because it is a powerful MCDM tool to assign weights and rank the selected sites for selecting the best site among the competent.

Pair wise comparison method is one of the most essential methods in AHP which was proposed by (Saaty, 1980) and many researchers is interested to use pair wise comparison method which is used to determine the relative importance of each alternative in terms of each criterion and it is a powerful method in AHP for assigning weight. It is used to obtain the weights of importance of the decision criteria and the relative performance measures of the alternatives in terms of each individual decision criterion (Evangelos and Stuart, 1995). The weights of criteria have been computed using comparison by using scale values of 1-9 shown in Table 3-2. (Satty, 1998), suggests that the score of 1 is equal importance, 3 is moderate importance, 5 strong, 7 very strong and 9 extreme importance, 2, 4, 6 and 8 are intermediate value and fractions from 1/9 to 1/2 representing importance of one factor against another in the pair.

Table 3-2: Scale for pair wise comparison (Satty, 1998)

Scale of pairwise comparison	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

The first step in AHP is a pair wise comparison matrix is developed after comparing two factors at a time using scale of 1 to 9 illustrated in Table 3-5 below. After construction of pairwise matrix, the second step is calculation of weight which has been derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The higher weight has the great impact on selection of landfill disposal site. The last important in AHP is consistency ratio (CR) which was calculated in order to ensure that the comparison of criteria made by decision makers was consistent. It is calculated by dividing the Consistency Index for the set of judgments by the Index for the corresponding random matrix.

$$CR = \frac{CI}{RI} \qquad (3.1)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (3.2)$$

Where, n is total number of elements being compared. CI is consistency index of a randomly generated pair wise comparison matrix, value of RI varies with no. (Satty, 1998) Suggests that if CR ≤ 0.1, it is acceptable but if CR> 0.1, it is not acceptable.

Table 3-3: Saaty's ratio index for different value of n (Satty, 1998)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56

Based on our expert opinion, two criteria had to be considered at a time and for each comparison it was decided which of the two criteria was most important, and then assigned score was given to show how much more important it is.

To decide which of the one criterion is the most important than others criteria were decided from different journals by taking the average percentage of each factor weights which is illustrated below the Table 3-4 the highest percentage value is the most important factor for this study than others.

Table 3-4: Weight percentages for different criteria

Different journals	Criteria in (%)											
	LULC	GE	SO	GD	GW	SW	SL	F	HS	Bu	RO	AR
Tirusew and Amare,2013	32.1	-	-	-	-	4.93	2.4	-	-	-	7.3	-
Hakan and Fikri, 2009	3.3	7.4	-	-	-	-	8.7	13	1.7	-	5.4	2.3
Ali *et al.*, 2015	7.1	-	9.7	-	-	15.5	4.4	-	-	-	2.6	2.6
Ahmad *et al.*, 2011	-	-	-	5	15	10	10	10	-	-	10	-
Eskadari *et al.*, 2015	20	-	6.7	-	14.4	14.4	-	2.2	-	-	10	-
Sashakkuman and lalwin, 2012	25	22	18	-	-	-	-	-	-	-	-	-
Sumaiya *et al.*, 2014	-	7.5	-	13.3	14.4	13.3	-	6.8	-	-	2.4	1.6
Issa and Shehhi, 2012	-	15	-	15	15	-	10	-	10	-	10	-
Berisa and Birhanu,	-	-	-	-	12	18	-	-	-	20	20	-
Tyowuah and Hundu, 2015	-	-	-	-	-	22.2	-	-	-	16.7	2.78	-
Average	17.5	12.9	11.5	11	14.2	14	7	8	6	18.3	7.83	2.2

Where LULC= land use land cover SW= surface water GW= ground water well GE= geology SO=soil FA= fault RO= road SL= slope AR= airport Bu= built up area GD= ground water depth HS= historical site.

The weight of each factors were assigned based on their importance of criteria based on these the above value of percentage weight from different journals were taken to know which one is the most important factor to others. Therefore, by referring the above journals the order of each factor based on their importance illustrated in Table 3-5.

Table 3-5: Pair wise comparison matrix

Parameter	Bu	LU	GW	SW	GE	SO	GD	F	RO	SL	HS	AR
Bu	1	2	3	3	3	3	5	5	7	7	7	9
LU	1/2	1	2	3	3	3	5	5	7	7	7	9
GW	1/3	1/2	1	2	2	3	3	5	5	5	7	9
SW	1/3	1/3	1/2	1	2	3	3	3	5	5	5	7
GE	1/3	1/3	1/2	1/2	1	2	2	3	5	5	5	7
SO	1/3	1/3	1/3	1/3	1/2	1	2	2	3	3	5	5
GD	1/5	1/5	1/3	1/3	1/2	1/2	1	2	3	3	5	5
F	1/5	1/5	1/5	1/3	1/3	1/2	1/2	1	2	3	5	7
RO	1/7	1/7	1/5	1/5	1/5	1/3	1/3	1/2	1	2	3	3
SL	1/7	1/7	1/5	1/5	1/5	1/3	1/3	1/3	1/2	1	2	3
HS	1/7	1/7	1/7	1/5	1/5	1/5	1/5	1/5	1/3	1/2	1	2
AR	1/9	1/9	1/9	1/7	1/7	1/5	1/5	1/7	1/3	1/3	1/2	1

Where LULC= land use land cover SW= surface water GW= groundwater well GE= geology SO=soil F= fault RO= road SL= slope AR= airport Bu= built up area GD= ground water depth HS= historical site.

Table 3-6: Result of weight for different parameters

Parameters	Weight	Weight (%)
Built up area	0.227	22.7
Land use/cover	0.191	19.1
Ground water well	0.139	13.9
Surface water	0.11	11
Geology	0.09	9
Soil	0.065	6.5
Ground water depth	0.054	5.4
Fault	0.045	4.5
Road	0.027	2.7
Slope	0.023	2.3
Historical site	0.017	1.7
Airport	0.012	1.2
Total	1	100

CR = 0.046< 0.1 it is acceptable

Consistency ratio of the developed matrix is 0.046 which is less than 0.1 therefore it is acceptable reciprocal matrix. The higher weight has high influence for selection of landfill. Hence, for this study built up area and land use land cover have high percentage of weight as shown that indicates they have a great percentage of influence for selection of landfill site as shown in Table 3-6. The weight was analysed to produce weight that sum one

3.6.4 Weighted linear combination

Weighted Linear Combination is a type of Multi Criteria Evaluation Method in GIS environment used to evaluate the suitability of a site for landfill. It is an analytical technique, which is used when there are more than one criteria to be considered based on the content of weighting average (Habiba *et al*., 2018). On the top of that WLC also known as Simple Additive Weighting, which combines maps by applying a standardized score to each class of a certain parameter and a factor weight to the parameters themselves (Drobne and Anka, 2009). Simple additive weighting is defined by the following equation for calculation of final grading values in multi-criteria problems (Saaty, 1980). It multiplies each standardized factor map by its factor weight then sums the results. Based on, this it provides better site selection because of its flexibility in selecting the solid waste disposal sites. The WLC analysis was determined using the following equation.

$$s = \sum wiyi \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3.3)$$

Where *s* is suitability index for the area, *w* is the weight of a criterion, *y* is the score of a criterion and *i* is the criterion number.

In this study, GIS based Multi Criteria Evaluation Analysis was employed. This methodology is best suited for siting suitable landfills accurately in time and cost effective manner and hence it is used by many researchers hence the technique is effective to select suitable disposal site. Appropriate solid waste disposal site selection methodology was carried out through two ways of weighting process. In the first step, each layer was internally weighted based on the minimum and maximum distances and environmental evaluation, excluding unsuitable (restricted) area based on standards and criteria set by national and international environmental acts and rules was identify potential landfill sites and the remaining areas were classified into classes of high and low priority for being used as waste disposal areas. Finally, the layers were standardized and thematic map of each criterion/layer was produced. In the second step each layer was externally weighted based on the fact that how critical and important the data layer is to the waste disposal problem. MCDM which was used for ranking the candidate sites and identify the best site based on the weights assigned to each criterion. After standardization and assigning weight of each criteria, weighted linear combination technique were applied to combine each factors and to prepare landfill suitability map.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Determinants of suitable solid waste disposal site selection

4.1.1 Suitability of geology

Geology is one of the important criteria that should be considered during landfill site selection processes and geological map is obtained from Geological Survey of Ethiopia. On the other hand, Geologic structure that influence the movement of leachate. As mentioned above in literature to minimize the risk of ground water, Impermeable strata and consolidated material are suitable for landfill site as they do not allow movement of leachate. In the study area there are two classes of geological types used for solid waste disposal site selection analysis shown in Figure 4-1. These are Termaber basalt and Marsh soil.

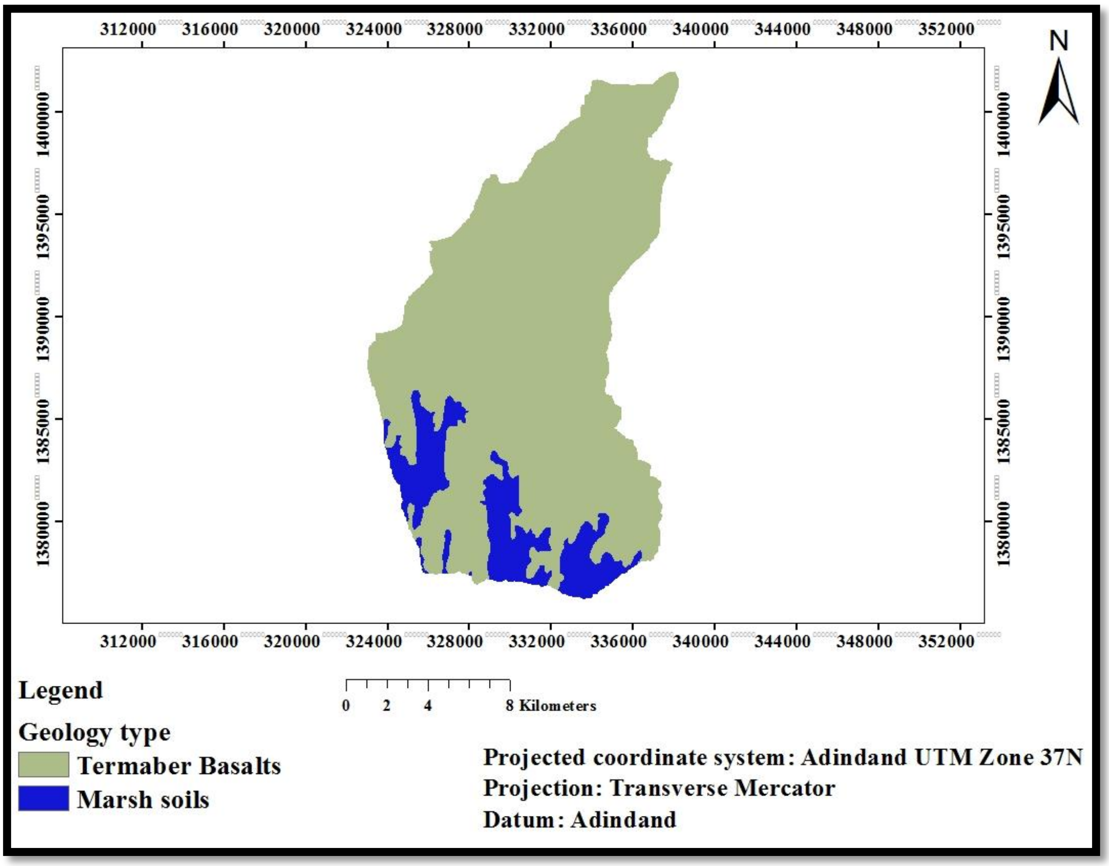

Figure 4-1: Geological map of study area

Table 4-1: Geology type, area coverage and its suitability for disposal sie

Geology type	permeability	Suitability	Rank	Area (km^2)	Area (%)
Termaber Basalts	Low permeable	Highly suitable	4	212	87.6
Marsh soils	Highly permeable	Unsuitable	1	30	12.4

Source attribute table of Arc map

Table 4-1 shows that most part of study area (87.6%) is covered by termaber basalt which is low permeable due to moderate degree of weathering and fractures and it is highly suitable for landfill site and given value 4. The remaining 12.4% of the study area is covered by Marsh soil which is said to be unsuitable and given value 1 because it has high permeability and has high chance to increase the movement of leachate to pollute ground water. Its suitability map shown in Figure 4-2.

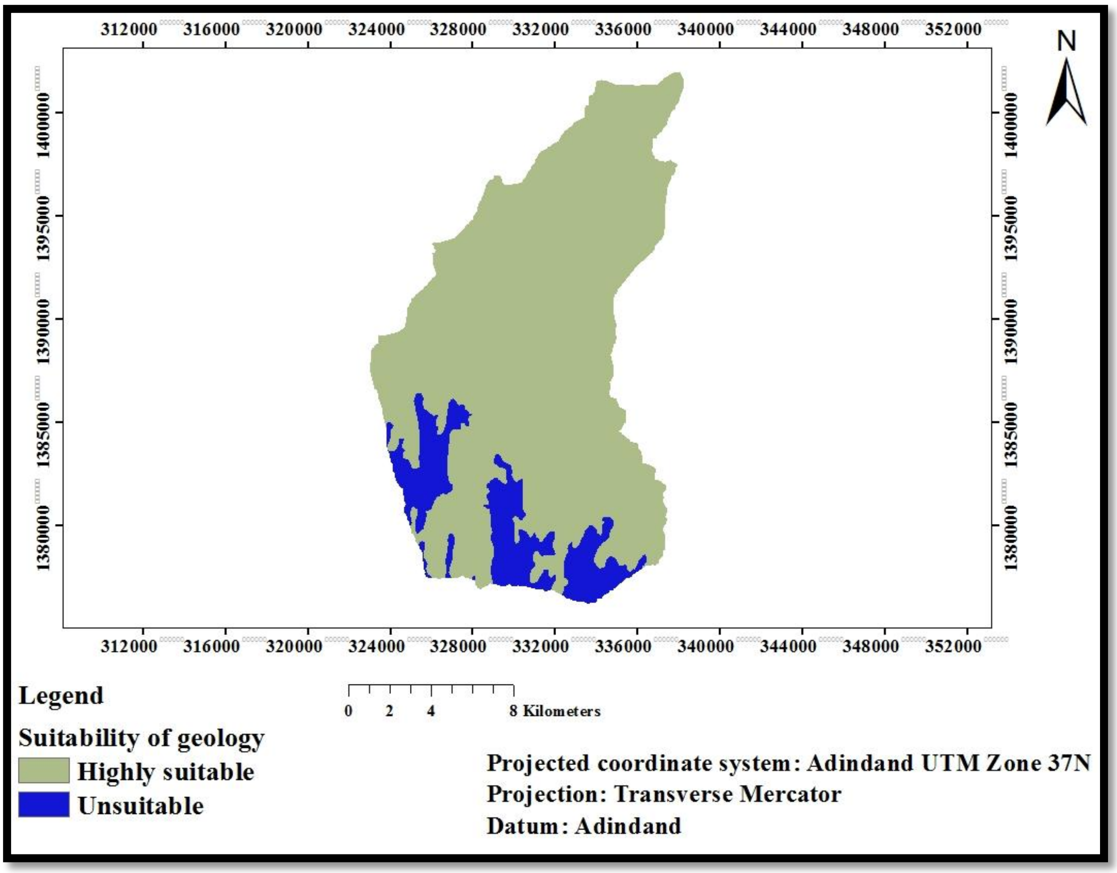

Figure 4-2: Suitability map of geology

4.1.2 Soil suitability

Soil is one of the criteria to select landfill site. Landfill site should not be sited in the area with high permeability soil to minimize the risk of leachate movement.

Therefore, clay-rich environments are most preferable site. Thus, in the study area there are four classes of soil types used for solid waste disposal site selection analysis shown in Figure 4-3. These are Eutric regosols, Eutric cambisols, Chromic vertisols and calcic cambisols.

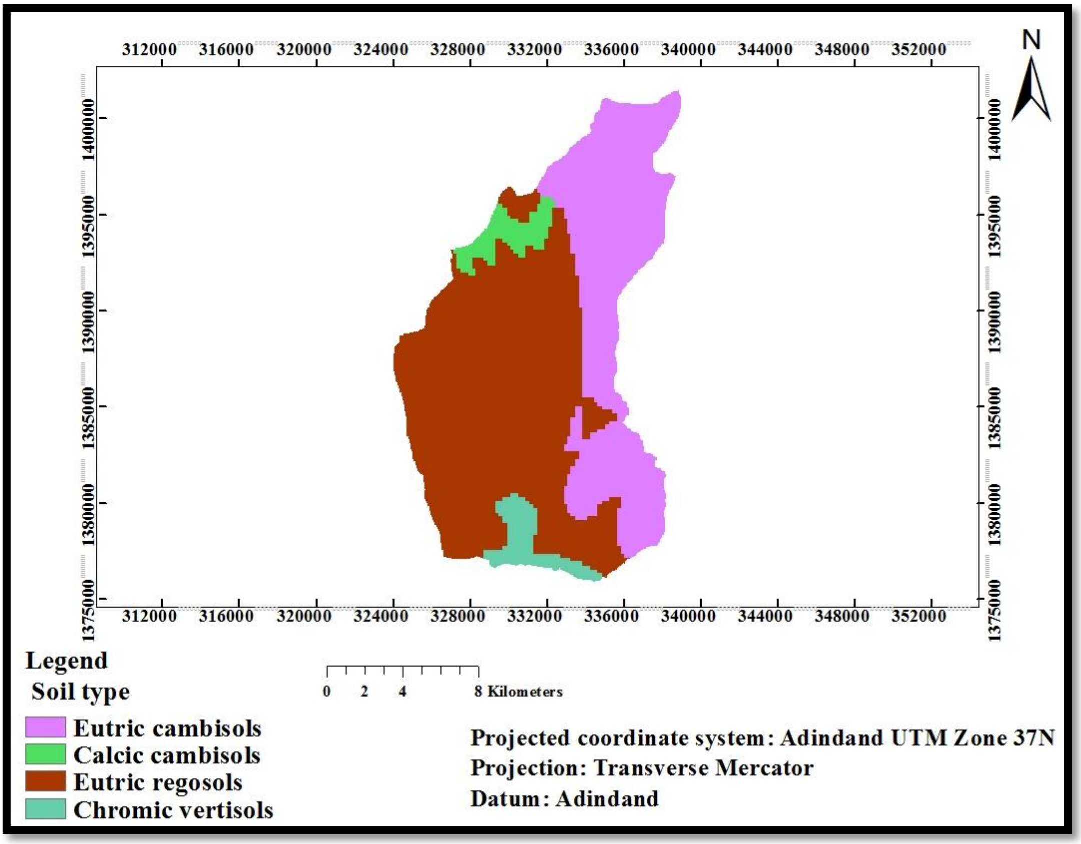

Figure 4-3: Soil map of study area

Table 4-2: Soil type, area coverage and its suitability for disposal site

Soil type	Permeability	Suitability	Rank	Area (km^2)	Area (%)
Eutric regosols	Moderately permeable	Low suitable	2	139	38.8
Eutric and Calcic cambisols	Low permeable	Moderately suitable	3	94	57.5
Chromic vertisols	Very low permeable	Highly suitable	4	9	3.7

Source attribute table of Arc map

Table 4-2 indicates that 38.8% of the study area covered by Eutric regosols which has moderately permeability and ranked number two.The third ranked moderately suitable area covering the 57.5% of the study area and 3.7% of the study area covered by vertisols which is highly suitable areas. Chromic vertisols are clay type of soil that have very low permeability and can control the movement of leachate in ground water therefore it is preferable type of soil for solid waste disposal site. Its suitability map is shown in Figure 4-4.

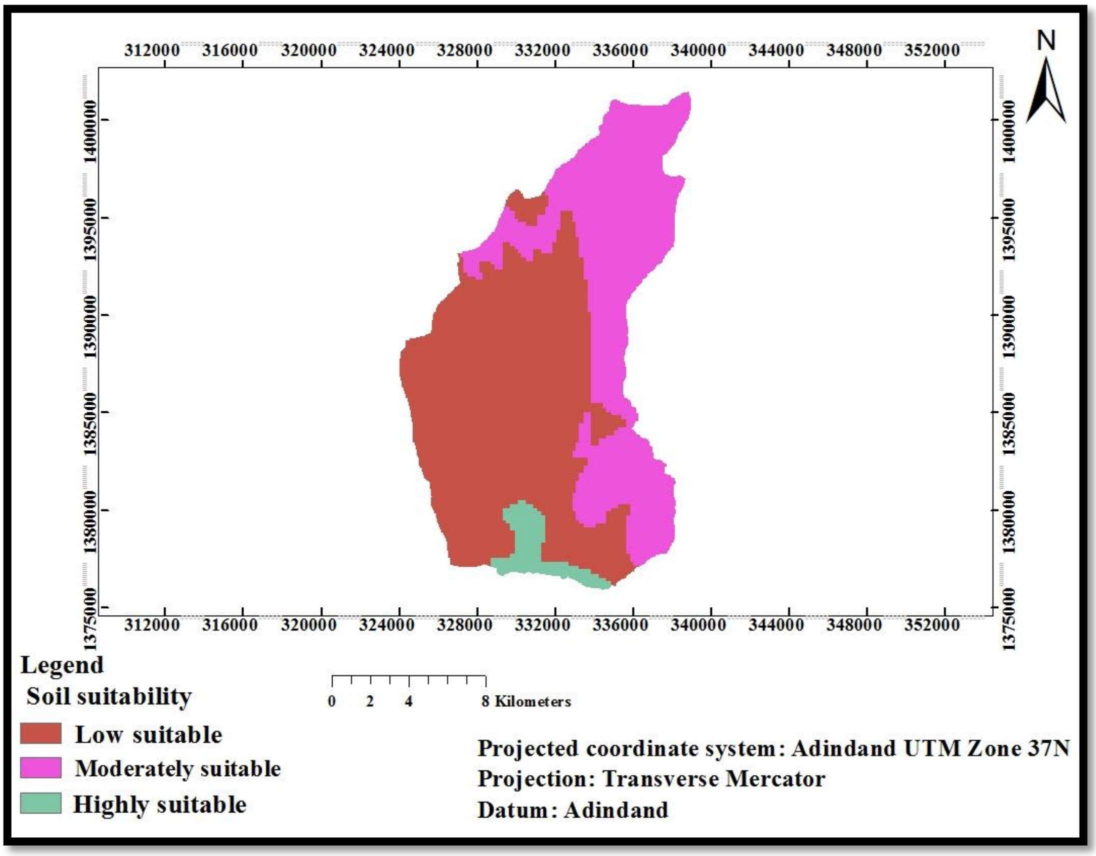

Figure 4-4: Suitability map of soil

4.1.3 Distance to fault

Faults were digitized from the geological map of the study area. It is one of environmental threaten near to landfill site therefore it is safer landfill site placed away from the fault. Fault maps can be used in locating fracture patterns that could control groundwater distribution.Thus the landfill site should be placed away from fault area to control pollution of ground water. Eskandri *et al.* (2015) used 200 m as a minimum buffer distance, Samuthi *et al.* (2007) used 500 m and Allen *et al.* (2003) used 60-2000 m. According to Allen *et al.* (2003), buffer distance of the study area between dedicated site and fault area used 1000m. Multiple ring buffers from analysis tools were used to prepare multiple polygons around each fault line within the following distances: <1000m, 1000-1500m, 1500-2500m and >2500m. Fault and the area < 1000m considered as unsuitable (restricted) and the remained area classified according to their suitability. And its distance classification and ranking was done as suggested above literature and it is illustrated in Table 4-3 and Figure 4-5.

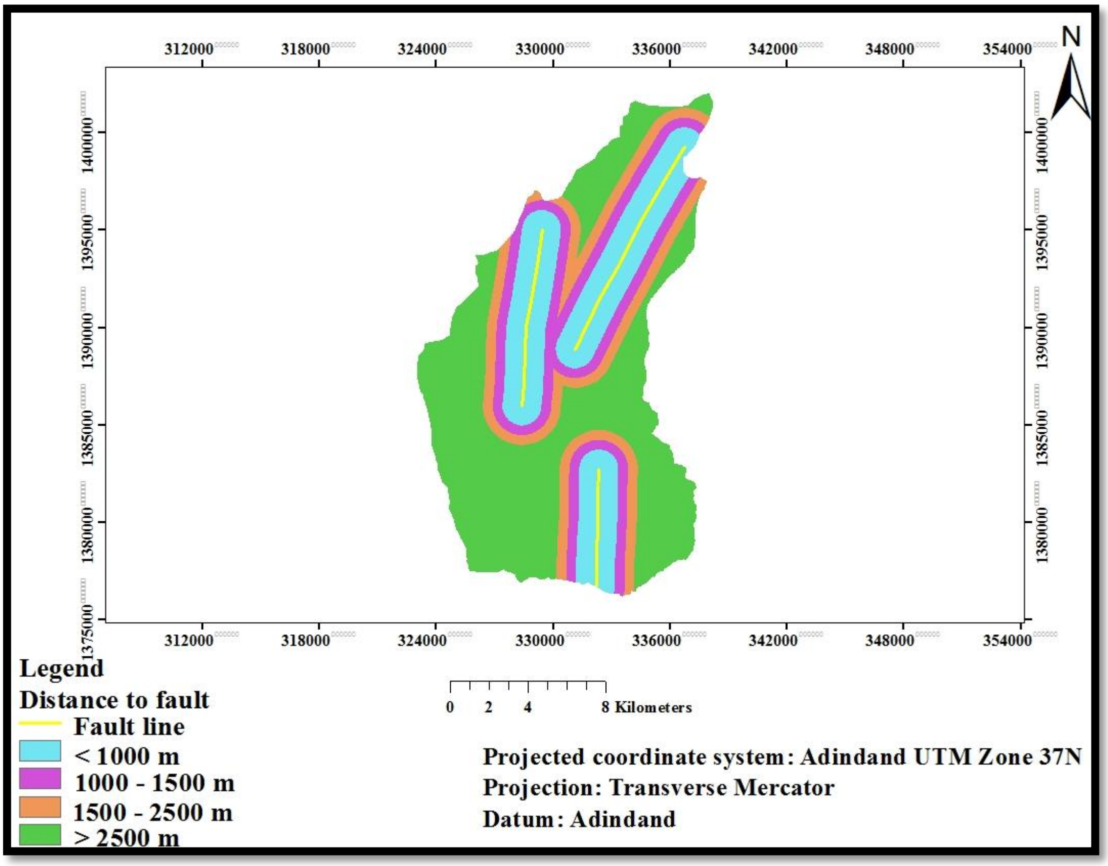

Figure 4-5: Reclassified map of fault

Table 4-2: Distance to fault, area coverage and its suitability for disposal site

Distance (m)	Suitability	Rank	Area (km^2)	Area (%)
<1000	Unsuitable	1	61	25.2
1000-1500	Low suitable	2	35	14.5
1500-2500	Moderately suitable	3	32	13.2
>2500	Highly suitable	4	114	47.1

Source attribute table of Arc map

Table 4-3 indicates that unsuitable area covered 25.2% of the study area and given the value 1 and the second ranked low suitable area covering the 14.5% which was followed by the moderately suitable and highly suitable areas covering 13.2% and 47.1% respectively. Landfill site area beyond 2500m has potential to minimize the risk of pollution of ground water and engineering structures. Suitability map of fault is shown in Figure 4-6.

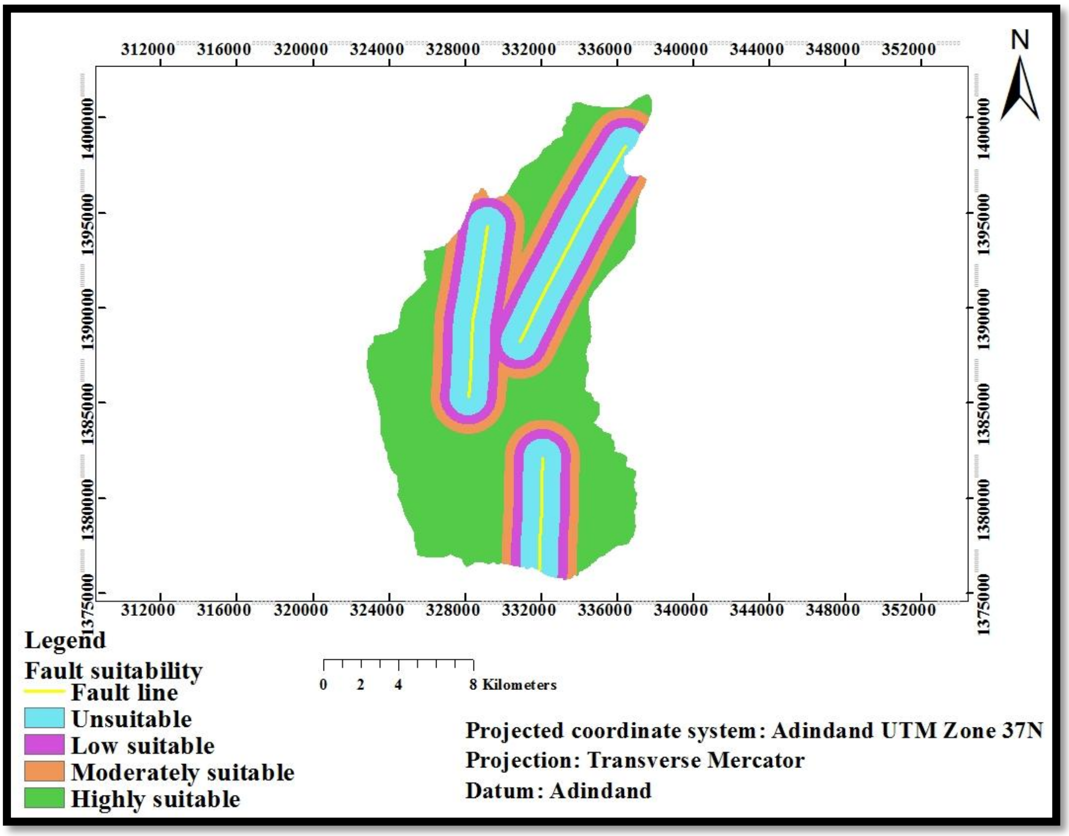

Figure 4-6: Suitability map of fault

4.1.4 Distance to ground water well

Groundwater well is one of the criteria in solid waste disposal site selection and it is one of the main which could be leaching into landfill. As a result, solid waste disposal site should be placed away from the water well. Multiple Ring Buffer tools were used to prepare buffer zones around each well. In order to minimize ground water pollution coming from leachate, different researchers set buffer distance such as Akbari *et al.* (2008) set 400m as a minimum distance and Allen *et al.* (2003) set 300 – 1000 m.According to Allen *et al.* (2003), the present study considered 1000m buffer distance as minimum distance between the landfill site and ground water well to minimize the movement of leachate in ground water. Because the greater the distance from ground water wells the more suitable for landfill site selection. The area was classified into four buffer zones classes: <1000m, 1000-1500m, 1500–2500m and >2500m. Groundwater well and the area within 1000m considered as unsuitable (restricted) and the remained area were classified and ranked according to their suitability with the help of literature review. And the distance classification of ground water well is shown in Table 4-4 and Figure 4-7.

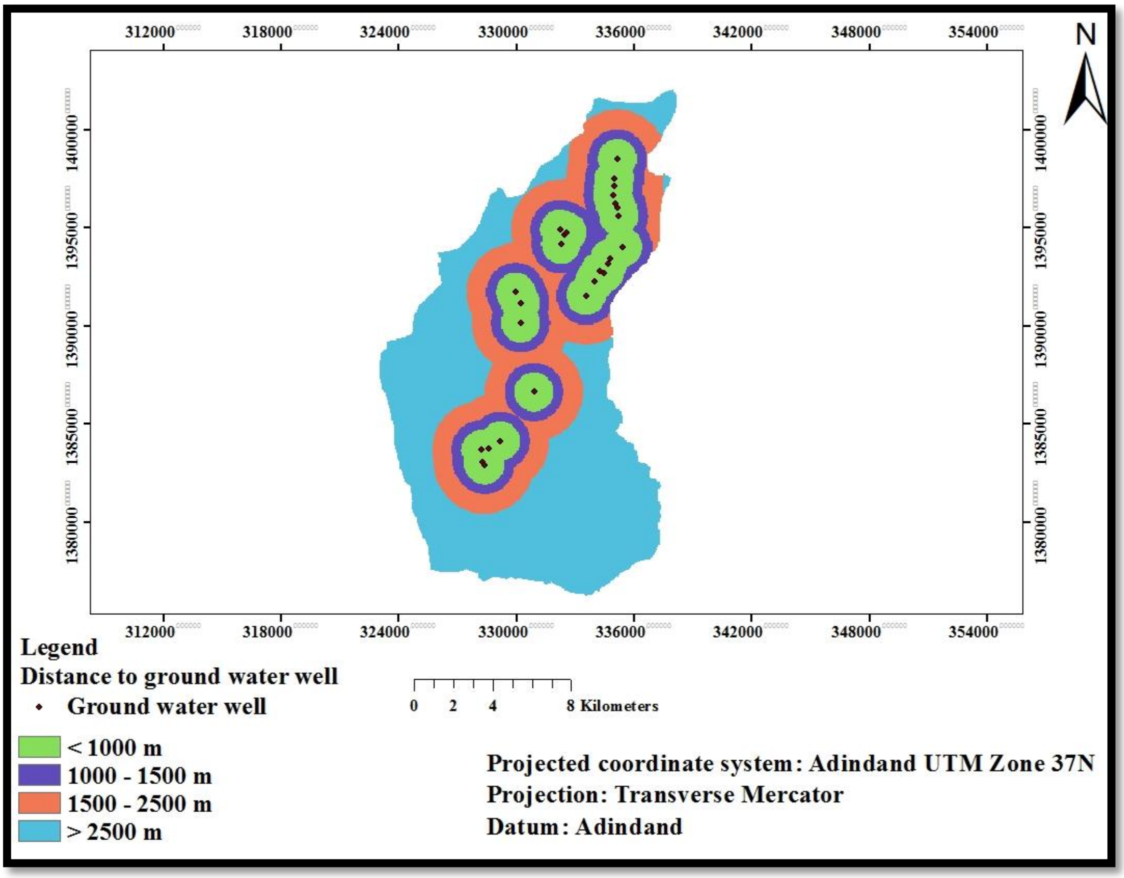

Figure 4-7: Reclassified map of ground water well

Table 4-3: Distance to ground water well, area coverage and its suitability for disposal site

Distance (m)	Suitability	Rank	Area(km^2)	Area (%)
<1000	Unsuitable	1	39	16.1
1000-1500	Low suitable	2	30	12.4
1500-2500	Moderately suitable	3	51	21.1
>2500	Highly suitable	4	122	50.4

Source attribute table of Arc map

Table 4-4 shows that the full coverage of the study area and the area which is said to be unsuitable covered 16.1% which was ranked number one and the second ranked low suitable area covering the 12.4% which was followed by the moderately suitable and highly suitable areas covering 21.1% and 50.4% respectively. The area is above 2500m which covers 50.4% are highly suitable for selection of landfill disposal site to minimize the movement of leachate. The suitability map of groundwater well was illustrated in Figure 4-8.

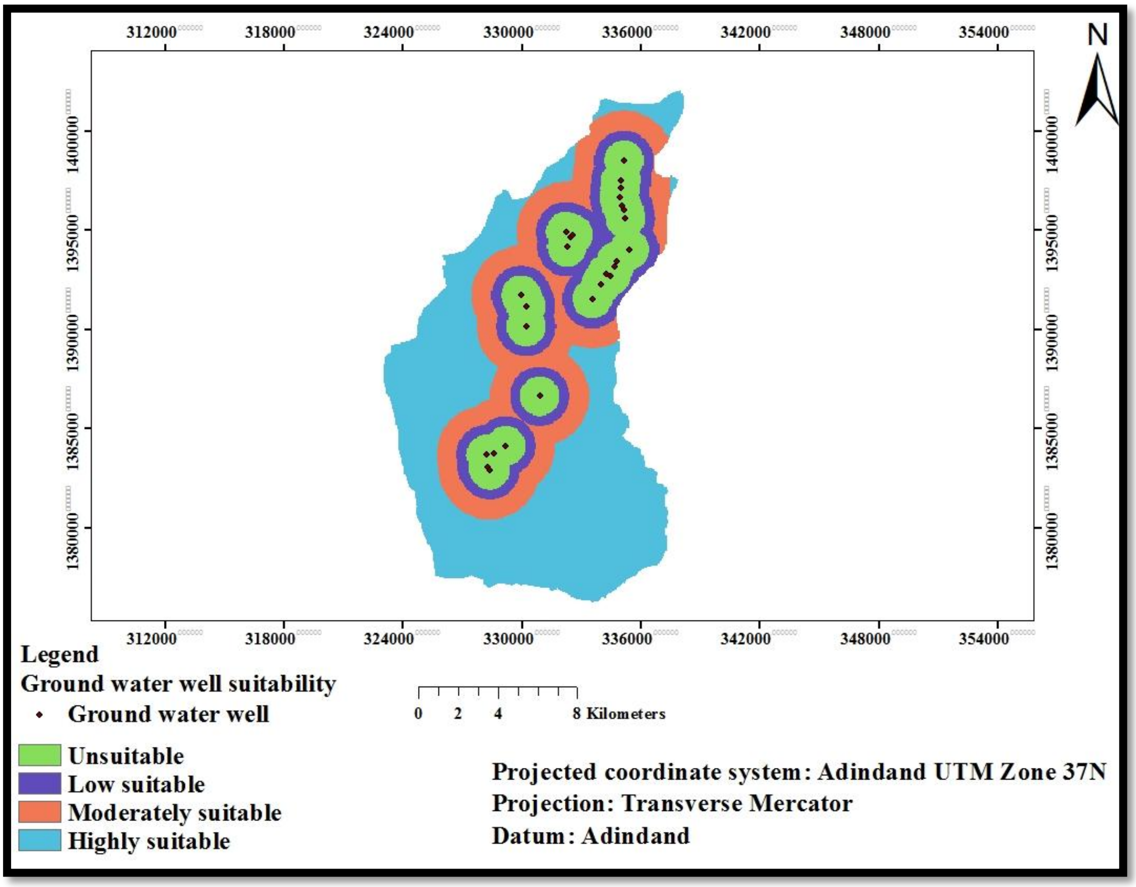

Figure 4-8: Suitability map of ground water well

4.1.5 Ground water depth

It represents the depth to ground surface to water table. To control ground water pollution solid waste should be placed on >50m depth of water table (Ahmad *et al.*, 2011). A high groundwater level has high risk of ground water pollution. Ground water table map was prepared using inverse distance weighting (IDW) interpolation technique of water level data. The data obtained from existing wells in the study area. According to Sener (2004), 10m depth of water table is unsuitable and > 50m depth is suitable for solid waste disposal site. Therefore, for this study 20m depth of water table was used as unsuitable (restricted). The greater depth of water table may decrease the risk of ground water pollution. With the help of literature, the area was classified into four classes: <20m, 20–30m, 30–50m and >50m. The depth classification of water table is shown in Table 4-5 and Figure 4-9.

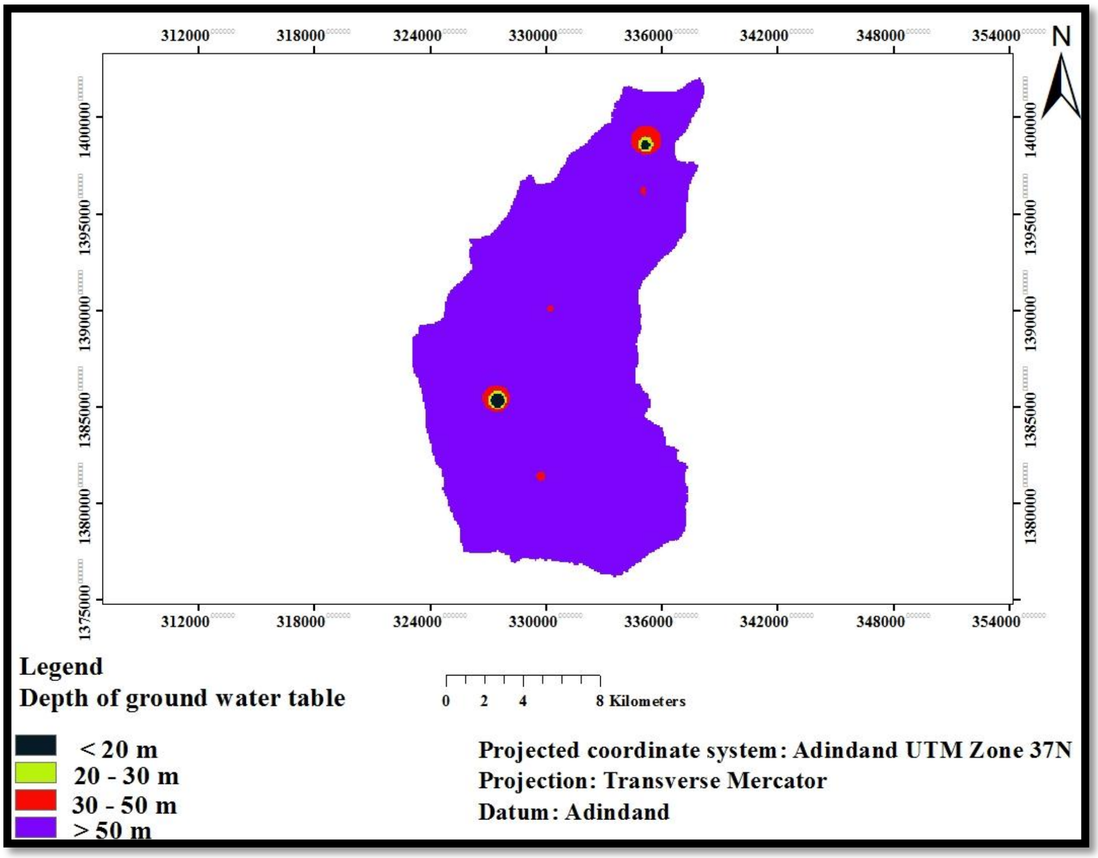

Figure 4-9: Reclassified map of ground water depth

Table 4-4: Ground water depth, area coverage and its suitability for disposal site

Depth (m)	Suitability	Rank	Area (km^2)	Area (%)
<20m	Unsuitable	1	1	0.4
20–30m	Low suitable	2	3	1.2
30–50m	Moderately suitable	3	1	0.4
> 50m	Highly suitable	4	237	98

Source attribute table of Arc map

Table 4-5 shows that 0.4% of the area is unsuitable and given the value 1 and low suitable area covers 1.2% of the study area and given the value 2. The remaining moderately and highly suitable area covers 0.4% and 98% respectively. Most of the study areas are > 50m depth of water table therefore that is suitable for landfill site selection.

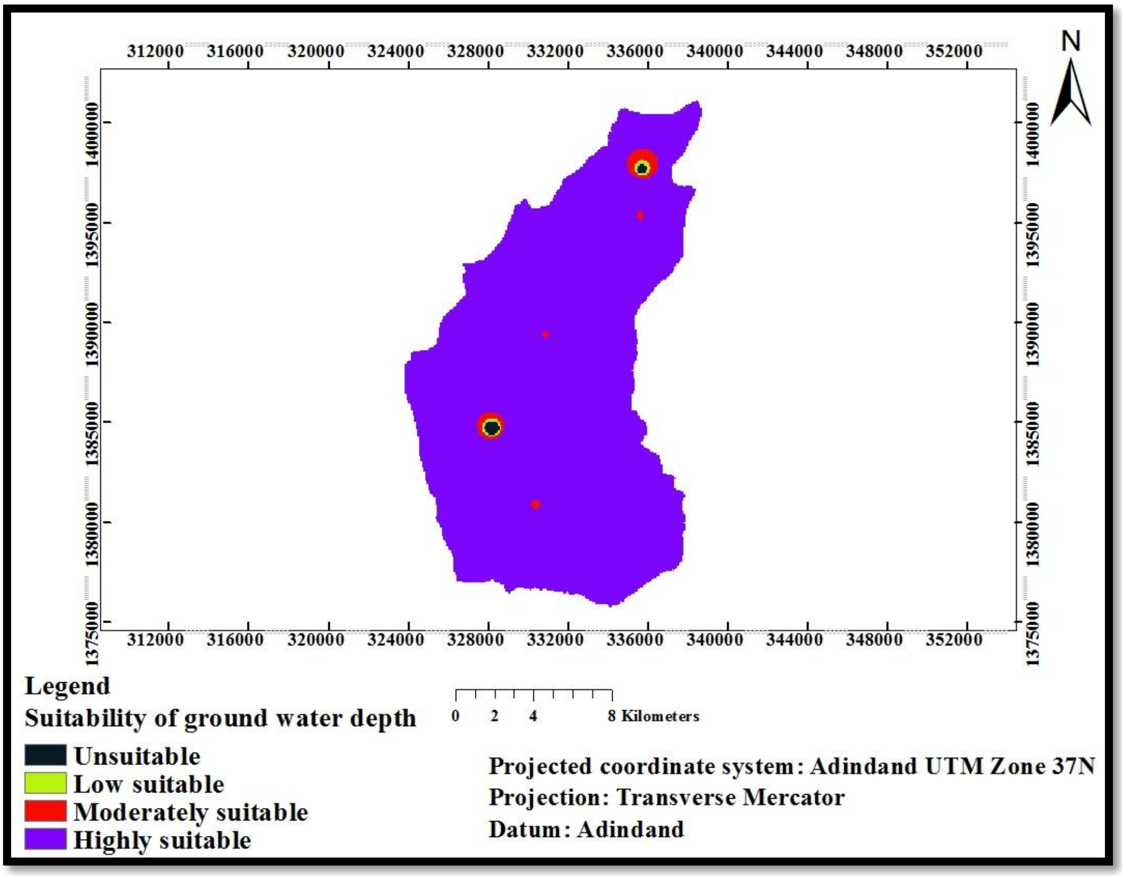

Figure 4-10: Suitability of ground water depth

4.1.6 Distance to surface water

Keha, Angereb, Shinta and Dimaza rivers are found in this town that are the tributaries of Megech river and Lake Tana. Keha and Angereb rivers are found in north western and north eastern direction of the town. Currently Keha river used for urban agriculture and Angereb river used for drinking water for the town. There are several small streams originating from the mountains and hills surrounding the town. Landfill should not be located near to surface water sources in order to protect this surface water from pollution, Therefore, to minimize such pollution, Akbari *et al.* (2008) used 200 m as a minimum distance, EPA (2007) used 300 m and Allen *et al.*, (2003), used 300–1000 m. According to Allen *et al.* (2003), for this study 500m buffer distance was used as a minimum distance. Multiple ring buffers from analysis tools were used to prepare multiple polygons around each streams and rivers within the following distances: <500m, 500-1000m, 1000-2000m and >2000m. Surface water and the area within 500m considered as unsuitable (restricted) and the remained area classified according to their suitability. Distance classification and the rank of surface water as suggested in literature are illustrated in Table 4-6 and Figure 4-11. The more distance from surface water, the more suitable for landfill sitting to reduce pollution of surface water.

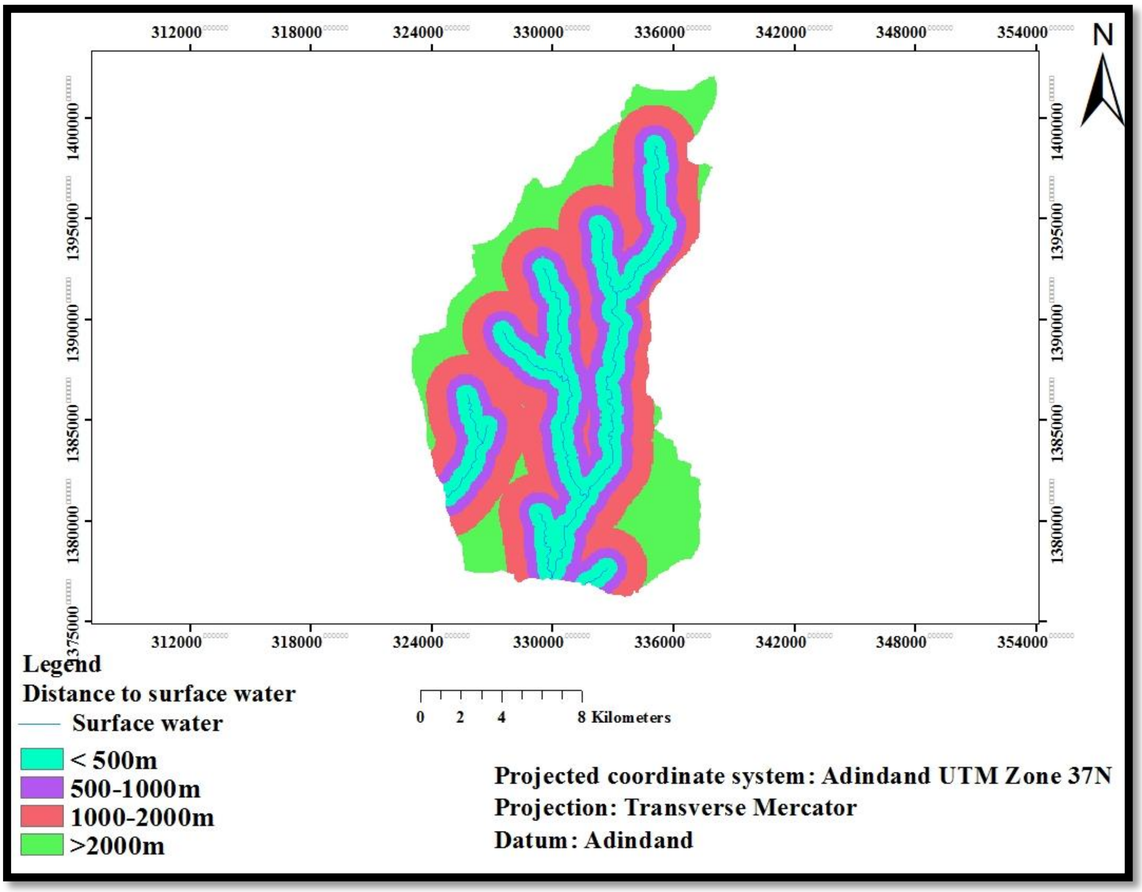

Figure 4-11: Reclassified map of surface water

Table 4-5: Distance to surface water, area coverage and its suitability for disposal site

Distance (m)	Suitability	Rank	Area(km^2)	Area (%)
<500	Unsuitable	1	58	24
500-1000	Low suitable	2	54	22.3
1000-2000	Moderately suitable	3	78	32.2
>2000	Highly suitable	4	52	21.5

Source attribute table of Arc map

Table 4-6 indicates that unsuitable area covered 24% of the study area and given value 1 and low suitable area covering 22.3% of the study area and given the value 2. The remaining areas are moderately and highly suitable areas covering 32.2% and 21.5% respectively. The area beyond 2000m which covered 21.5% is highly suitable for selection of landfill site to minimize the risk of pollution of surface water. The map of suitability of surface water is shown in Figure 4-12.

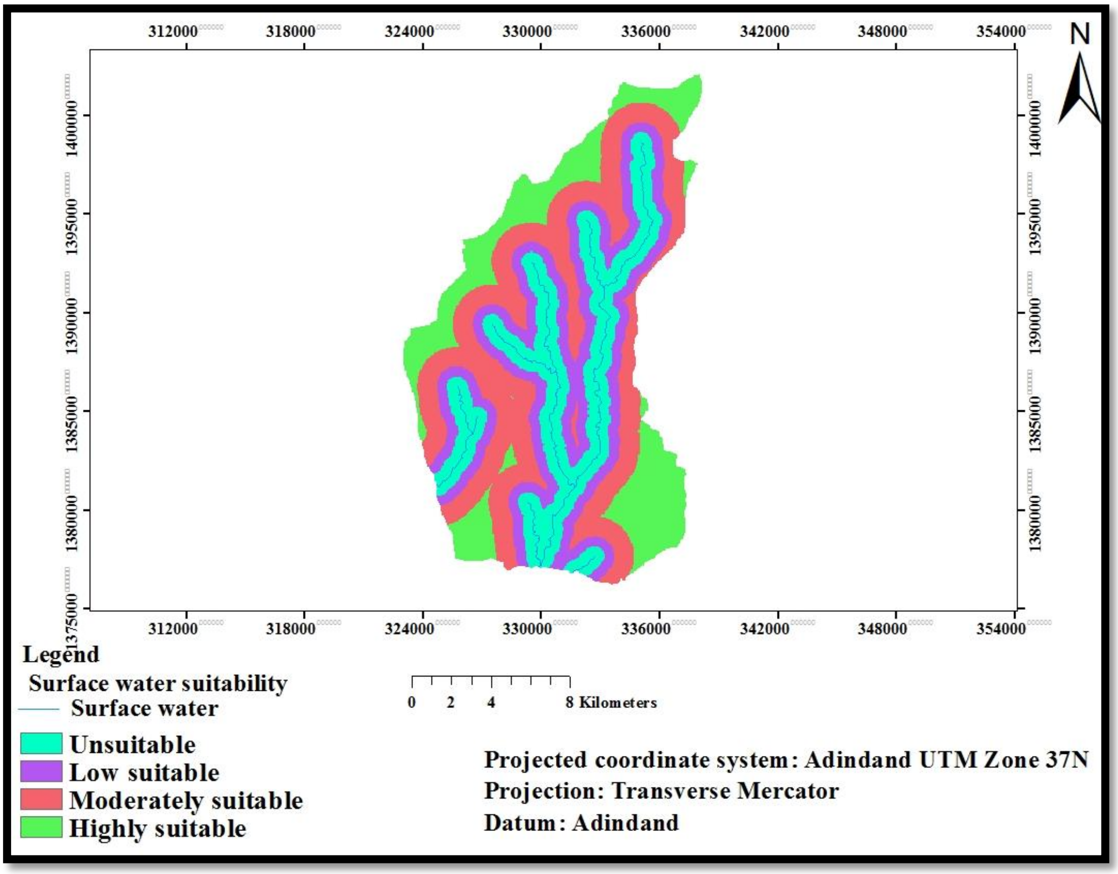

Figure 4-12: Suitability map of surface water

4.1.7 Land use land cover

Land use/Land cover is one of the criteria used to select suitable sites for solid waste disposal in the town of Gondar. The land use/land cover of the study area classified into five classes such as forest and agricultural land, bare land and grass land, built up and water body clearly shown in Figure 4-13. Their suitability is classified according to Kontos *et al.* (2005), water bodies, ponds and swampy area are reclassified as unsuitable, built up areas are reclassified as low suitable, agricultural and forest lands are reclassified as moderately suitable and bare land and grasslands are reclassified as highly suitable.

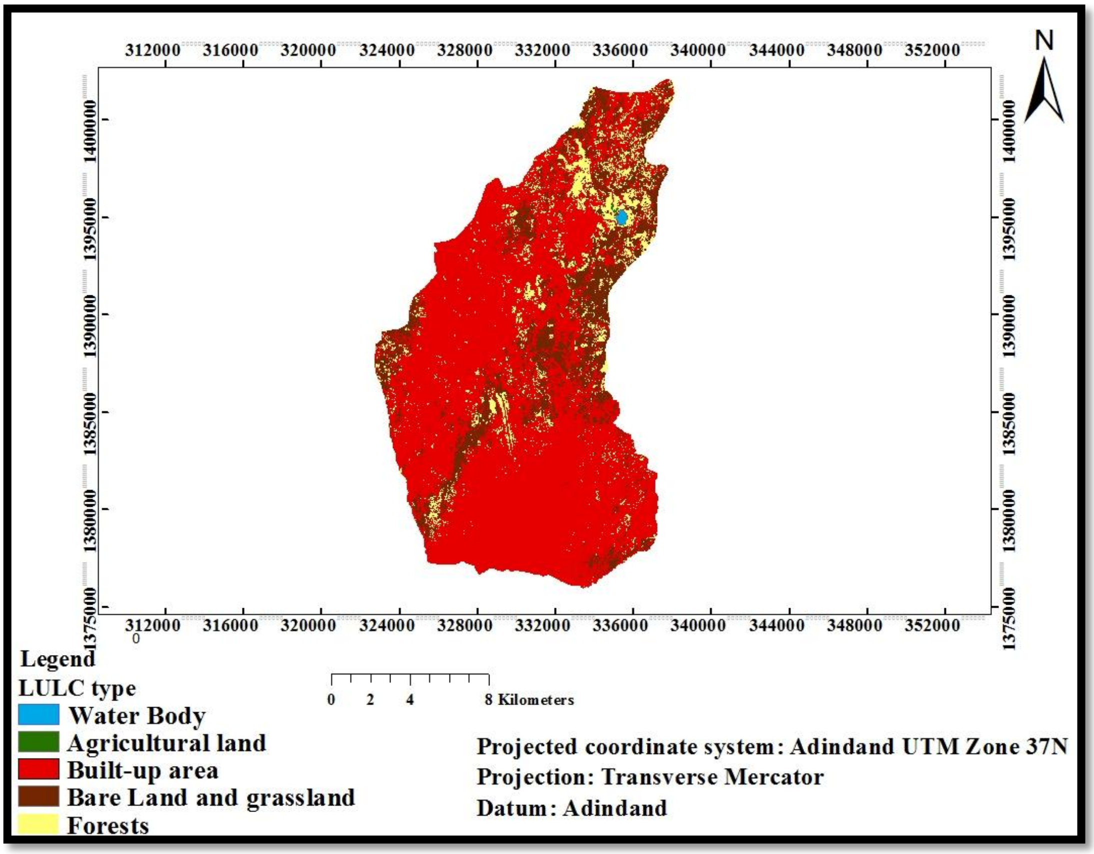

Figure 4-13: LULC map of study area

Table 4-6: Land use type, area coverage and its suitability for disposal site

LULC type	Suitability	Rank	Area(km^2)	Area (%)
Water body and built up area	Unsuitable	1	182	75.2
Agricultural area and forest	Moderately suitable	3	19	7.8
Bare land	Highly suitable	4	41	17

Source attribute table of Arc map

Table 4-7 shows that the area which is covered 75.2 % said to be unsuitable and given value 1 and moderately suitable and highly suitable areas covering 7.8% and 17 % respectively. To prevent public health and pollution of surface and ground water built up area and water bodies are unsuitable for best selection of disposal site. Suitability map of LULC is shown in Figure 4-14 from high suitable to unsuitable.

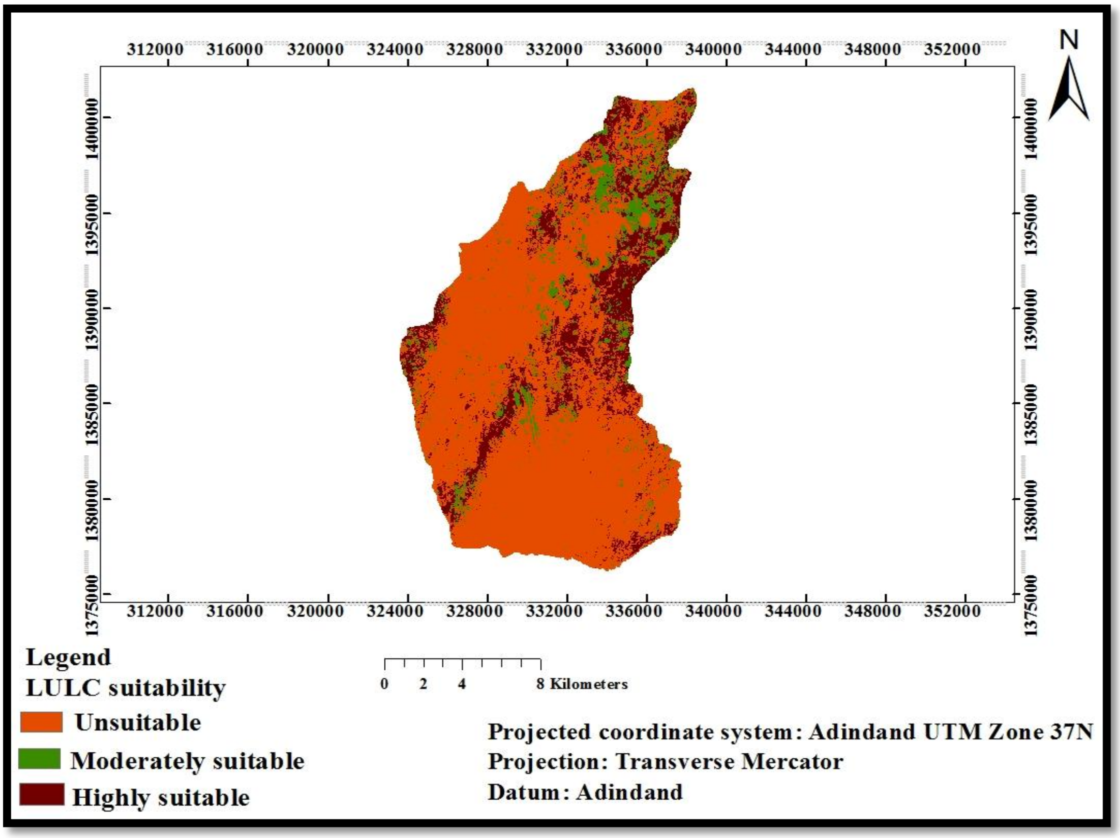

Figure 4-14: Suitability map of LULC

4.1.8 Slope suitability

Slope is one of the key criteria in landfill sitting. DEM (20*20m) resolution was generated and used to derive slope. The area which have high slope is not good for solid waste disposal and >20% is not suitable (Akbari *et al.*, 2008) and (Senser *et al.*, 2011). To minimize erosion, water runoff and for easier construction of the site, a low slope is required. Thus according to Akbari *et al*. (2008) and Senser *et al*. (2011), slope of the land with 0-10% highly suitable, 10-15% moderately suitable, 15-20% low suitable and >20% unsuitable. It is classified and ranked into four classes as suggested above in literature and their percentage classifications are shown in Table 4-8 and Figure 4-15.

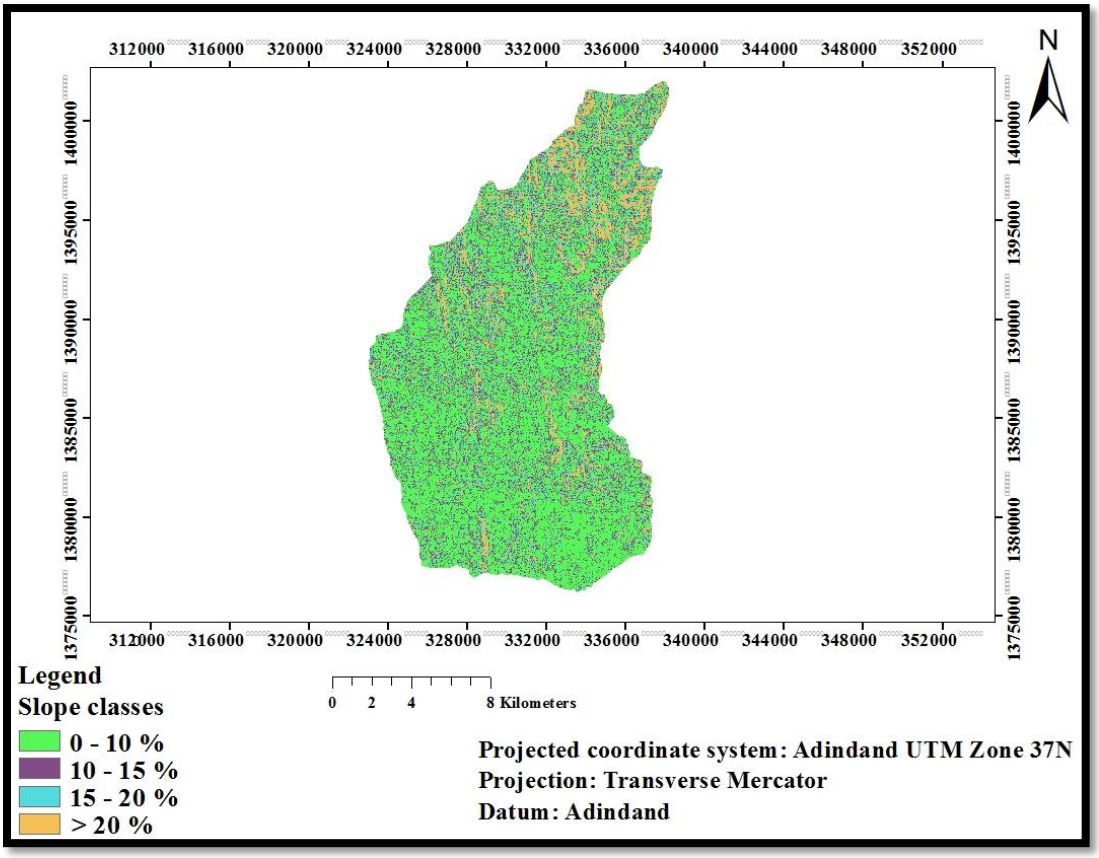

Figure 4-15: Reclassified map of slope

Table 4-7: Slope percentage, area coverage and its suitability for disposal site

Slope percentage	Suitability	Rank	Area (km^2)	Area (%)
< 10 %	Highly suitable	4	140	57.8
10 – 15 %	Moderately suitable	3	52	21.5
15 – 20%	Low suitable	2	26	10.7
>20%	Unsuitable	1	24	10

Source attribute table of Arc map

Table 4-8 indicates that the unsuitable area covered 10% of the study area and given the value 1because it is steep slope that increases the costs of construction of landfill and the second ranked low suitable area covering the 10.7% which was followed by the moderately suitable and highly suitable areas covering 21.5% and 57.8% respectively. The area <10% that covers 57.8% is highly suitable for selection of landfill site to minimize the cost of landfill construction and most of the land of the study area is suitable for disposal of waste selection.

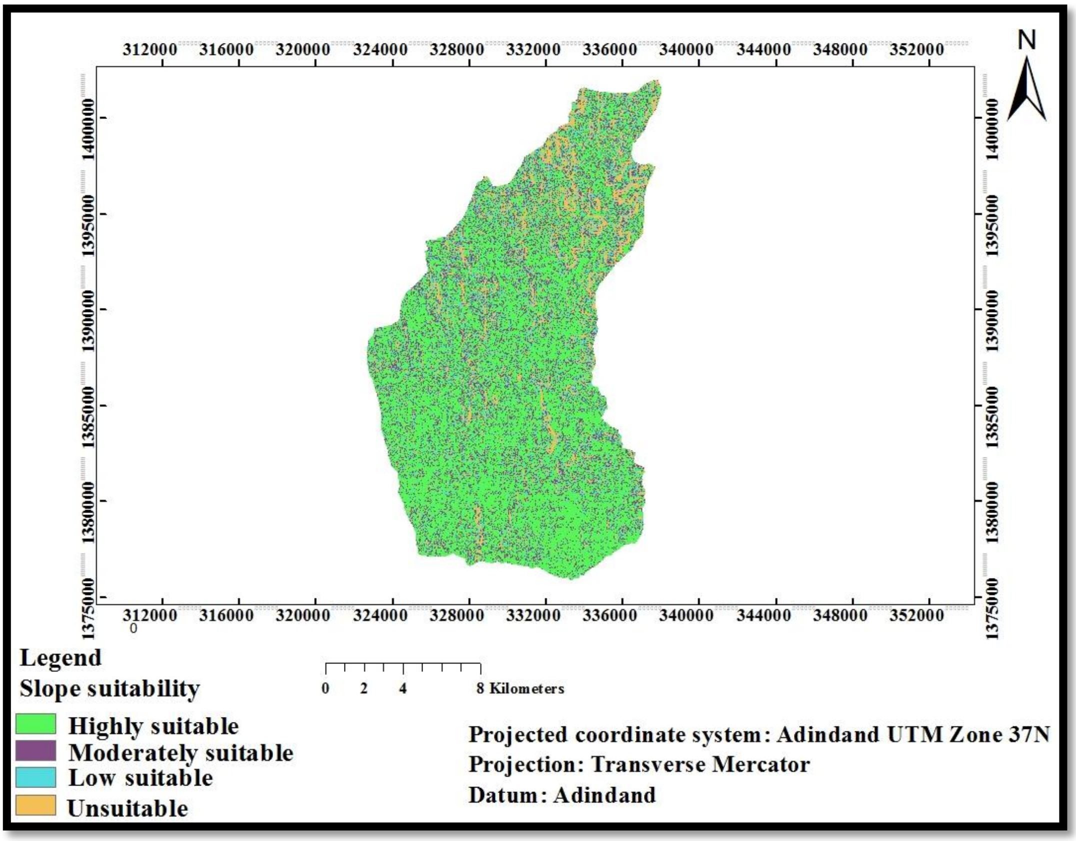

Figure 4-16: Suitability map of slope

4.1.9 Distance from road networks

Landfill sites should not be located too far away from road causes that will increase costs significantly and also should not be near to the road that might cause odour and environmental pollution. To prevent the public health and minimize the cost of transportation, EPA (2007) areas below 500m and above 5000m from highway were considered as unsuitable and Allen *et al*. (2003) used 60–600m buffer distance. Therefore, according to Allen *et al.* (2003) and EPA (2007), 500m buffer distance considered for this study as restricted distance. However, based on the effect of waste transportation and public health; the area was classified into four buffer zones classes: <500m, 500 – 1000m, 1000 – 1500m and >1500m. Road and the area within 500m considered as unsuitable (restricted) and the remained area classified according to their suitability.Distance classification of road is illustrated in Table 4-9 and Figure 4-17.

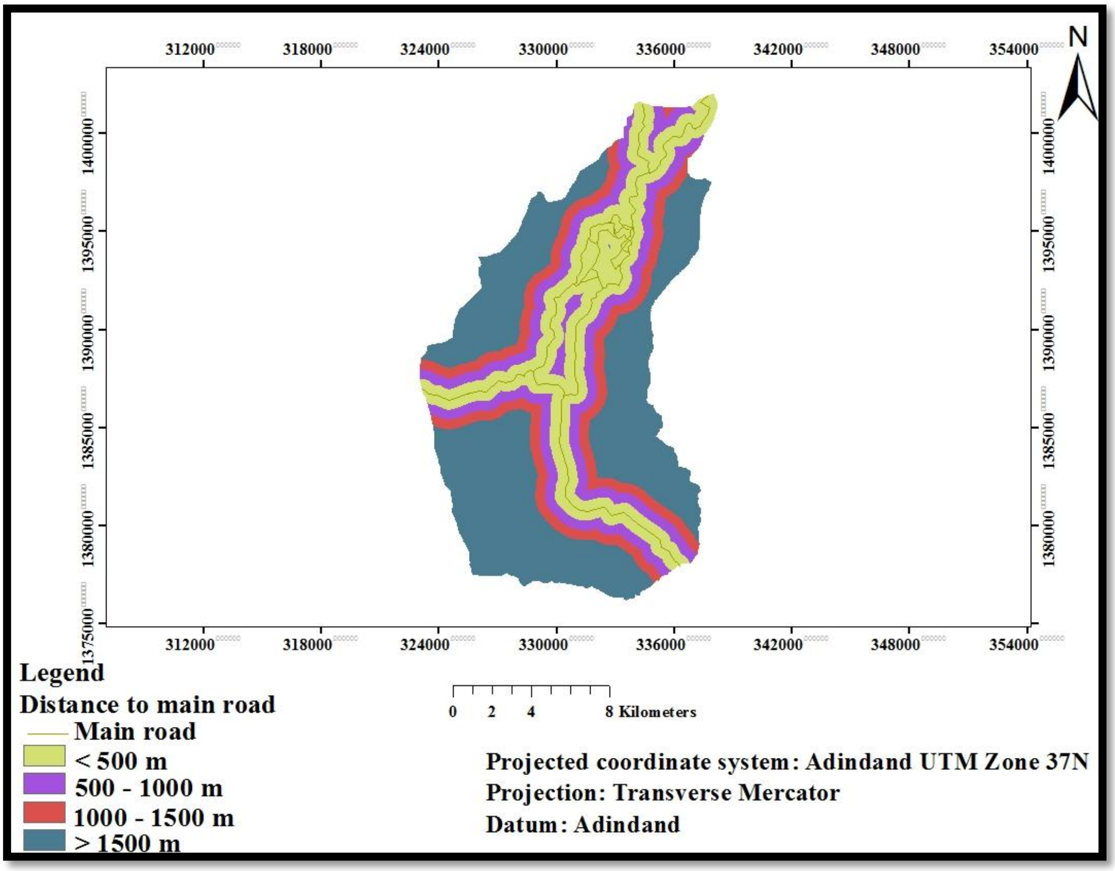

Figure 4-17: Reclassified map of road

Table 4-8: Distance to road, area coverage and its suitability for disposal site.

Distance (m)	Suitability	Rank	Area (km^2)	Area (%)
<500	Unsuitable	1	58	24
500-1000	Low suitable	2	38	15.7
1000-1500	Moderately suitable	3	31	12.8
>1500	Highly suitable	4	115	47.5

Source attribute table of Arc map

Table 4-9 indicates that unsuitable area covered 24% of the study area because it has an adverse effect of public health and that was given number one value and low suitable area covering the 15.7% of the study area and given value 2. The remaining areas are moderately suitable and highly suitable areas covering 12.8% and 47.5% respectively.

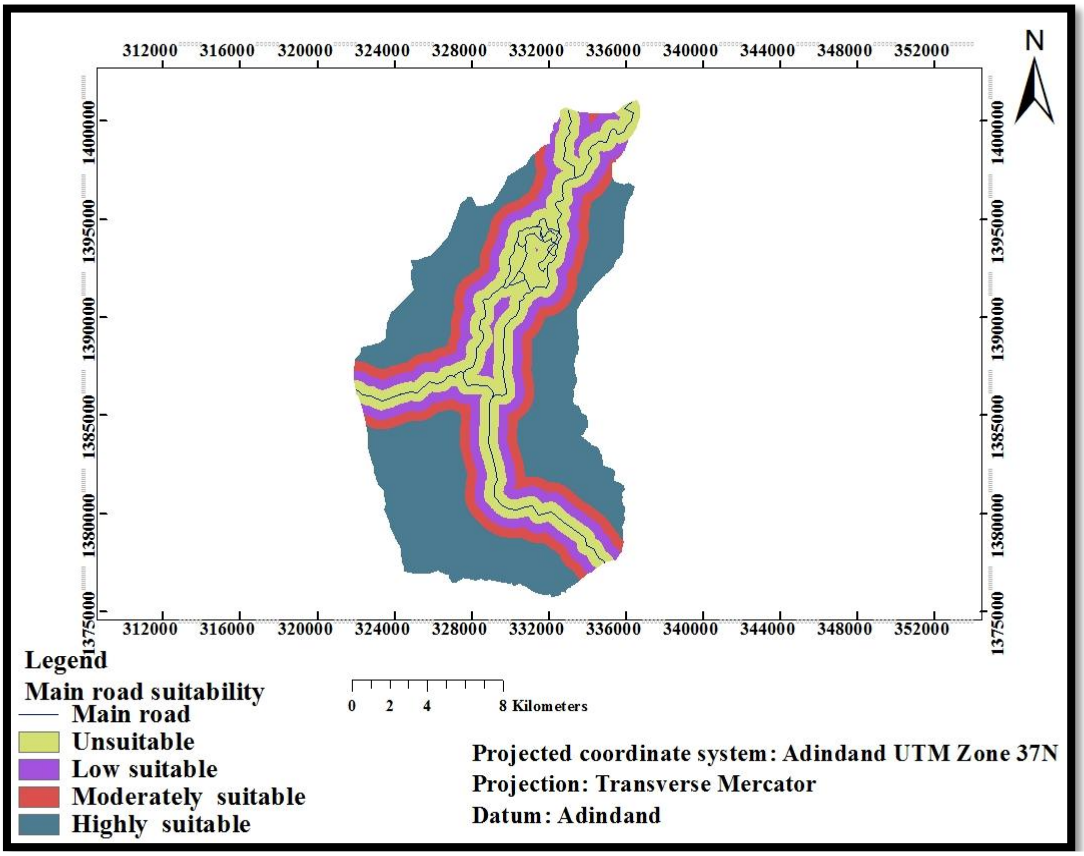

Figure 4-18: Suitability map of road

4.1.10 Distance to built-up area

Solid waste disposal sites should not be located near to the people, since they might cause different types of pollution. Built up area includes commercial areas, governmental and private institutions, schools, health-centres, religious institutions, educational institutions, residential area and other social services area. The greater the distance from residential areas the more suitable for landfill site selection, according to EPA (2007), set a built up distance 500 m as a minimum buffer distance and Hasan *et al.* (2009) set 500 – 2000m. To control the effects of public health and aesthetic value of the land the area was classified into four classes: <500m, 500-800m, 800-1000m and >1000m. The built up area within 500m considered as unsuitable (restricted) and the remained area classified and ranked according to their suitability with the help of literature review. The distance classification of built up area is shown in Table 4-10 and Figure 4-19.

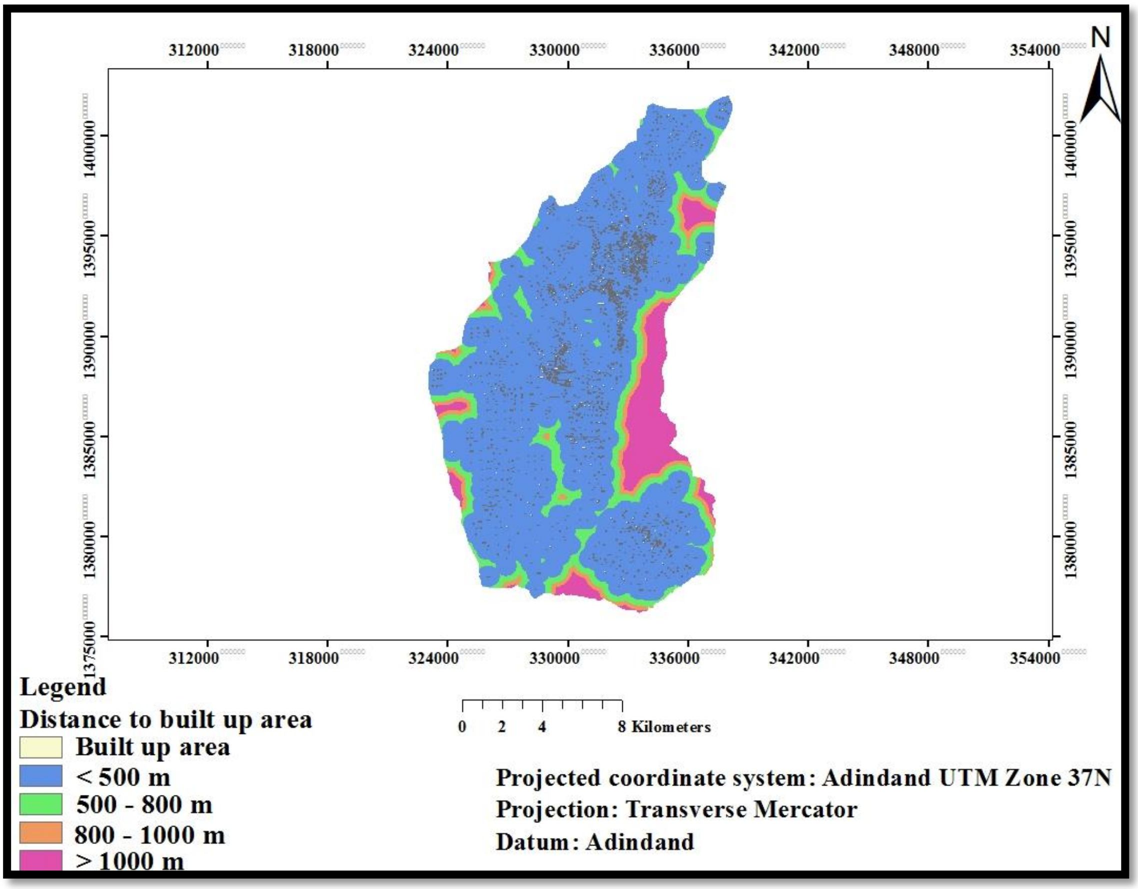

Figure 4-19: Reclassified map of built up area

Table 4-9: Distance to built-up area, area coverage and its suitability for disposal site

Distance (m)	Suitability	Rank	Area(km^2)	Area (%)
<500	Unsuitable	1	189	78.1
500-800	Low suitable	2	25	10.3
800-1000	Moderately suitable	3	9	3.7
>1000	Highly suitable	4	19	7.9

Source attribute table of Arc map

Table 4-10 shows that unsuitable area covered 78.1 % of the study area and given value 1and low suitable area covered 10.3 % of the study area and given the value 2 and the remaining areas are moderately suitable and highly suitable areas covering 3.7 % and 7.9% respectively. The area that above 1000m which covers 7.9% is highly suitable for selection of landfill site to minimize the risk of pollution of environment and public health.

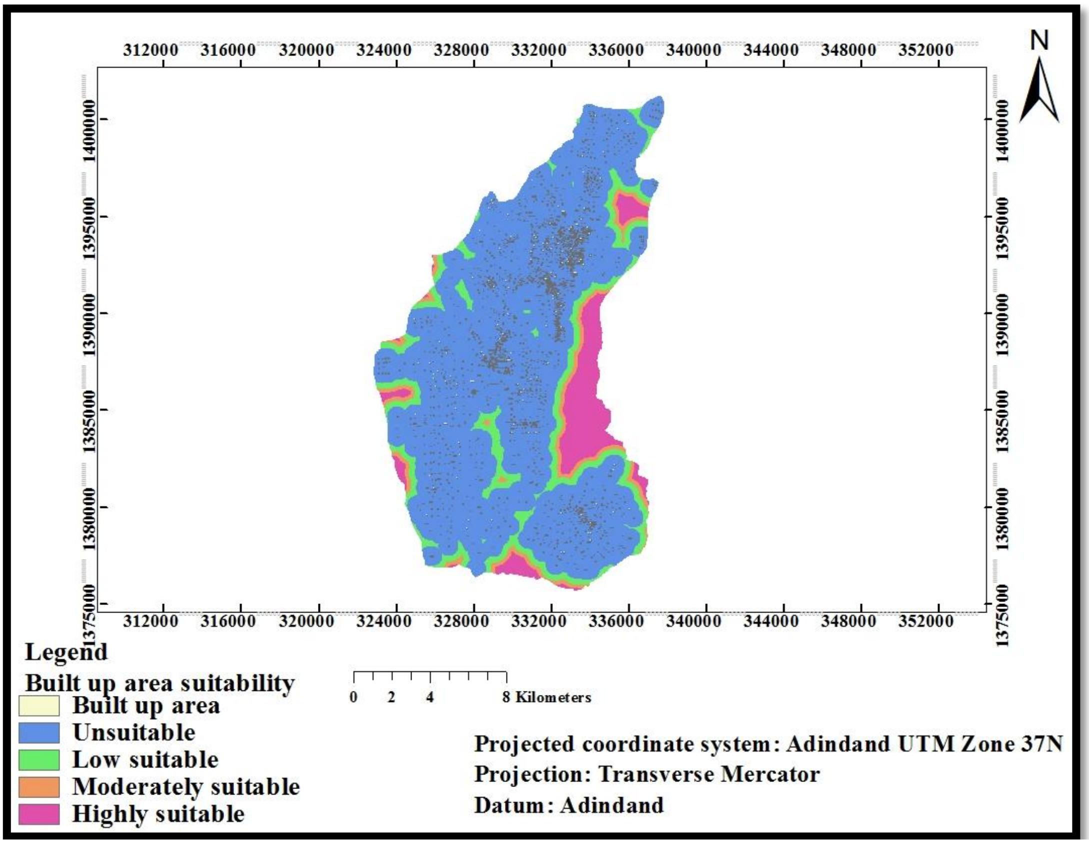

Figure 4-20: Suitability map of built up area

4.1.11 Distance to historical site

Historical site of the study areas are Fasil castle and Fasil bath. Landfill should not be located near to historical sites. According to Hakan and Fikri (2009), the distance greater than 3000 m from the site selected as highly suitable for solid waste dumping site and less than 1000m from the disposal site considered as unsuitable. The area was classified into four classes <1000 m, 1000-2000 m, 2000-3000 m and >3000 m. The historical site within 1000 m considered as unsuitable (restricted) and the remained area classified and ranked according to their suitability with the help of literature review. The distance classification of historical site is shown in Table 4-11 and Figure 4-21.

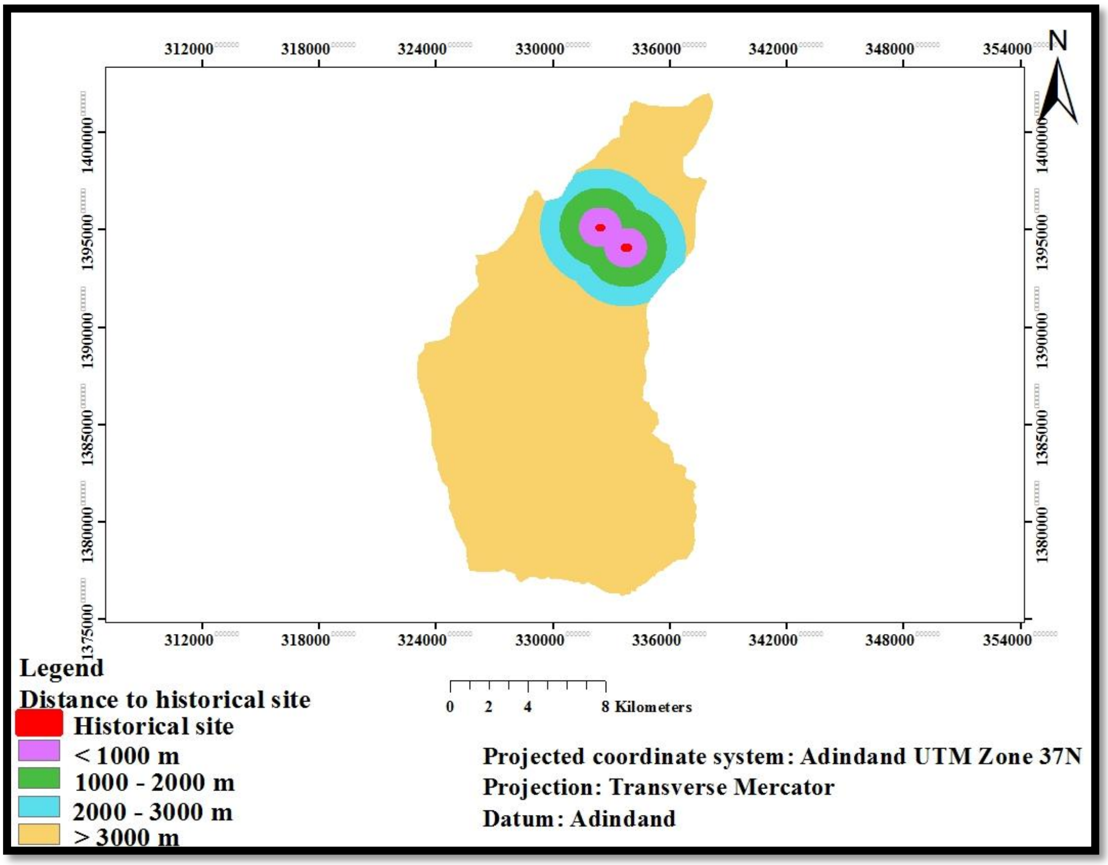

Figure 4-21: Reclassified map of historical site

Table 4-10: Distance to historical site, area coverage and its suitability for disposal site

Distance (m)	Suitability	Rank	Area (km^2)	Area (%)
<1000 m	Unsuitable	1	7	3
1000 – 2000 m	Low suitable	2	13	5.3
2000 – 3000m	Moderately suitable	3	18	7.4
> 3000 m	Highly suitable	4	204	84.3

Table 4-11 indicates that 3% of the study area are unsuitable and given the value 1 and low suitable area covers 5.3% and given the value 2. The remaining areas are moderately suitable and highly suitable which covers 7.4% and 84.3% respectively.

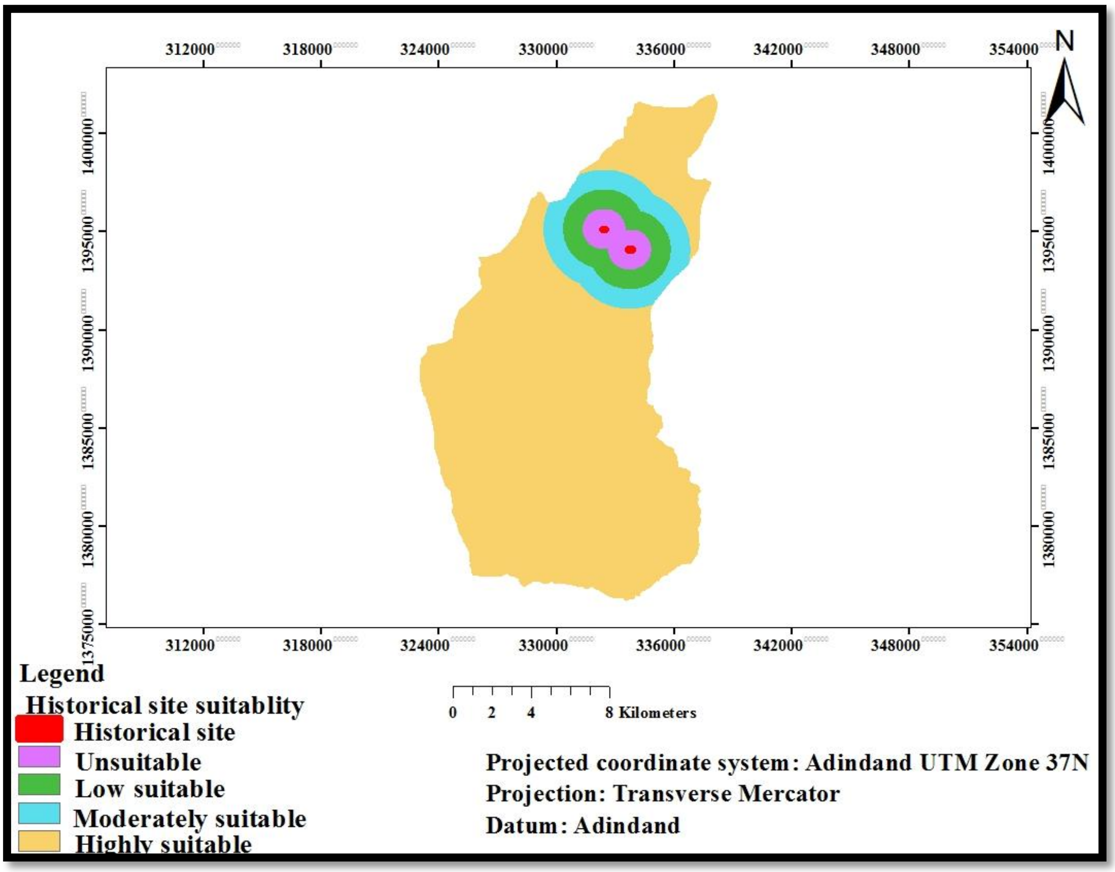

Figure 4-22: Suitability map of historical site

4.1.12 Distance to airport

Landfill sites attract variety of birds to be accumulated around which may interfere with the operation of airplanes. To control the interfere with airplane operation, according to Kontos *et al.* (2005), Worldbank (2004) and UNEP (2005), 3000 m used as safe distance for landfill site selection. For this study the area was classified into four buffer zones: <1000 m, 1000 – 1500 m, 1500 – 3000m and > 3000m. The airport area within 1000m considered as unsuitable (restricted) and the remained area classified and ranked according to their suitability with the help of literature review. And the distance classification is illustrated in the Table 4-12 and Figure 4-23.

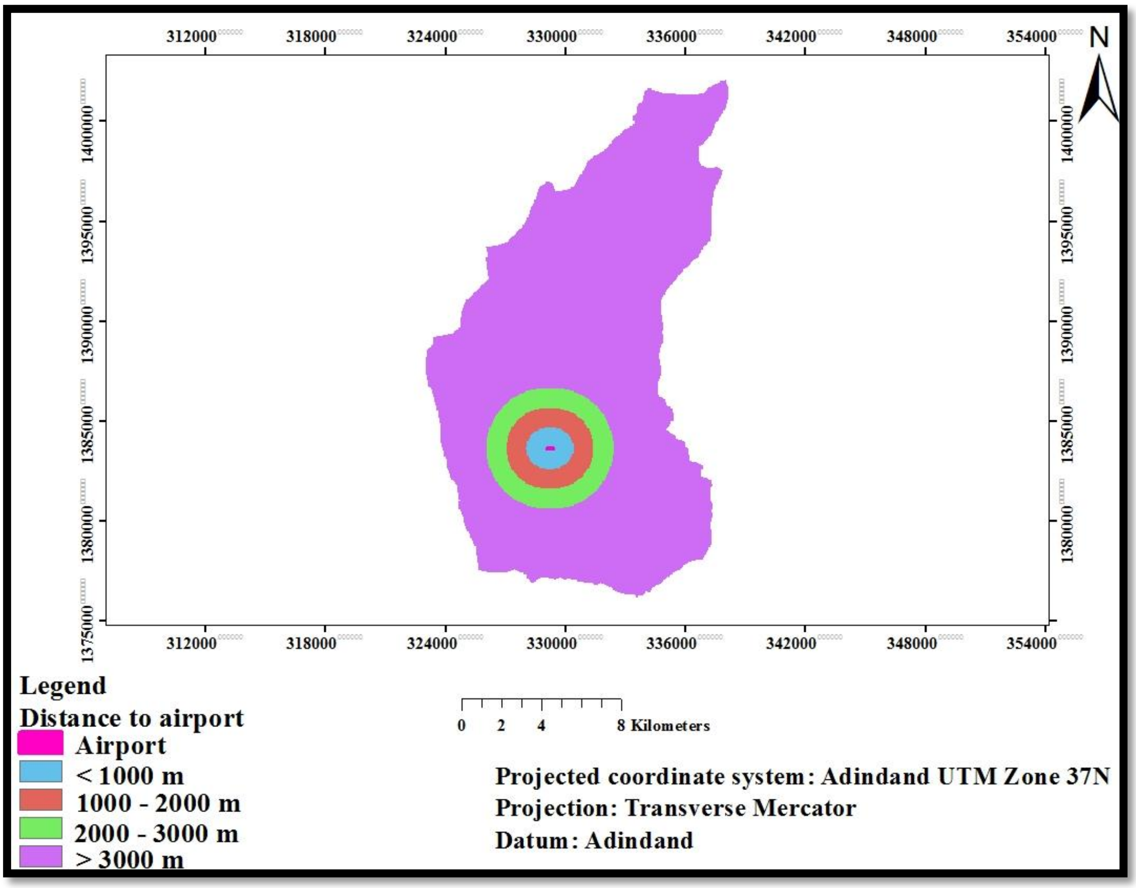

Figure 4-23: Reclassified map of airport

Table 4-11: Distance to airport, area coverage and its suitability for disposal site

Distance (m)	Suitability	Rank	Area(km^2)	Area (%)
< 1000	Unsuitable	1	30	12.4
1000 - 1500	Low suitable	2	52	21.5
1500 - 3000	Moderately suitable	3	91	37.6
> 3000	Highly suitable	4	69	28.5

Source attribute table of Arc map

Table 4-12 shows that unsuitable area covered 12.4% of the study area and given value 1 and the second ranked low suitable area covering the 21.5% of the study area and the remaining areas are moderately and highly suitable areas covering 37.6% and 28.5% respectively. The ranked and suitability map of airport is illustrated in Figure 4-24.

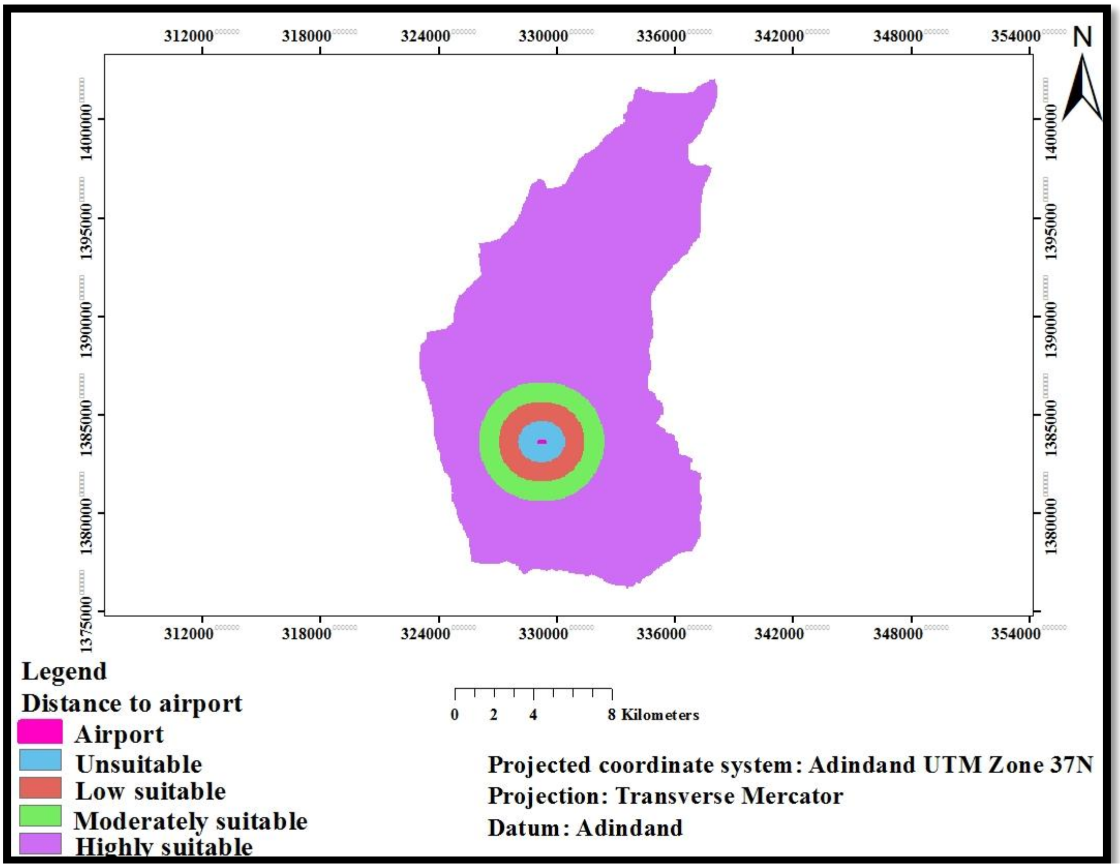

Figure 4-24: Suitability map of airport

4.2 Existing landfill site

Solid waste disposal site of Gondar town which is located 8km from urban centre. And it is the only disposal site in Gondar town which has been serving for the last 6 years. The existing dumping site located surrounding in residential areas which has an impact on environments, public health and aesthetics. The X and Y coordinates of existing landfill site were collected through filed survey method that was used GPS to acquire coordinates. These are 331341.00m E and 1390075.00m N. The collected coordinates of existing landfill site were entered into GIS 10.4.1 as a text file and then converted into shape file to demonstrate solid waste dumping site. The dumping site of Gondar town is found on the eastern part of the country, near to fault, main road and which is not reasonable distance from built up area that have a great impact on social and environmental like nuisance, disease and economic disturbances. It was selected cause of open space. Open space was identified as the best option for landfill site selection. The map (Figure 4-25) shows that, the dumping site is located at environmentally and socially unsuitable area that does not satisfy the international and national environmental standards.

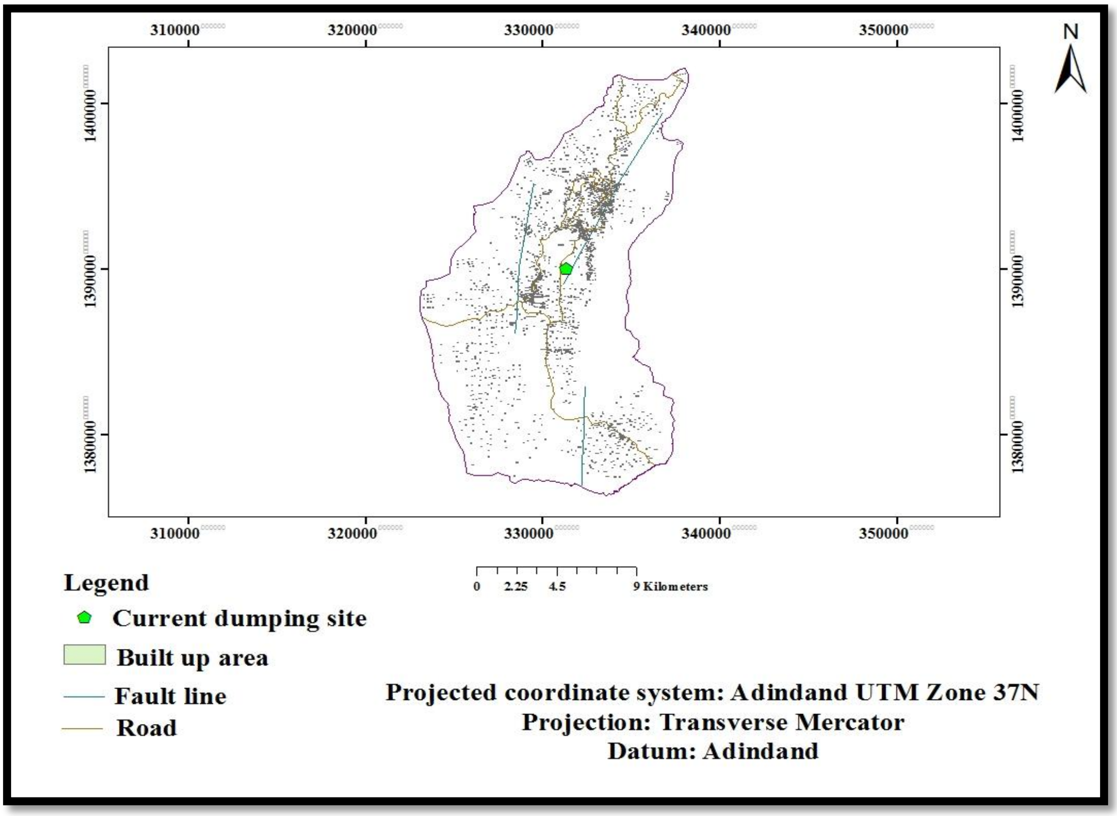

Figure 4-25: Current dumping site

4.3 Landfill suitability

To identify the potential landfill site different criteria was stated such as LULC, geology, soil, fault, road network, slope, airport, built up area, historical site, ground water depth, ground water well and surface water. Distance analysis and environmental evaluation had been taken for stated to minimize the impact on environment and public health and the highly suitable area was far away from fault, built up area, surface water and ground water well and it was found in low permeability of geology. On the top of that the identified area for solid waste disposal site may facilitate transportation and reduce the cost transport. Open lands in the study area identified the best choice for solid waste disposal site, slope > 20% were excluded as it is unsuitable and <500 m and > 5000m were excluded to prevent public health and to reduce cost of transportation.

For each criteria weight were assigned using pairwise comparison of 9 point continuous scale as it is one of an input of analytical hierarchy process (AHP) and its consistency ratio was 0.046 which is acceptable. The result of assigned weight and the map layer of each parameter were used as an input of analytical hierarchy process (AHP) for weighted linear combination of overlay analysis. To combine all map layers standardization of each data was carried out with the common scoring system 1, 2, 3, 4 ranks 1 which represents unsuitable, rank 2 represents low suitable, rank 3 represents moderately suitable and rank 4 represents highly suitable.

Ultimately all parameters were standardized and assigned their weight and weighted linear combinations of overlay analysis were taken to produce suitable site.After the overlay analysis of a given parameter four classes of suitable dumping site produced andranked as a value 1; unsuitable, 2; low suitable,3; moderately suitable and 4; highly suitable. It is shown in Table 4-13 and Figure 4-26.

Table 4-12: Area coverage and suitability of landfill site

Landfill suitability	Rank	Area (km^2)	Area (%)
Unsuitable	1	67	27.7
Low suitable	2	102	42.1
Moderately suitable	3	51	21.1
Highly suitable	4	22	9.1

Table 4-13 indicates that from the full coverage of study area 9.1% (22 km^2) fall under highly suitable categories because it satisfies the environmental, social and economic criteria. High suitable landfill site were found in eastern, western, north eastern and south eastern parts of the study area 21.1% (51 km^2) of the area falls under moderately suitable area, low suitable area covers 42.1 % (102 km^2) and the remaining 27.7% (67km^2) falls under unsuitable for solid waste disposal sites indicated in Figure 4-26.

Suitable disposal site area from the town found in eastern direction the area that covers 4.97% (12.1 km^2), western direction the area which covers 0.43% (1 km^2), north eastern direction the area that covers 0.83% (2km^2) and the south east direction the area that covers 0.43%(1.km^2) (Figure 4-26 and 4-27).

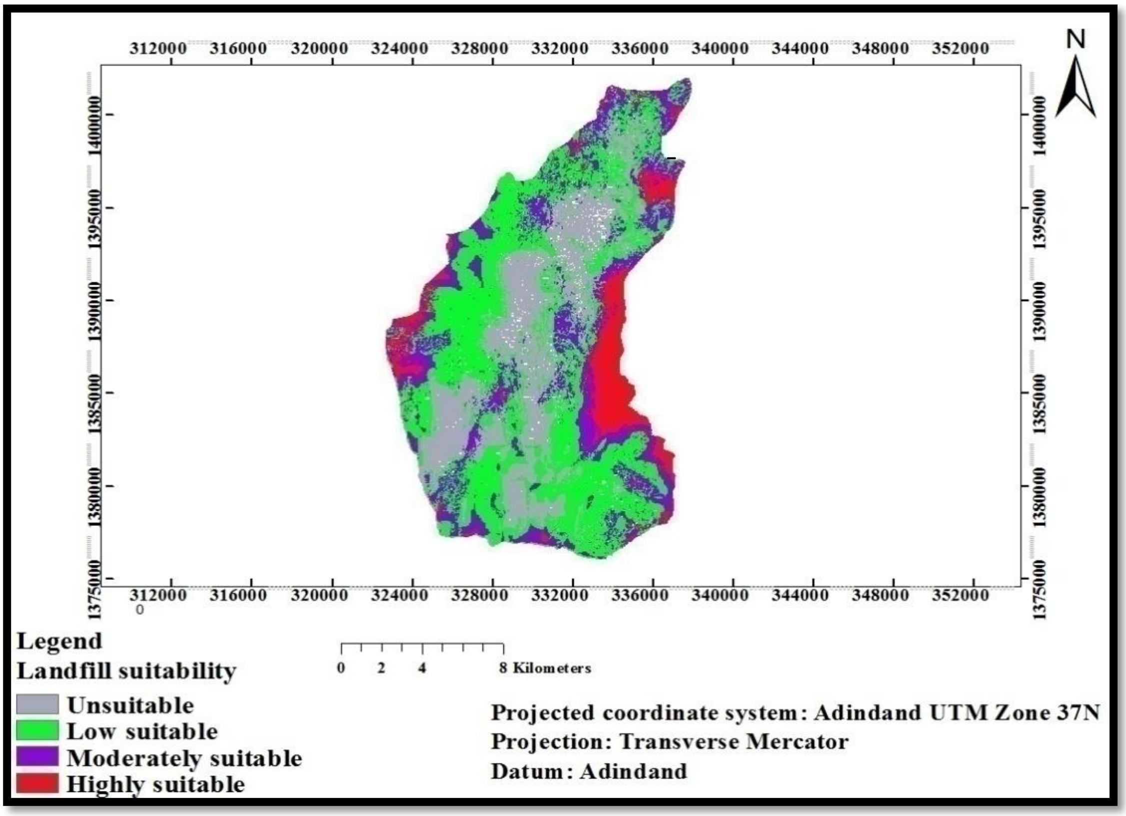

Figure 4-26: Landfill suitability map

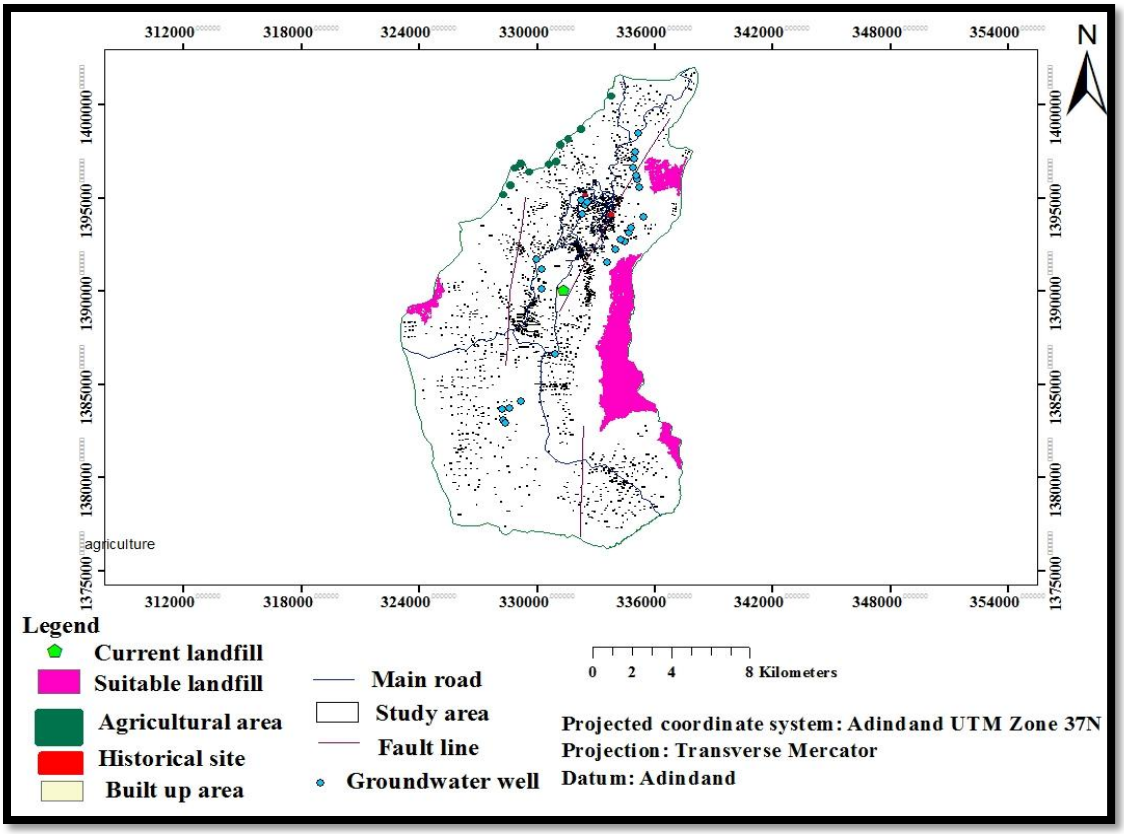

Figure 4-27: Landfill suitability and current landfill site map

Figure 4-27 shows that the green colour is the current landfill site which is found in unsuitable area because it is located near to the road and fault. And the pink colour indicates that the most suitable area that is found far away from residential area, free from environmental and public health risks and it may facilitate transportation and reduce the cost of transportation.

CHAPTER FIVE

CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

To select the site twelve criteria were considered, namely geology, distance to fault, distance to surface water, ground water well, ground water depth, soil permeability, land use/land cover, slope, distance to road, distance to built-up area, historical site and distance to airport for appropriate landfill site selection in Gondar town. A map was created for each criteria using GIS technique. The current landfill site was found in unsuitable area that is near to community settlements, road and fault that have a negative effect on environment and public health.

The overlay analysis of all factors using GIS based WLC analysis produced suitable dumping site of the town shown in Figure 4-26. The final solid waste disposal site suitability map was divided into four categories: unsuitable, less suitable, moderate suitable and most suitable and ranked as value 1, 2, 3 and 4. The suitability classes showed that 9.1% (22 km^2) highly suitable, 21.1% (51km^2) of the area falls under moderately suitable area, 42.1% (102km^2) of the study area are low suitable and the remaining 27.7% (67 km^2) falls under unsuitable (restricted) for landfill site .

The most suitable disposal sites were located in eastern, western, north eastern and south eastern direction that have no negative effect on environment and public health because it is located far away from built up area, water sources, fault and < 10% of slope and it is easy for access of transportation. The total area of the most suitable site is 22 km^2 from this four most suitable sites were identified these are located in eastern covers the area 12.1km^2, western direction area 1 km^2, north eastern direction 2 km^2 and south eastern direction 1 km^2 and the sites found in eastern direction is the most appropriate site and have largest area hence it serves more than 10 years.

5.2 Recommendations

The following recommendations are given based on the finding of the study.

- ❖ The current dumping site around Ayra located in unsuitable area that near to community settlement, fault and close to the main road across to Addis zemen, Bahirdar. Therefore, the concerned body should improve the selection of disposal of the solid waste site by considering social, economical and environmental criteria.
- ❖ As a result of population growth and urbanization increase, the solid waste generation increase and become complex. The town use only one landfill site therefore the concerned body should select another site by considering social, economical and environmental criteria.
- ❖ To control downstream surface water pollution, runoff must not flow into and out of the sanitary landfill. Therefore, drainage system should be constructed around the landfill.
- ❖ The rates and volumes of solid waste produced from the town should be known in order to determine the dimension of the solid waste disposal site.
- ❖ The selected solid waste disposal site used for only for non-hazardous waste. Hazardous waste should be dumping separately because it should have different parameter.

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APPENDICES

Appendix 1: AHP results

[Suitability analysis with the AHP]

[Analysis context/objective]

No context/objective specified

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[No of criteria]

12

[Criteria and source layers]

built	recass20.RASTER.1
lulc	C:\Users\Tigist\Desktop\new file\new lulc\lulc
wellrs	C:\Users\Tigist\Desktop\new file\new lulc\wellrs
riverrs	C:\Users\Tigist\Desktop\new file\new lulc\riverrs
goclss	C:\Users\Tigist\Desktop\new file\geology\goclss
solrs	C:\Users\Tigist\Desktop\new file\new lulc\solrs
reclassff	C:\Users\Tigist\Desktop\new file\ground depth\reclassff
fnalfalt	C:\Users\Tigist\Desktop\new file\fault\fnalfalt
rodrs	C:\Users\Tigist\Desktop\new file\road\rodrs
slopord	C:\Users\Tigist\Desktop\new file\slope\slopord
histori	C:\Users\Tigist\Desktop\new file\histosite\classified
aiportrs	C:\Users\Tigist\Desktop\new file\new lulc\aiportrs

[Criteria hierarchy]

[Objective]

built [0.227] -> [0.227]

lulc [0.192] -> [0.192]

wellrs [0.139] -> [0.139]

riverrs [0.11] -> [0.11]

goclss [0.09] -> [0.09]

solrs [0.065] -> [0.065]

reclassff [0.054] -> [0.054]

fnalfalt [0.045] -> [0.045]

rodrs [0.027] -> [0.027]

slopord [0.023] -> [0.023]

histori [0.017] -> [0.017]

aiportrs [0.012] -> [0.012]

[AHP preference matrices and results]

Parent criterion: Objective

[Preference matrix]

	built	lulc	wellrs	riverrs	goclss	solrs	reclassff	fnalfalt	rodrs	slopord	histori	aiportrs
built	1.0	2.0	3.0	3.0	3.0	3.0	5.0	5.0	7.0	7.0	7.0	9.0
lulc	0.5	1.0	2.0	3.0	3.0	3.0	5.0	5.0	7.0	7.0	7.0	9.0

wellrs	0.333	0.5	1.0	2.0	2.0	3.0	3.0	5.0	5.0	5.0	7.0	9.0
riverrs	0.333	0.333	0.5	1.0	2.0	3.0	3.0	3.0	5.0	5.0	5.0	7.0
goclss	0.333	0.333	0.5	0.5	1.0	2.0	2.0	3.0	5.0	5.0	5.0	7.0
solrs	0.333	0.333	0.333	0.333	0.5	1.0	2.0	2.0	3.0	3.0	5.0	5.0
reclassff	0.2	0.2	0.333	0.333	0.5	0.5	1.0	2.0	3.0	3.0	5.0	5.0
fnalfalt	0.2	0.2	0.2	0.333	0.333	0.5	0.5	1.0	2.0	3.0	5.0	7.0
rodrs	0.143	0.143	0.2	0.2	0.2	0.333	0.333	0.5	1.0	2.0	3.0	3.0
slopord	0.143	0.143	0.2	0.2	0.2	0.333	0.333	0.333	0.5	1.0	2.0	3.0
histori	0.143	0.143	0.143	0.2	0.2	0.2	0.2	0.2	0.333	0.5	1.0	2.0
aiportrs	0.111	0.111	0.111	0.143	0.143	0.2	0.2	0.143	0.333	0.333	0.5	1.0

[Eigenvalues]

12.7656

0.1896

0.1896

-0.15

-0.15

-0.0748

-0.0748

-0.1067

-0.1067

-0.1766

-0.1527

-0.1527

[Eigenvector of largest Eigenvalue]

0.6091

0.5157

0.3726

0.2968

0.2413

0.1738

0.1439

0.1212

0.0736

0.0609

0.0451

0.0333

[Criteria weights]

built	22.6677
lulc	19.1905

wellrs	13.8651
riverrs	11.0428
goclss	8.9807
solrs	6.4659
reclassff	5.3559
fnalfalt	4.5102
rodrs	2.7396
slopord	2.2645
histori	1.6789
aiportrs	1.2382

[Consistency ratio CR]

0.0464

(A revision of the preference matrix is recommended if CR > 0.1)

Appendix 2: Ground water well points

Well location	X	Y	Depth of water table (m)
china well 1	332300	1394139	65
china well 2	332461	1394631	120
china well 4	332597	1394758	91.7
Angereb 1	335026	1397495	108
Angereb 2	334986	1397091	86
Angereb 3	335144	1395982	65
Angereb 4	335236	1395580	174
Angereb 5	334934	1396639	72
Angereb 6	335160	1398499	18
Angereb 7/GTW7	334673	1393121	120
Y-1 kehaval	332240	1394903	92
shinta 1	330233	1390128	50
shinta 2	330229	1391160	140
shinta 3	329980	1391692	80.9
Angereb Nw1	333851	1391110	141
Angereb Nw2	333566	1391524	164
Angereb Nw3	333846	13911778	173
Angereb Nw4	333995	1392223	140
Angereb Nw5	334483	1392668	132
Angereb Nw6	334785	1393410	140
Azezo TW1	328605	1383715	107
Azezo TW2	329204	1384103	150
Azezo TW3	330914	1386610	150
Azezo TW4	328216	1383658	100
Angereb TW5	334274	1392754	109
Angereb TW6	335444	1394001	95
DBW 5	328279	1383057	150
DBW 6	328399	1382893	190
DBW 7	327543	1385295	120
DBW 8	329738	1381422	71