



ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF EARTH SCIENCES

**SOLID WASTE DUMPING SITE SUITABILITY SELECTION USING GIS
AND REMOTE SENSING: A CASE STUDY IN LOGIA TOWN, AFAR
REGION, ETHIOPIA**

A Thesis Submitted To
*The School of Graduate Studies of Addis Ababa University, In Partial
Fulfillment of the Requirements for the Degree of Masters of Science,
Specialization in Remote Sensing and Geo-Informatics*

**By: - AHMED MUSSA
ID: GSR/4818/09**

A wide-angle photograph of a large, open area covered in a massive amount of discarded waste, including plastic bags, papers, and other debris. The waste is piled up in the foreground and middle ground, extending towards the horizon. In the background, there are some buildings and a clear sky.

**Addis Ababa University
May, 2018**



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This is to certify that the thesis prepared by **Ahmed Mussa Yimam** entitled as “**Solid Waste Dumping Site Suitability Selection Using GIS and Remote Sensing: A Case Study in Logia Town, Afar Region, Ethiopia**” is submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geo-informatics compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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DECLARATION

I hereby declare that the thesis entitled “**Solid Waste Dumping Site Suitability Selection Using GIS and Remote Sensing: A Case Study in Logia Town, Afar Region, Ethiopia**” has been carried out by me under the supervision of Dr. K. V. Suryabhagavn, School of Earth Sciences and Prof. M. Balakrishnan, Department of Zoological Sciences, Addis Ababa University during the year 2017–2018 as a part of Master of Science Program in Remote sensing and Geo-informatics. I further declare that this work has not been submitted to any other University or Institution for the award of any Degree or Diploma.

Place: Addis Ababa

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Date: May, 2018

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List of Figures

Figure 1.1: Photographs A & B that show different types of solid waste dumping at river bank. (Photo by Ahmed Mussa, 2018)	4
Figure 3.1: Location map of Logia town	17
Figure 3.2: General workflow of the present study	28
Figure 3.3: Well points buffer distance map (a) and reclassified well point suitability map (b)..	29
Figure 3.5: River buffer distance map (a) and reclassified river buffer suitability map (b)	32
Figure 3.6: Constraint buffer distance map (a) and constraint buffer reclassified river map (b)..	32
Figure 3.7: Slope class map (a) and reclassified Slope suitability map (b)	34
Figure 3.8: Land-use/land-cover type map (a) and reclassified land-use/land-cover suitability map (b).....	35
Figure 3.9: Lithology type map (a) and reclassified Lithology suitability map (b).....	36
Figure 3.10: Fault buffer distance map (a) and reclassified fault buffer distance suitability map (b)	38
Figure 3.11: Fault constraint buffer distance map (a) and reclassified fault constraint map (b) ..	39
Figure 3.12: Soil type map (a) and reclassified soil type suitability map (b)	39
Figure 3.13: Road buffer distance map (a) and reclassified road buffer suitability map (b)	40
Figure 3.14: Road constraint buffer distance map (a) and constraint buffer reclassified road distance map (b).....	41
Figure 3.15: Built-up area buffer distance map (a) and reclassified built-area buffer distance map (b).....	41
Figure 3.16: Built-up constraint buffer distance map (a) and reclassified built-up constraint buffer distance map (b).....	42
Figure 4.1: Open dump site of solid waste disposal along different features.	43
Figure 4.2: Wellpoint rank suitability map (a) and river rank suitability map (b).....	44
Figure 4.3: Slope rank suitability map (a) and Land-use/land-cover rank suitability map (b).....	46
Figure 4.4: Geological type suitability map (a) and fault suitability map (b).....	47
Figure 4.5: Soil rank suitability map.....	48
Figure 4.6: Road network rank suitability map (a) and built-up rank suitability map (b)	49
Figure 4.8: River buffer constraint suitability rank map (a) and road buffer constraint suitability rank map.....	50
Figure 4.11: Overall solid waste dump site suitability map for Logia town.....	54

List of Tables

Table 3.1: Source and type of Secondary data	20
Table 3.2: Scale for pair-wise comparison of solid waste site selection (Saaty, 1980)	25
Table 3.3: Solid waste dump site selection criteria of ground well points	29
Table 3.4: Solid waste dump site selection criteria of river	31
Table 3.5: Solid waste dump site selection criteria of the slope	33
Table 3.6: solid waste dump site selection criteria of land-use/land-cover	35
Table 3.7: Solid waste dump site selection criteria of lithology	36
Table 3.8: Solid waste dump site selection criteria of fault	37
Table 3.9: Solid waste dump site selection criteria of soil.....	37
Table 3.10: Solid waste dump site selection criteria of the road network	40
Table 3.11: Solid waste dump site selection criteria of built-up.....	40
Table 4.1: Criteria accepted for dump site selection suitability and their rank.....	45
Table 4.2: Constraint criteria accepted for dump site selection	51
Table 4.3: Preference matrix for the solid waste site selection in Logia town.	52
Table 4.4: Normalized comparison matrix for solid waste dump site selection Logia town.....	53

Tables of contents

Contents	page
Acknowledgments.....	i
List of Figures	ii
List of Tables	iii
Tables of contents	iv
List of Acronyms	vii
Abstract	viii
CHAPTER ONE	1
1. Introduction.....	1
1.1 Background of the Study.....	1
1.2 Statement of the Problem.....	3
1.3 Objectives.....	5
1.3.1 General objectives.....	5
1.3.2 Specific objectives	5
1.4 Research Questions	5
1.5 Significance of the study	5
1.6 Scope of the study	5
1.7 Limitations of the Study.....	5
1.8 Organization of the Thesis	6
CHAPTER TWO	6
2 Review of Literature	6
2.1 Solid Waste	6
2.2 Types of wastes	7
2.2.1 Urban solid waste.....	7
2.2.2 Hazardous waste	7
2.2.3 Hospital waste.....	8
2.3 Solid Waste Management System.....	8
2.4 Solid waste management in developed and developing countries	9
2.4.1 Solid Waste Management System in Low-Income countries.....	10
2.4.2 Solid waste management in Ethiopia.....	11
2.4.3 Dump site selection.....	13
2.5 Application of RS and GIS for Solid Waste Dumping Site Selection	14
2.5.1 Application of Remote Sensing	14
2.5.2 Application of GIS	15

2.6	Multi-criteria decision analysis for solid waste dumping site selection.....	15
CHAPTER THREE.....		17
3	Materials and Methods.....	17
3.1	Description of the Study Area.....	17
3.2	Physiography and Drainage	17
3.3	Population.....	18
3.4	Economic activity and housing	18
3.4.1	Climate.....	18
3.4.2	Geology.....	19
3.5	Methods.....	19
3.5.1	Hardware/software used.....	19
3.5.2	Source of data	19
3.5.3	Primary data	19
3.5.4	Secondary data	20
3.5.5	Methods used for solid waste dump site selection.....	20
3.5.6	Image pre-processing.....	22
3.5.7	Digitizing	22
3.5.8	Image classification	22
3.5.9	Buffering.....	23
3.5.10	Analytic hierarchy process.....	23
3.5.11	Weighted overlay analysis	24
3.5.12	Aggregation of suitability sites using the methodology	25
3.6	Identification and reclassifications of criteria	27
3.6.1	Groundwater depth.....	28
3.6.2	River.....	30
3.6.3	Slope	33
3.6.4	Land use/land cover (LU/LC).....	34
3.6.5	Lithology.....	35
3.6.6	Fault and soil.....	36
3.6.7	Road networks and built-up area	39
CHAPTER FOUR.....		43
4	Results.....	43
4.1	Present Waste disposal sites in Logia town	43
4.2	Groundwater well points and river rank suitability.....	44
4.3	Slope and Land-use/land-cover rank suitability.....	46
4.4	Geology and Fault suitability	47

4.5	Soil suitability	48
4.6	Road network and built-up area suitability	48
4.7	Constraint criteria.....	49
4.8	River and road constraint buffer distance suitability map.....	49
4.9	Fault and built-up area constraint buffer distance suitability map	50
4.10	Constraint map	51
4.11	Assigning criteria weights.....	52
4.12	Dumpsite Suitability map.....	53
CHAPTER FIVE.....		55
5	Discussion.....	55
CHAPTER SIX.....		58
6	Conclusion and Recommendations.....	58
6.1	Conclusion.....	58
6.2	Recommendations	58
References.....		60
Appendices.....		66
Appendix 1: Format for thesis originality test report.....		66
Appendix 2: Open dump sites current location in Logia town		67
Appendices 3: Functional ground water well points.....		67
Appendix 4: Point data for filed verifications of land-use/land-cover.....		68
Appendix 5: Land-use/land-cover accuracy assessment.....		70

List of Acronyms

AHP	Analytical Hierarchy Process
BOA	Bottom-Of-Atmosphere
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EGSSAA	Environmental Guidelines for Small-Scale Activities in Africa
EPA	Environmental Protection Authority
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
LU/LC	Land-Use/land-cover
MCDA	Multiple Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
MCE	Multi-Criteria Evaluation
MCE	Multi-Criteria Evaluation
MSWM	Municipal Solid Waste Management
NMA	National Metrological Agency
RS	Remote Sensing
SMCDA	Spatial Multi-Criteria Decision Analysis
SRTM	Shuttle Radar Topography Mission
SWM	Solid Waste Management
TOA	Top-Of-Atmosphere
UN	United Nation
USGS	United States Geological Survey
UTM	Universal Transfer Mercator

Abstract

Solid waste dumping site is a serious problem in Logia town as most solid wastes are not dumped in suitable sites. The main objective of this study was to select suitable solid waste disposal sites that are economically feasible, environmentally sound, and socially acceptable in Logia town by applying Geographic Information System and Remote Sensing technologies. For this research, data were gathered from different sources. Sources include STRM image from USGS with a spatial resolution of 30×30 m for slope, fault and drainage extractions; Google Earth map of the study area for digitizing road, land-use/land-cover maps generated from Sentinel 2A image with a spatial resolution of 10×10 m. To accomplish the objectives, the present study used factor maps as groundwater well points, slope, fault, built-up area, road network, river, land-use/land-cover, geology and soil map, which were reclassified in GIS environment followed by preparation of the suitability map. Even if the degree of weight to each factor varies, factors were considered important and mandatory in the selection of suitable sites for solid waste disposal. Analytical Hierarchy Process pair-wise comparison module was used to accomplish weights of factor parameters, and finally suitability map was prepared by overlay analyses and assigned as highly suitable, suitable, moderately suitable, less suitable and unsuitable. The final result shows that from total area, 5.93 % (499.43 ha) is highly suitable, 6.4% (537.5 ha) is suitable, 3.23 % (272 ha) is moderately suitable, 1.02% (86.10 ha) is less suitable and 84.99 % (7154.61ha) is unsuitable for solid waste dumping in Logia town. In general, the selection of highly suitable sites requires further geotechnical and hydro-geological analyses to ensure conformity with serious standards required for design and construction of the facility. It was recommended that Logia should consider closing its current dump site for a better location from the possible suitable sites selected in this study especially the site/location on the northern part of Logia town, which is suitable in terms of all buffered parameters as well as other confounding factors that include economy, accessibility and elevation as well as slope.

Keywords: Analytic hierarchy process, Dumping site, Geographic information system, Solid waste, Remote sensing

CHAPTER ONE

1. Introduction

1.1 Background of the Study

Waste is a material discharged from daily human activities, which makes adverse impacts on human health and environment. Solid wastes can be defined as non-liquid and non-gaseous products of human activities, like those from households, municipal, supermarket, construction and industries. Generation of solid waste has become a global environmental and health issue in the contemporary world both in developing and developed countries. Increasing population, rapid economic growth, improved living standards, expansion of urban and industrial activities accelerate solid waste generation (Tirusew Aysheshum and Amare Sewnet, 2013).

Fast expansion of urban, agricultural and industrial activities encouraged by rapid population growth has produced vast amounts of solid and liquid wastes that pollute the environment and destroy natural resources (UNEP, 2005). In many countries, with an increase in human population and the rising demand for food and other essentials resources, there has been a rise in the amount of solid waste generated making its management and disposal problematic. Solid waste management has long been a worldwide environmental problem. Common problems associated with systematic management of solid waste include transmission diseases, fire hazards, foul odor, atmospheric and water pollution and economic victims (Jilani *et al.*, 2002).

Waste as the side products of various activities/events in human life and as a result of natural processes often creates serious problems in areas of settlements. Aggregation of human settlements has the potential to produce a large amount of solid waste. Increasing population, rapid economic growth and the rise in community living standards accelerate solid waste generation in the world (Elmira *et al.*, 2010). Unscientific disposal system of solid waste can develop contamination of surface and groundwater through leaching, soil contaminants of surface water and groundwater through percolate waste accumulation results in soil contamination air pollution spreading of diseases and uncontrolled release of methane by anaerobic decomposition (Visvanathan and Glawe, 2006). Solid wastes indiscriminately thrown around human environment results in aesthetic problems, nuisance, and pollution of land and water bodies (Hammer, 2003).

In Ethiopia, people are following unsafe solid waste disposal practices, such as open dumping, burning and burying. Many households practice uncontrolled open dumping and others burn such waste in the open area. However, all self-managed waste disposal practices do not guarantee cleanness and safety.

Most solid waste disposal sites in Ethiopian cities and towns are found on the borders of the urban areas around water bodies, faults, crop fields, settlements and on roads sides. Such inappropriate disposal of solid waste leads to serious environmental pollution and health-related problems, contamination of surface and groundwater, soil contamination through direct waste contacts, greenhouse gas emission, environmental pollution, ecosystems damage, injuries to people and property, discourages tourism and business activities (EGSSAA, 2009). Therefore, locating proper sites for dumping solid waste far from environmental resources, residential areas, water bodies, roads, faults and settlements is essential for the management of solid waste in a proper way.

There are problems of solid waste disposal sites in Logia town. Even if most of the solid wastes are collected from sources using push carts to temporary transfer stations, there is no scientifically approved site for disposal. There is also no standard transfer station in the town. All health institutions and private sectors follow their way of removal of waste and others dispose of it in and around water bodies (Logia river), Tendaho dam and Awash river. These dumping sites are not well planned and they are open field disposal (no sanitary landfill) close to rivers and not at an appropriate distance from the center of the city. In order to improve these problems, integrating Geographic Information System (GIS) and Remote Sensing (RS) techniques can be used to select the best possible solid wastes dumping as the concurrent technology. Selection of solid waste disposal sites using GIS and RS requires many factors that should be integrated into one system for proper analysis. The selection criteria should consider and combine fault, surface water, soil type, slope, built-up, groundwater, geology, land-use/land-cover and road networks.

Remote sensing can provide information about the various spatial criteria such as land-use/land-cover (Emun, 2010), whereas, GIS can be used to utilize, creating and analyzing spatial or attribute data for the solid waste dumping site selection process. In the multi-criteria evaluation, many data layers are to be handled by GIS and RS in order to arrive at the suitable site, which can be achieved conventionally using GIS. Therefore, the present study is aimed at providing suitable solid waste

disposal sites by using GIS and RS techniques in order to minimize the risk of an ecological and human health problem for Logia town.

It is also helpful to set appropriate selection criteria for the identification of new solid waste dumping sites through scientific methods. Although proposed to adopt GIS technology in Ethiopian municipalities by several researchers, the practical application of GIS in dump site selection is still very limited. In the waste management sector, just like other industries, people are largely uninformed of the tremendous potential of GIS and RS application in waste management (Emun, 2010). In environmental planning, waste management has become a serious problem afflicting the cities, mainly due to lack of knowledge on newly developed technologies for efficient environmental performance. A geographical information system is being the appropriate robust technology due to its ability to select the best sites for landfill location and collection routes optimization. This present study emphasizes to select suitable solid waste disposal sites that are economically feasible, environmentally sound, and socially acceptable for Logia town, by applying geographic information system and Remote Sensing technology.

1.2 Statement of the Problem

Solid waste management has been a big challenge to both the developed and developing countries all over the world. As a result of urbanization development activities and population growth, high amounts of solid wastes are generated every day. People are coming to the town for find jobs in Tendaho sugar project, Samara/Logia town urban infrastructure and, to open commercial activities like shop, cafes, hotel, and supermarket. Also, it is a truck stop of Ethiopia-Djibouti road passing through the town. It is a busy place with many shops and cafes set along the side of the road and houses set behind them (CSA, 2013).

The high rate of waste generation is facing the problem of disposal and as a result it has the very high potential effect to pollute environments such as surface water, groundwater, soil, and air. The most common problems associated with unsuitable management of solid waste include diseases transmission, fire hazards, odor atmospheric and water pollution, social and economic losses (Jilani, 2002). Public health is also highly affected by uncontrolled solid waste generation and due to the absence of suitable disposal site. In Ethiopia, most diseases are related to poor environmental sanitation and water pollution. Lack of suitable waste disposal site, public toilet and general clean mechanism in the area affect the community's economic and social activities directly or indirectly

(Tsegaye Mekuria, 2006). Discovering a good waste disposal area is difficult since land is a scarce resource. Increasing environmental awareness, increasing the cost of living, community and political opposition and public health concerns have made choosing suitable land for dump site difficult (Din *et al.*, 2008).

The major sources of solid wastes in the town are house, hotels and restaurants, hospitals and private clinics. Due to the absence of suitable dumping site, communities have been dumping wastes around their homes, near the road, and other places. Especially there is no any suitable site to dispose of waste in the town. This leads to high potential environmental, human health risk in the lower part of the river as it is polluted by wastes. As a result of the waste, beauty of the town, animals and plants are affected. Therefore, it is very important to select appropriate sites for waste disposal to solve the existing problems in the township. Some of the existing open dump sites in the study area are on the roadside, near the river and built up areas (Fig 1.1). Figure 1.1a shows there is solid waste disposal in the nearby Logia river, roadsides and built-up and Figure 1.1b shows there is solid waste disposal in the nearby Awash river.



Figure 1.1: Photographs A & B that show different types of solid waste dumping at river bank. (Photo by Ahmed Mussa, 2018)

1.3 Objectives

1.3.1 General objectives

to select suitable solid waste disposal sites that are economically feasible, environmentally sound, and socially acceptable for Logia town by applying geographic information system and Remote Sensing technology.

1.3.2 Specific objectives

The specific objectives of the present study were:

- to examine the present waste disposal system of Logia town.
- to investigate and implement a derived scientific methodology for selecting solid waste disposal site selection
- to produce factor maps that are used for solid waste dumping site suitability analysis and
- to produce suitable solid waste dumping site map for Logia town.

1.4 Research Questions

To fulfill the objectives, the following questions were proposed:

- ❖ What factors are used for selecting suitable dumping site selection which is environmentally sound, economically feasible and politically acceptable for Logia town?
- ❖ Which of the areas are suitable for solid waste disposal from the locations after the selected criteria will be analyzed?
- ❖ Is multi-criteria decision making important for selecting solid waste disposal site in Logia town?

1.5 Significance of the study

From this study, the result is suitable solid waste disposal sites and map of suitable solid waste disposal sites to protect the environment and for the economic, political and social safety of Logia town. Unsuitable solid waste disposal sites affect the social and economic activities of the communities as well as it affects the health of the people. Therefore, the final result of this research is expected to solve problems caused by solid waste related to health, environment, and economy of the local people through the applications of RS and GIS technology.

1.6 Scope of the study

This study is to explore technical aspects of selecting suitable solid waste disposal site in Logia town. It focuses only on the study of solid waste dumping suitability for Logia town.

1.7 Limitations of the Study

The study was constrained by the following limitations:

- ❖ Lack of organized secondary data due to the absence of documentation and organized database system in the study area, like soil texture data
- ❖ The data collected at national levels are in collected as small sample in a very wide range of area, so that the data lack well representation of the area.

1.8 Organization of the Thesis

This thesis contained six chapters. The first chapter is the introduction including introduction, statement of the problem, objectives of the study, research questions, scope, significance and limitation of the study. The second chapter contains a review of the literature, mainly including, the concept and types of solid waste management systems, solid waste management, solid waste management in developed and developing countries, solid waste management applications of GIS and RS in suitable dumping site selection and Multi-criteria decision analysis for solid waste dumping site selection. The third chapter deals with the description of the study area and the materials and methods. The fourth chapter presents the results of the suitable dumping site selected for the study area. Chapter five presents the overall discussion and chapter six conclusions and recommendations.

CHAPTER TWO

2 Review of Literature

2.1 Solid Waste

Waste is generated as a direct consequence of human activities. Wastes are generally classified into solid, liquid and gaseous. Solid wastes, the subject of this study, are mainly disposed of to landfill as it is the simplest, cheapest and most cost-effective method of disposing of waste. Such

wastes are generated by the full extent of human activities that range from relatively innocuous substances such as food and paper waste to toxic substances such as paint, chemicals used batteries, healthcare waste, and sewage sludge derived from wastewater treatment (Zhag *et al.*, 2010).

Numerous classifications of solid wastes have been proposed and the following represents a simple classification of waste into broad categories according to its origin and risk to human and environmental health. These include household waste, municipal waste, commercial and non-hazardous industrial wastes, hazardous (toxic) industrial wastes, construction and demolition waste, healthcare wastes generated in health care facilities (e.g. hospitals, medical research, and laboratory), human and animal wastes and incinerator wastes (Sivasankar and Kuppu, 2017). Household waste represents waste generated at home and usually in city and townships collected by municipal waste collection services. Municipal solid waste includes wastes collected from shops, homes and offices, food waste from restaurants, waste derived from street cleaning and green (organic) waste generated in parks and garden (Debishree and Samadder, 2014).

2.2 Types of wastes

Solid waste can be divided into different types of groups based on their source: (Eberchi and Godwill, 2016).

2.2.1 Urban solid waste

The urban solid waste contains construction waste, household and destruction debris, healthcare wastes, and waste from roads. This waste is generated mainly from settlements and profitable complexes. With increasing urban expansion and revolution in life and food habits, the amount of municipal solid waste has been increasing rapidly and varying its composition (Eberchi and Godwill, 2016).

2.2.2 Hazardous waste

Hospital and industrial wastes are considered as harmful as they may also include poisonous substances. Same types of household waste are also hazardous. Dangerous wastes could be extremely toxic to animals, humans and plants. Domestic wastes that can be classified as hazardous waste include used materials like, car batteries, shoe polish, clinical instrument, paint materials, and medical instruments. Human and animal healthcare waste with chemical substances are also

dangerous. These chemicals include formaldehyde and phenols, which are used as antiseptics and mercury, which is used in thermometers or instrument that measure blood pressure. In the industrial sector, the major producers of risky waste are the metal, chemical, paper, insecticide, dye, purifying and plastic industries. Direct contact with chemicals such as dangerous such as cyanide and mercury can be fatal (Eberchi and Godwill, 2016).

2.2.3 Hospital waste

Hospital waste is generated during the diagnosis, treatment and injection of human beings or animals or in exploration activities in these fields or in the production or laboratory testing. It may contain wastes like scissors edge material, disposables, dry waste, culture medicinal wastes, anatomical waste, discarded medicines and chemicals. These are in the form of wastes such as syringes, swabs, bandages, body fluids and excreta. These are highly infectious and can be a serious threat to human health if not managed in a scientific and discriminate manner (Eberchi and Godwill, 2016).

2.3 Solid Waste Management System

Solid waste management is the discipline associated with the control of generation, storage, collection, transfer, transport, processing and disposal of solid wastes in a manner that is in agreement with the best principles of public health, engineering, economics, aesthetics, conservation and environmental considerations, and to change the attitude of people (Zhag *et al.*, 2010).

Scientific management of solid waste around human habitat reduces its adverse impacts on the environment and human health and supports economic development and improved quality of life. The main methods of solid waste management systems are a waste reduction, waste reuse and recycling. There are many environmental benefits that can be derived from the reuse, reduction and recycling methods. They reduce or prevent greenhouse gas emission, conserve resources, reduce the release of pollutants, save energy, and reduce the demand for waste treatment technology and landfill space. Therefore, it is advisable that these methods be incorporated as part of the solid waste management plan (Debishiree, 2014). Poor waste management systems coupled with hot climatic conditions results in increasing environmental problems with significant local as well as global dimensions. In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by landfilling remains the most commonly employed method (Debishiree, 2014).

2.4 Solid waste management in developed and developing countries

Developed countries have serious environmental challenges about solid waste management due to fast urban developments. The increased population and improved standard of living in urban areas have led to the generation of varied categories of wastes. Because of urbanization, population growth, industrialization and economic growth, a trend of increase in a municipal solid waste generation has been recorded worldwide (PPCB, 2007). As such, managing solid waste is becoming a challenge for cities in most lower-income countries because of the degree of growing population and quick urbanization and which the increasing municipal solid waste (Zhang *et al.*, 2010; Guerrero *et al.*, 2013; Eberchi *et al.*, 2016). Waste generation has been rising with increasing wealth and economic growth. In developing countries also, the waste generation is rising rapidly and may keep increasing in quantum as a consequence of improvement in the standard of living, economic activities and population growth (UN-HABITAT, 2010b). Lack of waste disposal and inappropriate dumping sites are problems in most of the large urban areas in the world, which has its negative impact on human and environment (Mcfaden, 2003). In most of the urban countries of developing countries municipal solid waste management (MSWM) is highly insufficient and outside the abilities of their economic setup for handling and disposal (WHO, 1996; Henry *et al.*, 2006).

Waste disposal in developing countries is the process of collecting removing and relocating it to a place where it can be kept destroyed or recycled. With the rapid growth in urban population (which lead to an expansion of many cities) and industrial revolution result in high production, which in turn lead to the generation of more waste. Waste management becomes the second prominent problem (after water quality), affecting many cities in developing countries (Bartone, 2000).

Based on the World Bank (2012) projection, the global urban waste generation increases to 70%, and developing countries facing the highest consequences. It is expected that the total generation of waste per annum will increase from 1.3 billion tonnes to 2.2 billion tones by 2025. This will have an effect on the annual global costs of waste management as it will increase from \$205 billion to \$375 billion. The increase in population coupled with the socioeconomic activities in the metropolis has implications for a solid waste generation, disposal, and management, like all other developing countries (Ogwuche, 2013).

Nigeria is having the problem of managing waste in a modern way. This can be attributed to lack of awareness or ignorance (from both government and people) regarding modern practices of handling waste. In Nigeria, Landfill has been and continue to be the only and the most efficient method of handling waste. With the expansion of human settlements, most of the existing landfills encroach. Hence, settlements, which are adjacent to waste dumping site are severely affected. Unplanned location of the dump site, has subsequently polluted water resources and air making the environment becoming unfriendly (Clemson, 1995).

2.4.1 Solid Waste Management System in Low-Income countries

The open dump approach is the primitive stage of landfill development but remains the predominant waste disposal option in most of the African countries including Ethiopia. It is a strategy for municipal solid waste management, which involves disposal of waste with limited measures to control operations, including those related to the environmental effects. An operated or semi-controlled dump is often the first stage in a country's efforts to upgrade landfills (Lars *et al.*, 1999). When cities grow and produce more waste and their solid waste collection systems become more efficient, the environmental impact from open dumps becomes intolerable. The conversion of open or operated dumps to engineered dump sites and sanitary dump sites is an essential step to avoid future costs from mismanagement. The first step and challenges in upgrading open dumps to sanitary dump sites involve reducing irritations such as bad smell, dust, vermin and birds. The term sanitary dump is generally used for dump sites that engage in waste compaction and apply daily soil cover to reduce nuisances. Generally, in most of the African nations, the environmental economic impacts of poor solid waste management practices on groundwater as well as surface waters are becoming serious issues.

In low-income countries, the municipal solid waste management system is either not efficient or as such solid waste generated has become a threat to the environment. The growth in population, urbanization, industrialization and waste generation in the developing countries call for proper solid waste management as it has become a necessity for environmental conservation and sustainability. For a sustainable solid waste management system policies and techniques such as waste recycling, reuse, waste reduction, thermal treatment, landfilling and biological treatment must be in place. Engineered dump site method has been widely recognized as the most used of all waste management techniques (Sivasankar and Kuppu, 2017).

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

2.4.2 Solid waste management in Ethiopia

Municipal Solid Waste Management (MSWM) is a problem that is experienced by all counties in the world. It is an issue mostly witnessed in urban areas as a result of a high surge in population growth rate and increase in per capita income, thus posing a danger to environmental quality and human health (Javaheri, 2006). Because of its nature, it has one of the major environmental problems man continues to face. Investigation of waste management is now becoming critical in developing countries (Kyessi and Mwakalinga, 2009).

Waste management is understudied, in developing countries, but now receiving increasing attention. Municipal solid waste management problems have become more pronounced in recent years, as a result of inadequate collection and disposal of wastes. In most cities, wastes are not properly collected and where the proper collection is ensured, only a small fraction receives proper disposals. Urban waste management has been challenging for municipalities and urban governments in the developing world, largely due to poor infrastructure and limited institutional capacity. Municipalities throughout Ethiopia are not free of these problems as they have been facing major challenges with the solid waste collection and management (Issam *et al.*, 2007).

Per-capita waste generated in Ethiopia ranged from 0.11 to 0.35 kg/day for rural areas 0.17 to 0.48 kg/day for urban areas. The range depends on several factors such as income and season. In

Ethiopia, the total municipal solid waste generation in 2003 was 2.8 to 8.8 million tonnes. This can be split to approximately 0.6 to 1.8 million tons from rural areas and 2.2 to 7 million tons from urban areas (World Bank and EPA, 2004). In many of the cities in Ethiopia, municipality administration is responsible for waste collection. Though there is a wide variation in the performance in relation to waste collection in cities, it has become a common practice to have household waste to be pre-collected by individuals who are organized through formal or informal association. The pre-collected waste is then changed into containers, which are collected by municipalities. Nevertheless, for a long period of time, in many cities, there are not enough containers to cover the population and vehicles are typically under maintenance or out of service (CSA, 2007).

Jigjiga City, being the largest city in the Somali Regional State and one of the swiftly urbanizing centers in the country, has been grappled with an increasingly growing urban waste management problem. Based on taking per capita amount of waste generation in the nation and total population of the city into account, the total municipal solid waste generation of city 21.4 to 60.4 tones (CSA, 2007). Some studies have shown that only 43% of waste is properly collected in the country and disposed at an open dump site. The remaining waste is indiscriminately disposed of in drainage lines, open spaces, street sides or informally burned.

Currently, only 55% of the solid wastes generated per day is collected and disposed by the Harmed SWM Company in the Sheik Ali Gure dumpsite at 6km far from the center of city and the remaining 45% of the solid wastes is uncollected or dumped in unauthorized areas such as open fields, ditches, sewers and streets. Uncollected solid waste generation is an environmental hazard for all, especially, in areas where the roads and rivers are not suitable for collection. This causes bad odors and attracts various vectors and pests resulting in a deteriorated aesthetic quality of the city and spread diseases.

The community waste collection service is insufficient and scenes of scattered waste are similar in most part of Jigjiga city. As a consequence, the population has the opinion that the municipal solid waste collection service is not functioning properly. As a consequence of this, the willingness of the population to cooperate with waste collection operation and to pay for the service is low. Solid waste collected from hospitals, residential and business areas is dumped at the dumpsite on the outskirts of the city with little incineration in the hospitals. In terms of social waste processing

and recycling, little is done at all level of its management. There is no source separation or sorting and this happens at disposal sites too. But, some scavengers at dump sites practice an informal type of waste reuse.

The disposal of waste has proved to be a major public health issue and a vital factor affecting the environmental quality of all living things. This, especially in Ethiopian cities has become one of the most unmanageable environmental problems today. One of the main problems facing the city is the open and indiscriminate dumping of refuse.

2.4.3 Dump site selection

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

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

Dump site selection in an urban area is a critical issue because of its enormous impacts on the economy and the environmental health of the region, and many site selection factors and criteria should be carefully organized and analyzed. One of the complicated steps is locating of waste dump sites have precise steps including site selection and preparation of waste dump site. If these dump sites are near the individual's workplace or living places, it is considered as a negative outcome and it may cause irreparable consequences to human life (Seiied, 2015).

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

2.5 Application of RS and GIS for Solid Waste Dumping Site Selection

2.5.1 Application of Remote Sensing

Remote sensing is defined as the science or art of obtaining information about an object, area or phenomenon through the analysis of the data acquired by a device that is not in contact with the object, area or phenomenon under investigation. Remote sensing serves as a tool for environmental resource assessment and monitoring. Nishanth *et al.* (2010) also describe remote sensing as one of the excellent tools for inventory and analysis of environment and its resources, owing to its unique ability to provide the synoptic view of a large area of the earth's surface and its capacity of repetitive coverage. With the availability of remotely sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions have made RS as one of the best sources of data for large-scale applications and study (Assefa *et al.*, 2007).

Use of remote sensing is becoming frequent in environmental studies. In the recent years, no serious research of the environment performed without advanced image processing and analysis. One of the most important applications of remote sensing can be found in the case of solid waste dump site selection, where remote sensing data (satellite images) are used for extracting most of the site selection criteria used for siting dumping sites (Oštir *et al.*, 2003), (example, mapping land-use/land-cover, geology and surface water). Moreover, remote sensing can provide digital data as an input for GIS.

2.5.2 Application of GIS

The application of GIS in environmental planning has a strong support that can be utilized for materializing sustainable environmental management ways and in sustainable development (Wang *et al.*, 2009). As a management tool, GIS is used in a wide spectrum of disciplines, which include ecological management, fishery, water management, wildlife management, tourism, waste management, natural hazards prediction and management, agriculture and fire management, to mention (Wang *et al.*, 2009). The application of GIS in environmental management has been in diverse forms for it covers all environmental aspects due to its proven power through its application in environmental management; it has come to be every nation's ambition to adopt this powerful technological entity in order to achieve the best out of environmental management as well as saving time and having long-lasting data storage facility all aimed at sustainable development as it has come to be the major environmental concern, globally.

One of the benefits of GIS is its capability for dumping site selection, dumping siting is complex, tedious and costly as it requires multiple criteria from environment, social and economic point of view. Moreover, landfill siting is a complicated process requiring detailed assessment over a vast area to identify a suitable location for constructing a dump selection subject to many different criteria (Chang *et al.*, 2008). Geographic information system application can help in determining the dump location in accordance with technical requirements, with an overlay thematic map to get appropriate landfill (Akbari *et al.*, 2008).

A geographic information system is a tool that not only reduces time and cost of the site selection, but also provides digital data bank for future monitoring program of the site. The procedure followed under the GIS framework rejects unacceptable sites considering environmental factors exclusively, other than economic and political issues, contained in the form of multiple layers of attribute information. Therefore, GIS offers the spatial analytical capabilities to quickly eliminate parcel of land unsuitable for dump site and hence reduce cost and time of dumping site processes (Chang *et al.*, 2008).

2.6 Multi-criteria decision analysis for solid waste dumping site selection

The multi-criteria decision analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a careful choice (Chakhar and Mousseau, 2008).

Multi-Criteria Decision Analysis consists of a series of techniques such as weighted summation or concordance analysis that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked, for example experts, interest groups and stakeholders according to their degree of suitability or importance for locating a particular facility/service (Malczewski, 2004) like dump site. Analytic Hierarchy Process (AHP) is one of the most commonly used MCDA tools. This tool is applied in site selection processes as it assists the decision-makers to organize the criteria and alternative solutions of a decision problem in a hierarchical decision model (Eldrandaly *et al.*, 2005). Furthermore, Multi-criteria approaches have the potential to reduce the costs and time involved in selecting facilities by narrowing down the potential choices based on predefined criteria and weights while also permitting sensitivity analysis of the results from these procedures (Higgs, 2006). Hence, multi-criteria techniques could be particularly useful in situations where there are a large number of alternative sites for a development, where there are a large number of potential criteria to be taken into consideration or where subjective judgments by different stakeholders of the different alternatives is needed to try to reach an objective consensus in the final decision- making (Michael *et al.*, 2005).

Management of solid waste program often involves incompatible environmental, economic and socioecological influences. For example, selecting a new site for dump development at minimal cost is feasible, but the compromise could be the likelihood of groundwater pollution. The dumping site selection problems have often been tackled using Multi-Criteria Decision Analysis through defining the criteria for the dump site. According to Moeinaddini *et al.* (2010), selecting municipal solid waste dump site is a Spatial Multi-Criteria Decision Analysis (SMCDA) for which both GIS and Multi-Criteria Decision Analysis methods should be used. Moreover, dump site selection by GIS is a Multi-Criteria Evaluation (MCE) having four steps such as criterion establishment, standardization of factors, the establishment of factors weight and weighted linear combination. With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of results to yield a suitability map (Hasan *et al.*, 2009). Therefore, the role of Multi-Criteria Decision Analysis in dump site selection can be completed by integrating it with GIS. Based on Eldrandaly *et al.* (2005) emphasize, integrating GIS and MCDA can solve the challenges of dump site selection, which involves highly complex spatial decision-making processes.

CHAPTER THREE

3 Materials and Methods

3.1 Description of the Study Area

Logia town is located in Afar Region of Ethiopia, bounded by $11^{\circ} 40' 48''$ – $11^{\circ} 46' 51''$ N latitudes and $40^{\circ} 55' 1.9''$ – $41^{\circ} 1' 13.25''$ E longitudes 578 km of North–East of Addis Ababa the capital city in Ethiopia, at the elevation ranges between 362–450 m a.m.s.l. The total area covered is 8418.9 ha (Fig 3.1). Access to the study area is through the main asphalted road, which runs from Addis Ababa to Djibouti.

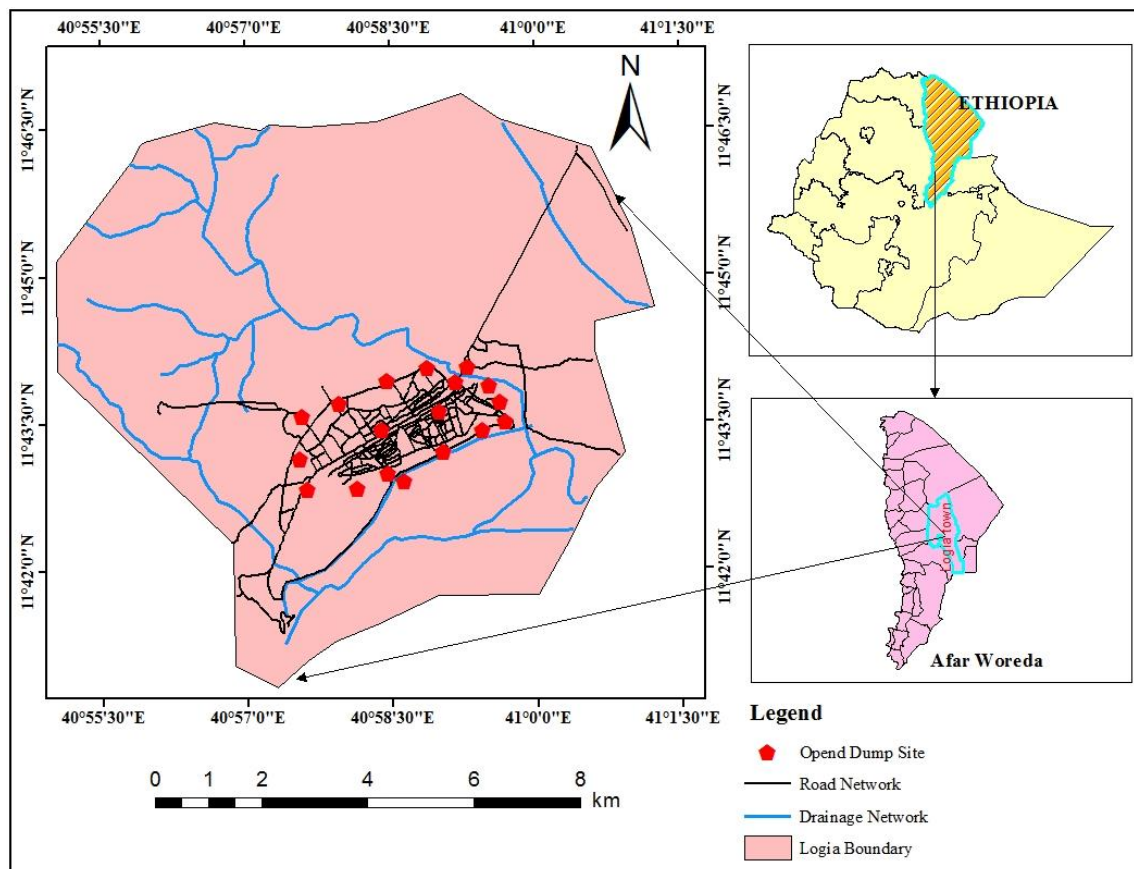


Figure 3.1: Location map of Logia town

3.2 Physiography and Drainage

The study area is located in the central part of Afar depression at the northern part of the main Ethiopian rift system. The physiography of the area is mainly controlled by volcano-tectonic rather than erosional activities. This area has no much diverse spatial variations of topographic features. The elevation of the area is from 362 m to 450 m. Geomorphologically the area is categorized into three major features as escarpment and hills, minor escarpment and small hills and plains.

Most of the drainage system is directed towards the south-east part of the study area. The lower courses of the streams and large rivers are floodplains, where a load of the streams and rivers come to rest. The Awash river forms the longest course and flows from the south direction across the ridges to plains of the southeastern part of Logia town. Because of the agricultural investment in the eastern part of the area, drainage has generally meandering nature, but the overall drainage pattern of the study area is dendritic. The most important perennial stream that drains the region is Awash river. The other river is Logia river, which runs from northwestern high land. This is a big seasonal river and tributary to the Awash river.

3.3 Population

Based on the data obtained from population projection values of the Central Statistical Agency of Ethiopia (CSA, 2014–2017), the total population of Logia town was 29,675 of which 18,343 were males and the rest 11,332 were females. As per CSA (2018), the population of the town is expected to be 64,393.

3.4 Economic activity and housing

Major economic activities of Logia town are a trade, office work, construction and other services. Among these activities trade, hotel and restaurants are the major ones. According to CSA (2007), physical characteristics of the housing units in Logia town is dense. Due to this reason, urbanization is expanded. Therefore, there are newly developing house units in the surroundings of Logia town. Its proximity to Addis Ababa and Djibouti creates a good opportunity for future developments. Logia has access roads linking the town with Addis Ababa, Kombolcha, Woldia, Dessie, and Mekele.

3.4.1 Climate

Rainfall conditions in Ethiopia are governed by National Metrological Agency of Ethiopia. The rainy season in Ethiopia changes from place to place. But, the dry seasons extends from October to March, the moist season begins in April, which is interrupted by a dry month of May. The main rainy seasons are from June to September. The area is known for its desert climate, with minimum annual rainfall. There is almost no rainfall all year long in Samara/Logia. The average annual temperature in Samara/Logia is 28.0°C. About 203 mm of precipitation falls annually. Precipitation is lowest in December, with an average of 2 mm. The highest amount of precipitation occurs in August, with an average of 52 mm. At an average temperature of 32.3 °C, June is the hottest month of the year, when it reaches around 44°C. The lowest average temperature in the

year occurs in January, when it is around 24.2°C. Vegetation is rare and only short bushy trees are seen in some relatively wet areas. Tall trees are confined to the banks of the river, such as the Awash and Logia river (NMA, 2016) Accessed on: <https://en.climate-data.org/location/55037/>.

3.4.2 Geology

Based on Geological Survey of Ethiopia, the study area geological map includes Stratoid Basalt, Rhyolitic, Flow basalt, Trap or flood basalt and Mud flats. Basaltic flow of northern parts of Logia cover is small area. The large plains are mudflat composed of clay, silt and sand cover almost more than half of the study area. Rhyolite (silicic center) is found in the West at Bowari mountain. It is characterized by high degree of deformation exhibiting faults, folds, fractures, joints, and foliations. Its color varies from dark brown to pink alternatively depending on the degree of weathering. It contains quartz, feldspar, plagioclase, and muscovite. Basaltic fissure flows are exposed in the northern parts of the study area. It is exposed along fractures and open surface fissures showing gray weathered and black fresh color. It has fine-grained texture, highly compacted and resistant for weathering (GSE, 2013).

3.5 Methods

3.5.1 Hardware/software used

For data preparation and organization, data analysis and output generation computer hardware and software were used. The hardware includes Personal Computer, hard disk, Printer and digital camera. The software's used were ERDAS Imagine 2015 for satellite image preprocessing, preparation and land-use/land-cover classifications. Handheld Garmin 78 GPS was used for field data collection. ArcGIS 10.4.1 for digitizing, proximity and overlay analysis and database creation, Geomatica software for extractions of faults, IDRISI Selva 17.2 for assigning weight and to calculate consistency ratio, and finally overlay using Weighted Linear Combination (WLC) method.

3.5.2 Source of data

To analyze the objectives of this study, two types of data were used. These were primary and secondary data collected from primary and secondary data sources.

3.5.3 Primary data

Ground control points were used as primary data types. In the field open dump site, land-use/land-cover field verification points and well points were collected using handheld GPS. In addition, some sample points from different land-use/land-cover types were also collected to verify the

current land-use/land-cover type of the study area. Photographs and field observations were also used to show the existing landfill site. Satellite images were also some of the primary data types used to show the character of land-use/land-lover classes for this study area. Interviews with experts of environmental protection officers and residents, who were near to the existing landfill were made to get more information. Results from interviews were used to identify the problem of existing dumpsite in the study area.

3.5.4 Secondary data

Different factor maps that help to select suitable dump site were used. These include road network map, soil texture map, geological map and land-use/land-cover type of the study area, built-up area extract from land-use/land-cover, DEM of Logia town to derive the slope, fault and river/drainage of the study area. Additionally, secondary data were acquired from reliable internet sources, reports, journals and governmental institutions manuals. In addition, demographic characteristics and related data were gathered from Central Statistics Agency (CSA) and from Administrative Offices in Samara/Logia town. All the above data were collected, tabulated and analyzed in remote sensing and GIS environment for further analyses (Table 3.1).

Table 3.1: Source and type of Secondary data

No	Type of Data	Source of Data	Software Used
1	Road network map	Google Earth	Online from google earth
2	Soil map	Ministry of Agriculture	ArcGIS 10.4.1
3	Land-use /land-cover type	Sentinel 2A image with 10 m resolution from Copernicus hub	ERDAS Imagine 2015
4	Slope	DEM	ArcGIS 10.4.1
5	Geological map	Geological Survey of Ethiopia	ArcGIS 10.4.1
6	River/Stream network	DEM	ArcGIS 10.4.11
7	Fault map	DEM	Geomatica2017

3.5.5 Methods used for solid waste dump site selection

This study used primary and secondary data which contain both spatial and non-spatial data, complemented with detailed ground truthing. As observed by different authors (Suman, 2012; Eneche *et al.*, 2017), there are numerous criteria used in the mapping of solid waste dumping sites in any geographic area. The present study considered factors such as fault, slope, land-use/land-cover, geology, soil, well points, waterbody, built-up areas, and road. Dump site selection using GIS-based multicriteria generally classified in three phases. During phase one, all the input

datasets were georeferenced to Adindan UTM Zone 37N coordinate system, calculated multiring buffer distance for thematic layers and restrictions of criteria and reclassified by giving weights and new maps were generated. During phase two, GIS was employed to screen out unsuitable areas based on the set criteria. Each criterion was distinguished into five suitability classes, namely, highly suitable, suitable, moderately suitable, less suitable and unsuitable (restricted) with ranks ranging from 1 to 5, where 5 class represents high suitable and 1, unsuitable. During phase three, MCDM was utilized to rank suitability sites and to identify the best among them on the basis of assigned weights. Weights of each class under each criterion was derived in IDRISI software in two stages through Analytic Hierarchy Processes (AHP) that rely on expert preferences in comparing the classes and preparing the numerical matrices.

In the first step, each layer was internally weighed based on buffer minimum and maximum distances and requirements and the layers were a standardized and thematic map of each criterion was produced. In the second stage, the importance or preference of each criterion relative to rest of the criteria on dump site selection was expressed by assigning weights. Analytical Hierarchical Process weight derivation module was employed to compare two criteria at a time based on expert judgment and a pair-wise comparison matrix from which a set of weights referred to as Eigenvectors together with consistency ratios for each of the criteria considered. After assigning external weights to each layer, Weighted Linear Combination (WLC) technique was applied to produce an overall dump site suitability map that combined all the criteria. These methods were implemented in both raster and vector GIS environments and IDRISI Silva software. With the Weighted Linear Combination, factors were combined by applying a weight to each followed by a summation of the results to yield a suitability map as shown in the following equation.

$$S = \sum_{i=1}^n W_i X_i \quad (1)$$

Where, S is suitability, w_i is the weight of factor i, and x_i is the criterion score of factor i. In case, where Boolean constraints also apply, the procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints as shown in equation 2.

$$S = \prod_{j=1}^m C_j \quad (2)$$

Where, C_j is the criterion score of the constraint j .

3.5.6 Image pre-processing

Sentinel-2 mission is combinations of two satellite configuration that offers a unique combination of systematic global coverage of land surfaces from 56°South to 84°North, high revisit every 5 days at equator under the same viewing conditions, high spatial resolution 10m, 20m and 60m, multi-spectral information with 13 bands (covering visible, near infrared and shortwave infra-red) and wide field of view 290 km.

The Sentinel-2 Level-1C products takes advantage of the stringent image quality requirements and provide users with ortho-rectified images representing Top of Atmosphere reflectance. Image pre-processing activity is required for obvious reasons that satellite images are subject to various distortions. Activities during image preprocessing are such as layer stacking and resolution merging (B02, B03, B04 and B08). Those are 10 m resolution and B11 and B12 are 20 m, image sub-setting or clipping by the study area, sun angle correction, top of atmospheric correction, geometric rectification and reprojection are performed for all images for better classification and high-quality data. Performances derived from validation activities were estimated for both Top-Of-Atmosphere (TOA) and Bottom-Of-Atmosphere (BOA) products (Baillarin *et al.*, 2012).

3.5.7 Digitizing

Digitizing in GIS is the process of converting geographic data either from a hardcopy or a scanned image into vector data by tracing the features. During the digitizing process, features from the traced map or image are captured as coordinates in either point, line, or polygon format. The data representing geographical features were saved as shapefiles manipulative by the ArcGIS software. Data were saved as discrete layers separately for the sake of separate buffering determinant on the specific parameters used for analyzing the data. For example, a layer for road network was saved separately from another geographic phenomenon like rivers and residential area layers. Using this application of GIS to develop/create features such as soil texture class, road network and lithology were produced from the soil map, google earth and geologic map, respectively (Sam and Steven, 2017).

3.5.8 Image classification

After all the pre-processing activities, one of the actual work of the project was image classification which was the basis for land-use/land-cover map measurement in the spatial metric system. Supervised classification requires the selection of training areas to get accurate classification output. According to Lillesand *et al.* (2004), supervised classification method (maximum

likelihood algorithm) was used for land-use/land-cover classification. Through, land-use/land-cover classification, training stage, classification stage, and output stage were followed. During the first stage, all numerical data were collected from training areas on spectral response patterns of this land-cover category. This stage is the main activity of supervised classification. The second stage of supervised classification was classification stage when each unknown pixel was compared to spectral patterns and assigned to a most similar category. The final stage was output stage when the final result was presented as Figure and Table forms.

3.5.9 Buffering

Buffering is a well-pronounced way of producing areas or regions of numerically calculated distances from a feature, which can be a point, line or polygon (Lunkapis, 2006). This process was achieved through reclassification of regions from a feature. Using ArcGIS 10.4.1, the considered environmental parameters using respective buffer distances were buffered. The buffered parameters included rivers, roads, well depth, faults and built-up but slope and geology is not including because both criteria are not considered as buffer distance. The buffer distances were drawn from literature (Pawandiwa, 2013). The Buffering analysis was executed for roads far a minimum distance 700 m for solid waste dump site selection. The contaminated runoff from the landfill will have an adverse effect on surface water. Accordingly, Tyowuah and Hundu (2017) used 500 m as a minimum buffer distance for river buffer distance criteria for solid waste dump site selection. Therefore, to minimize such pollution, different researchers set minimum buffer distance for solid waste dump site selection. Based on Rafee *et al.* (2011), fault was used buffer distance of 500 m for solid waste dump site selection. For built-up area (Sam and Steven, 2017) was used buffer distance of 700 m and accordingly Chang *et al.* (2008), minimum buffer distance of well point was used 500 m with the given values in meter. These values for buffering analysis were assigned and a new value was generated based on the geographical characteristics and clip buffer distance result using Logia town.

3.5.10 Analytic hierarchy process

Analytic Hierarchy Process (AHP) was used as a decision rule to analyze the data for waste disposal site selection using GIS (Sehnaz *et al.*, 2011). This process contains the construction of pair-wise comparison matrices and the extraction of weights by using the principal right eigenvector (Theo, 2010; Sehnaz, 2011). Pair-wise comparison matrix was created by setting out one row and one column for each factor in the problem. Therefore, the AHP divides the decision

problems based on the factors into understandable parts. Each of these parts was analyzed separately and integrated in a logical manner as suggested by Theo (2010). Analytic hierarchy process also facilitates sound decision applying both empirical data as well as subjective judgments of the decision maker. It assists to establish priorities among the elements within each stratum of the hierarchy. In AHP the 9-point scale, which is ranging from 1 (indifference or equal importance) to 9 (extreme preference or absolute importance) (Saaty, 1980) was used in the decision-making process for waste disposal site selection in Logia town (Table 3.2). In reference to rating scale of 9, (Theo, 2010) also suggested a 9-point scaling system where, 1 for equal importance, 3 for moderate importance, 5 for strong, 7 for very strong and 9 for extreme importance, integers in between for refinements 2, 4, 6, 8, and reciprocals for the inverse judgments. These criteria were developed by referring different sources from the literature. Then a pair-wise comparison of criteria was performed and results were put into a comparison matrix. The matrix is populated with values from 1 to 9 and fractions from $1/9$ to $1/2$, representing the importance of one factor (Table 3.2). Analytic hierarchy process allows some small inconsistency in judgment because human is not always consistent. The ratio scales were derived from the principal Eigenvectors and the consistency index was derived from the principal Eigenvalue.

3.5.11 Weighted overlay analysis

The weighted overlay is a procedure for applying a common measurement scale of values to different inputs to create an integrated analysis. The weight is given through empirical methods and subjective judgments by the decision maker. For this study, weighted overlay analysis was used for each input layer such as groundwater well points, surface water/river, land-use/land-cover, road network, geology, slope, fault, built up area and soil maps, and suitable site sensitivity index. In this process, weight was assigned to different thematic layers based on their influence in deciding the site suitability. Weighted overlay analysis was employed for deciding the suitable location of solid waste disposal of Logia town.

Table 3.2: Scale for pair-wise comparison of solid waste site selection (Saaty, 1980)

The intensity of pairwise comparison	Definition
1	Equal Importance
2	Equal to Moderately Importance
3	Moderate importance
4	Moderate to the strong importance
5	Strong importance
6	Strong to the very strong importance
7	Very strong importance
8	Very to the extremely strong importance
9	Extremely importance
Reciprocals	Values for inverse comparison

3.5.12 Aggregation of suitability sites using the methodology

To achieve the aim of this research nine criteria were identified that suits the area. These were the distance to river, built up, fault, road, well points and other criteria include like geology, slope, soil type, land-use/land-cover. Decision-making principles were used to transform layers into scales that allow all to be combined. In the study, three methods were used, multi-criteria evaluation and AHP. These phases were used to identify the most suitable site for landfill using multi-criteria evaluation, AHP, and GIS techniques. Weight Linear Combination (WLC) was applied for the MCE. Two types of criteria were used parameters and constraints. A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. Boolean evaluation and Weight Linear Combination (WLC) were applied for MCE. The constraint served to limit the alternatives under consideration, which were expressed in the form of a Boolean logical map in 0 and 1 (Mohammad *et al.*, 2009; Eastman, 2012; Shahabi *et al.*, 2013; Olusina and Shyllon, 2014).

The following equation was used for Multi-Criteria Evaluation (MCE)

$$S = \sum_{i=1}^n WiCi * \prod_{j=1}^m rj \quad (3)$$

Where,

S = suitability for a waste disposal site, W_i = weight of factor i , C_i = criterion for suitability of factor i , r_j = criterion for suitability of constraint j and Π = product.

Phase 1: Restriction model

In the first stage, a model was prepared and named Restriction Model. The formula used in achieving the logic was extracted from the multi-criteria evaluation as;

$$s = \prod_{j=1}^m r_j \tag{3a}$$

$S = (r_{road} * r_{fault} * r_{river} * r_{well\ point} * r_{built-up})$.

Where,

r_{road} ; restriction to location related to the river site

r_{fault} ; restriction related to fault site

r_{river} ; restriction related to river location

$r_{well\ point}$; restriction related to wellpoint location

$r_{built-up}$; restriction related to the built-up site.

Phase 2: Suitability model

The second stage deals with the factor criteria, so a Suitability Model is applied in archiving the task which is Weight Linear Combination (WLC) together with the AHP. The WLC is the most common technique for analyzing multi-scale evaluations. This technique also is called a ‘‘scoring method’’. The AHP was used to capture aspects of the decision. It was used in computing the weights for different criteria used by creating a pairwise comparison matrix. The following equation was used for the model:

$$S = \sum_{i=1}^n W_i C_i \tag{3b}$$

$S = (W_{lu}C_{lu} + W_{so}C_{so} + W_{ge}C_{ge} + W_{sl}C_{sl} + W_{ro}C_{ro} + W_{fa}C_{fa} + W_{ri}C_{ri} + W_{wp}C_{wp} + W_{bu}C_{bu})$

$W_{lu}C_{lu}$: weight and criteria for Land-use

$W_{so}C_{so}$: weight and criteria for soil

$W_{ge}C_{ge}$: weight and criteria for geology(lithology)

$W_{sl}C_{sl}$: weight and criteria for slope

$W_{ro}C_{ro}$: weight and criteria for road

$W_{fa}C_{fa}$: weight and criteria for fault

$W_{ri}C_{ri}$: weight and criteria for river

$W_{wp}C_{wp}$: weight and criteria for groundwater well points

$W_{bu}C_{bu}$: weight and criteria for built-up

Phase 3: Multi-criteria model

The third stage combined both the Boolean and Weight Linear Combination (WLC) which results in a final site using the following equation:

$$S = \sum_{i=1}^n WiCi * \prod_{j=1}^m rj \quad (4)$$

$S = ((r_{road} * r_{fault} * r_{river} * r_{well\ point} * r_{built-up}) * (W_{landuseClanduse} * W_{soilCsoil} * W_{lithClith} * W_{slopeCslope} * W_{roadCroad} * W_{faultCfault} * W_{riverCriver} * W_{wellCwell} * W_{built-up\ Cbuilt-up}))$.

A number of possible selections were examined for setting a suitable site by taking into consideration multiple criteria and contradictory objectives in a GIS-based MCE technique, using WLC analysis (Chang *et al.*, 2008; Ansari *et al.*, 2012). Data were obtained from different sources and stored in GIS system and used for suitable site selection studies.

3.6 Identification and reclassifications of criteria

Nine criteria or factors were used for dumping site suitability selection in Logia town. From the nine criteria, five (groundwater well points, faults, surface water/river, road network, and built-up area) needed buffer distance calculation, calculate constraint (limitation) using multiring buffer tool, and reclassification for suitability. After the above processes were concluded, giving suitability rank based on their buffer distance, suitability standard that was suitable for solid waste dumping site selection. The two criteria (soil type, lithology) were prepared using soil type from FAO (2007) clipping by Logia town shapefiles, lithology digitized from sentinel 2A satellite image after digitizing covert to a polygon to raster using a polygon to raster tools then reclassified based on permeability(porousness) and porosity(absorbency) based on mineral contents. The remaining two factors (slope and LU/C) were processed slope calculated in degree from digital elevation model and land-use/land-cover classified from sentinel 2A satellite image using supervised classification methods. For all factor reclassified and assigning suitability rank based on their weight when influencing the dump site selection. During assigning suitability rank giving value 1, 2, 3, 4, and 5 indicated the suitability rank unsuitable, less suitable, moderately suitable, and highly suitable, respectively. A detailed flowchart of the present study shown in Figure 3.2.

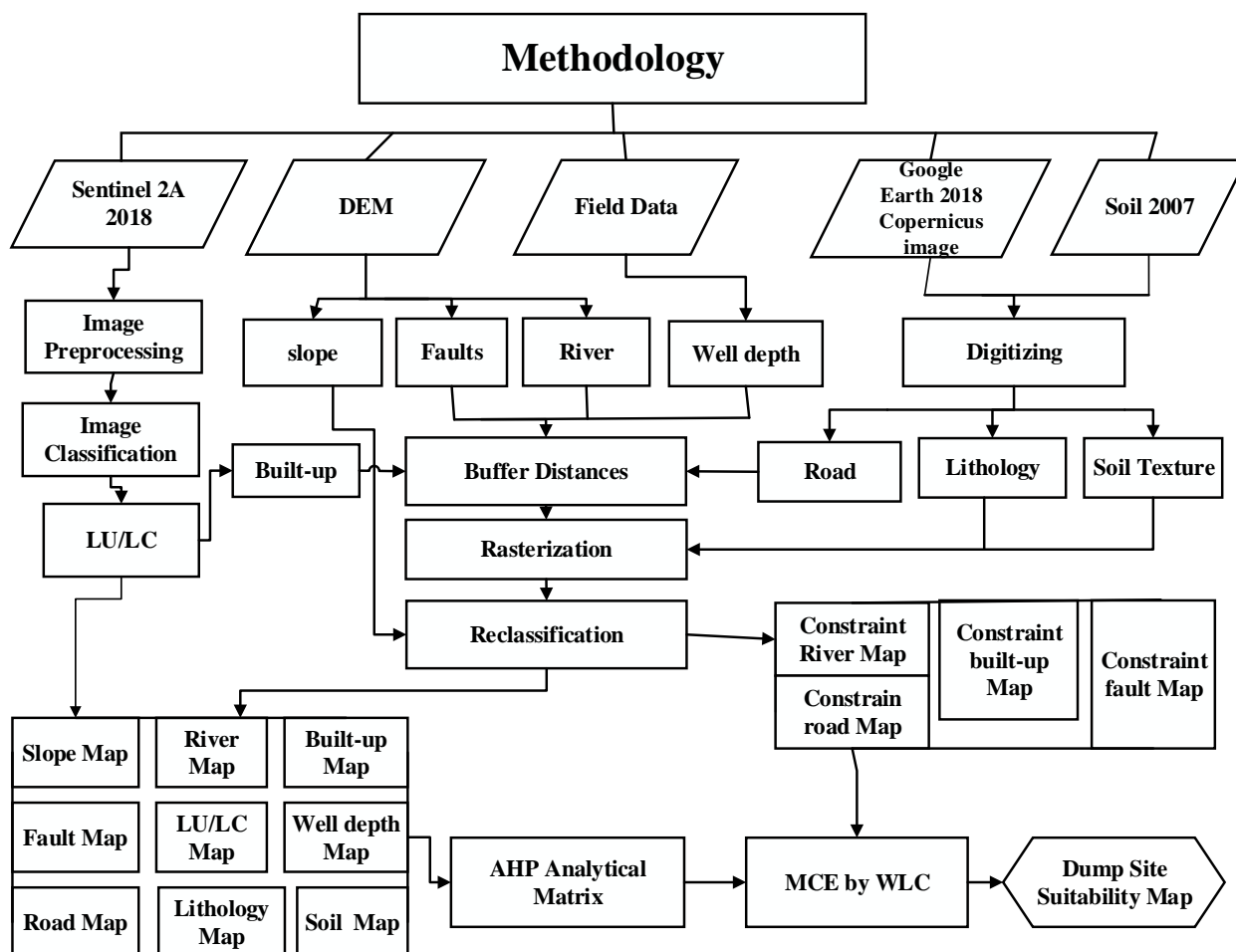


Figure 3.2: General workflow of the present study

3.6.1 Groundwater depth

The groundwater circulation and the downward flow of pollutants through rocks and soils are depending on the hydrogeological condition of the materials, specifically hydraulic properties such as porosity, permeability and transitivity (Tsegaye Mekuria, 2006). The proximity of a solid waste dump site to a groundwater well point is an important environmental criterion in the dump site selection so that well points may be protected from the runoff and discharge of the dump site. Therefore, Unsuitable solid waste disposal particularly in the areas that the depth of groundwater is very deep can suitable the consumer’s health due to the pollution of materials and penetration of these materials to ground water. The distance of dump site suitability from the water well depth is more than 1720 m. Additionally, it can have irreversible human and environmental effects. Proximity to well was considered as an important criterion for this research. In Logia town, 10 groundwater well points are currently functional. It was gathered from field survey and Multiple Ring Buffer methods and prepared buffer zones around each groundwater well point. For this

work, Multiple Ring buffering was performed at the groundwater well points in order to identify the best site for the dump sites.

The solid waste dump site very far from a well will have a minimum effect, and solid waste dump site very close to the groundwater well points will have a high effect related with health problems and environmental pollution. Generally, the close the solid waste dump site is located, the more probable for groundwater to be contaminated. Therefore, according to Chang *et al.* (2008), buffer distance of groundwater well points as 92–96 m, 96–101 m, 101–105 m, 105–110 m and >110 m was prepared around each and every groundwater well point. The map was prepared with the suitable and unsuitable areas based on this criterion (Table 3.3, Fig 3.3 and 3.4).

Table 3.3: Solid waste dump site selection using ground well points as criteria

No	Criteria value (m)	Classification suitability
1	92–96	Unsuitable
2	96–101	Less suitable
3	101–105	Moderately suitable
4	105–110	Suitable
5	>110	Highly suitable

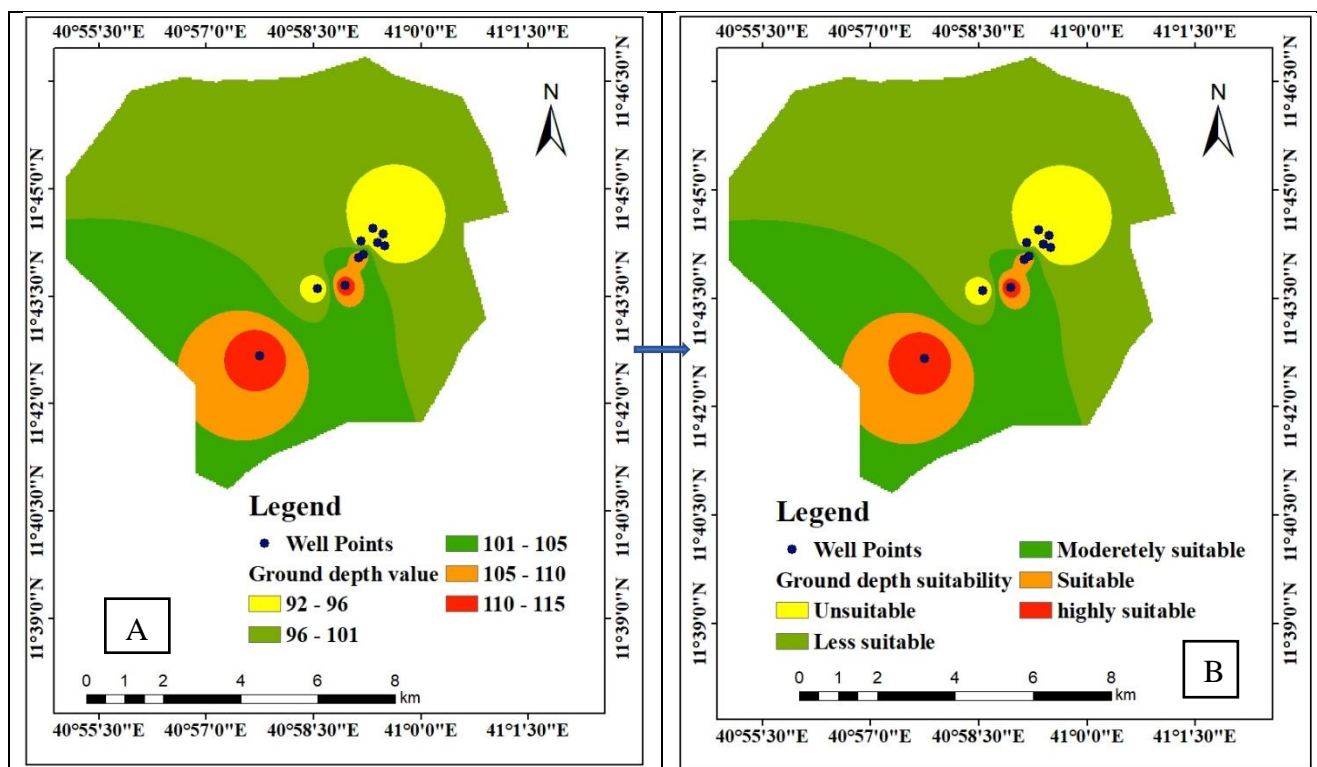


Figure 3.3: Well points buffer distance map (a) and reclassified well point suitability map (b)

3.6.2 River

The River criterion is important in environmental and economic concerns due to pollution. For instance, if water bodies neighboring the dump site are used as drinking water or represent a potential source for drinking water in the downstream, the site should be considered as unsuitable due to the risk of water contamination associated with the operation of dump site (ISWA, 2013). Surface water of the study area was generated from digital elevation model (DEM) in GIS environment. Using an elevation raster or digital elevation model (DEM) as input, it was possible to delineate drainage system and quantify the characteristics of the system. Based on ArcGIS 14.1 helps the following the steps involved in calculating a watershed and stream network from a DEM: The first steps of deriving hydrologic characteristics of a surface are the ability to determine the direction of flow from every cell in the raster. This was done with the Flow Direction tool. This tool takes surface as input and outputs a raster showing the direction of flow out of each cell. The direction of flow was determined by the direction of steepest descent, or maximum drop, from each cell. This was calculated as follows:

$$\text{Maximum drop} = \text{change in z-value} / \text{distance} \times 100$$

Where, the distance was calculated between cell centers. Therefore, if the cell size is 1, the distance between two orthogonal cells is 1 and the distance between two diagonal cells is 1.414 (square root of 2).

The second step was calculating sink and fills with DEM. With the Sink tool, any sinks in the original DEM were identified. A sink is usually an incorrect value lower than the values of its surroundings. It is a cell or set of spatially connected cells whose flow direction cannot be assigned one of the eight valid values in a flow direction raster. This can occur when all neighboring cells are higher than the processing cell or when two cells flow into each other, creating a two-cell loop. The output of the Sink tool is an integer raster with each sink being assigned a unique value. Sinks are numbered between one and the number of sinks. The depressions (the scattered colored points) are problematic because any water that flows into them cannot flow out. To ensure proper drainage mapping, these depressions can be filled using the Fill tool. The tool can also be used to remove peaks, which are spurious cells with elevation greater than would be expected given the trend of the surrounding surface.

The third step was creating a stream network, using the Flow Accumulation tool to calculate the number of upslope cells flowing to a location. The output flow direction raster created in a previous step was used as input. The result of Flow Accumulation is a raster of accumulated flow

to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell and output cells with a high flow accumulation are areas of concentrated flow and can be used to identify stream channels.

The fourth step was stream generated A threshold can be specified on the raster derived from the Flow Accumulation tool; the initial stage is defining the stream network system. This task was accomplished with the Con tool or using Map Algebra. The syntax to use in Con is new raster = con (accumulation > 5000, 1). All cells with more than 5000 cells flowing into them will be part of the stream network. Finally, conversion tool converts a raster dataset to polyline features. After converting polyline features creating buffer distance based on the standards. According to Tyowuah and Hundu (2017), the distance for surface water 500 m can be used as a minimum buffer distance for river criteria that are separate from the dump site. In order to reduce vulnerability to ground and surface water pollution from contamination, dump site should not be located near the river. In this study area a minimum distance of 500 m was used for site selection process to protect surface water from pollution. Accordingly, buffer tools were used to prepare a buffer zone with 0–500 m, 501–1000 m, 1001–1500 m, 1501–2000 m and >2000 m distance range (Table 3.4, Fig 3.5 and 3.6). This buffering was to identify safety site for the dump. This study area contains two rivers. These are Logia river and Awash river. The local community mostly used these rivers for drinking and agricultural purpose in the downstream. Therefore, the more distant from surface water, the more suitable for dump sitting to reduce the negative effects of solid waste.

Table 3.4: Solid waste dump site selection using river as criteria

Factor	Criteria value (m)	Classification suitability
River	0–500	Unsuitable
	501–1000	Less suitable
	1001–1500	Moderately suitable
	1501–2000	Suitable
	>2000	Highly suitable

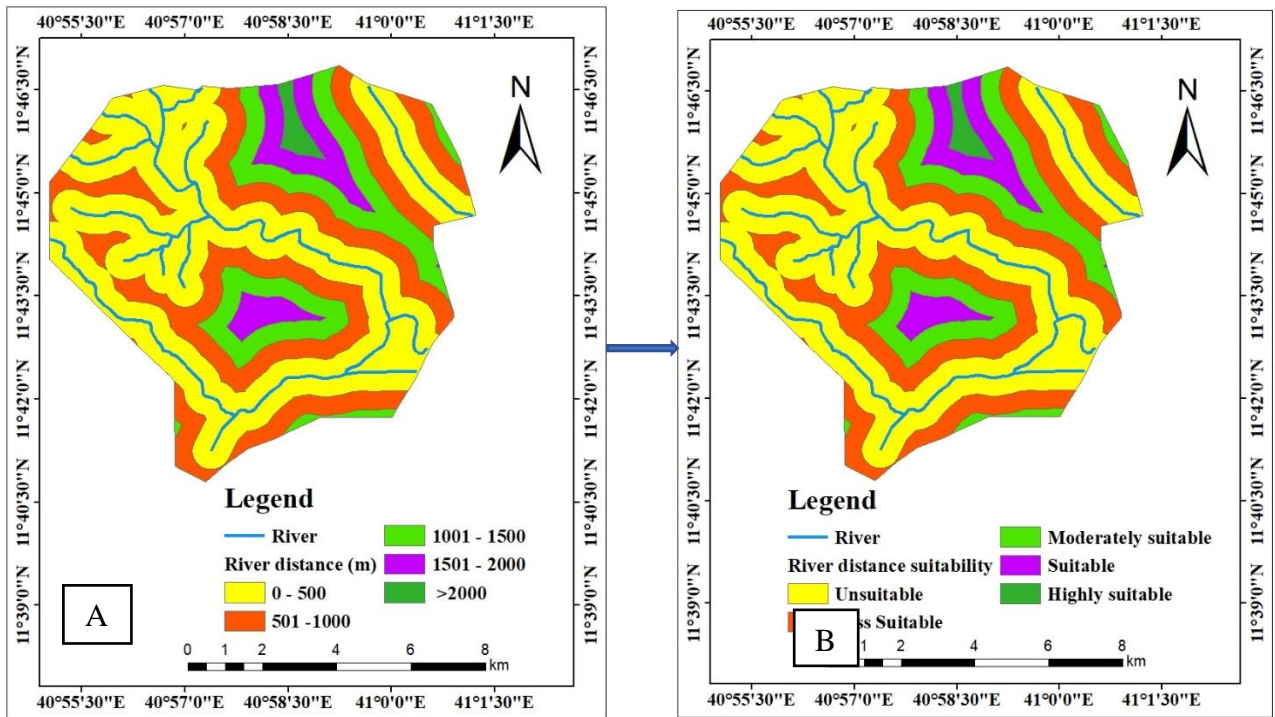


Figure 3.4: River buffer distance map (a) and reclassified river buffer suitability map (b)

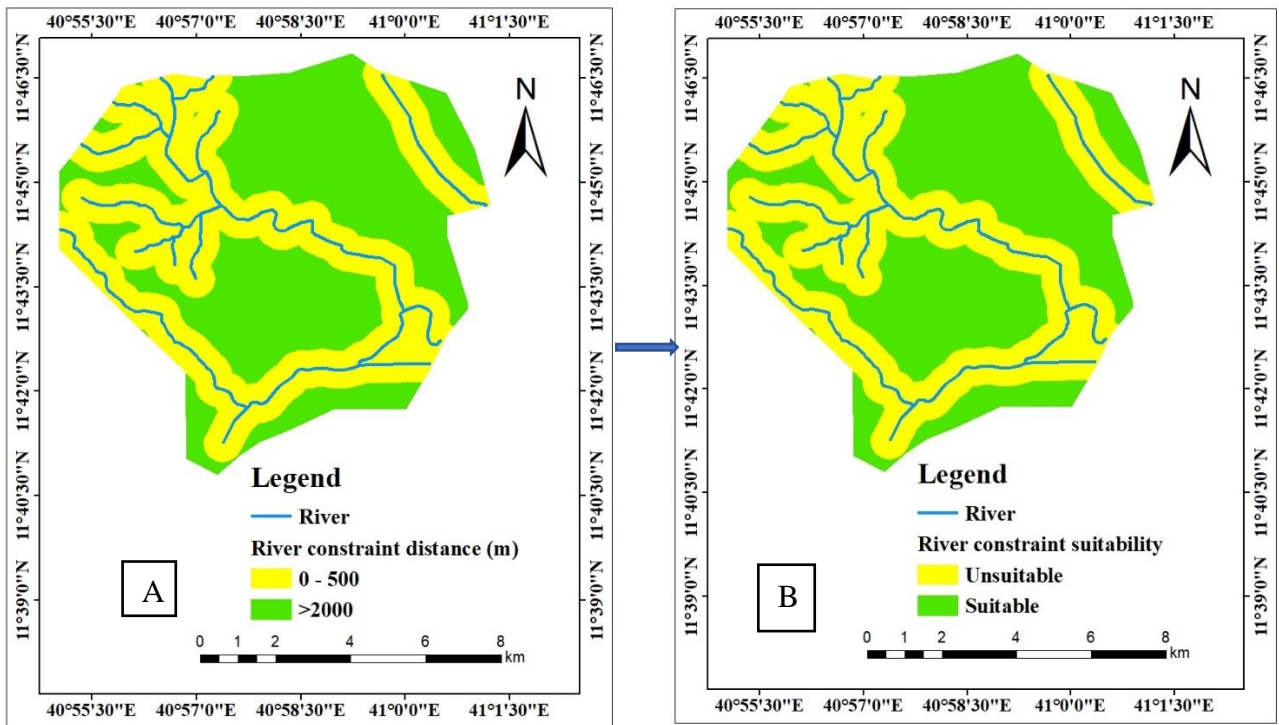


Figure 3.5: Constraint buffer distance map (a) and constraint buffer reclassified river map (b)

3.6.3 Slope

The topography of the site also influences the costs for the dump site. In the best case the topography of the site could be used in conjunction with an appropriate design of the dump site to manage water percolate flows without pumping through permeable materials, simply by gravity flow of the water percolate. This requires differences in the altitude between the drainage layer of the dump site, water percolate collection basins, water percolate treatment facility and final disposal site of the water percolate (e.g., receiving waters). The slope is one of the criteria to be considered in solid waste disposal site section. The slope of the study area was developed from DEM 30×30 m resolutions and used in GIS environment. According to Akbari *et al.* (2008), areas with high altitude or high slope are not suitable for landfill sites. The best place for solid waste dump site is medium altitude surrounded with no more than 20° slopes. The slope affects the amount of water in the soil, the possibility of erosion rate, surface runoff and groundwater pollution. The slope is crucial for the construction of dump sites, because a higher slope causes higher costs of construction. This is due to huge amount of materials, technology and human power need a high budget. Therefore, for this study slope was reclassified into three classes: 0–10°, 10–20° and >20°. Fig 3.7 indicates the slope map of the Town and (Table 5) elaborates the slope value and its classification (Akbari *et al.*, 2008).

Table 3.5: Solid waste dump site selection using slope as criteria

Factor	Criteria value in (Degree)	Classification suitability
Slope	0–10	Highly suitable
	11–20	Suitable
	>20	Unsuitable

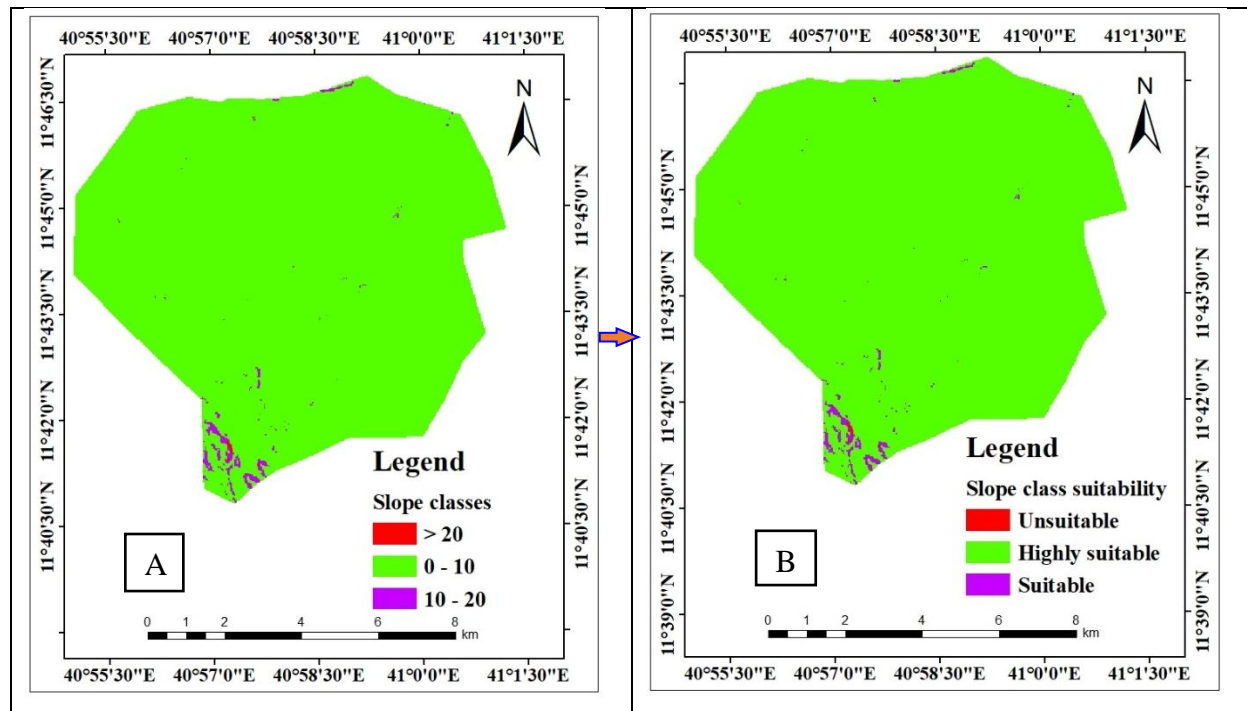


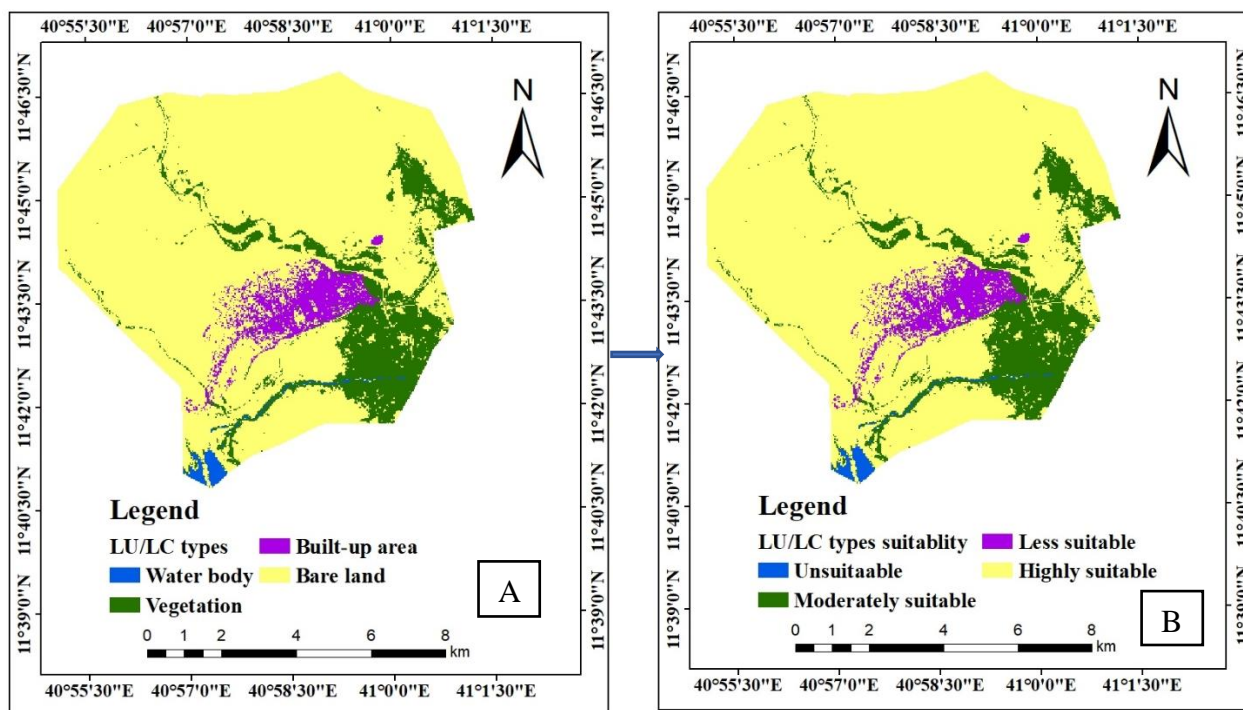
Figure 3.6: Slope class map (a) and reclassified Slope suitability map (b)

3.6.4 Land use/land cover (LU/LC)

Land-use/land-cover map of the study area was one of the criteria used to select potential sites for solid waste disposal in the town of Logia. For land-use/land-cover classification sentinel 2A image was acquired from Copernicus hub (because Sentinel 2A image is a better resolution than Landsat 8 image) and preprocessed using impact toolbox, like resolution merging, projection transformation, atmospheric correction, geometric correction and clipping by the study area shapefiles. After preprocessing the image was classified using supervised classification method. With the assistance of the Classification toolbar, created training samples to represent the classes using area of interest to extract the same class at the same time from different area and created a signature file from the training samples, which was used by the supervised classification tools to classify the image by using maximum likelihood algorithm (parameter rules). Finally, the land-use/land-cover of the study were classified into four classes such as vegetation, bare land, built-up and water body (Table 3.6 and Fig 3.8). In the study area, land-use/land-cover map was produced for solid waste dumping site with an overall accuracy of 86.48% using 74 Collected reference data: “ground truth”. (see Annex 4).

Table 3.6: Solid waste dump site selection using Landuse/Landcover as criteria

Factor	Criteria Value	Classification Suitability
LU/LC	Water body	Unsuitable
	Built-up area	Less suitable
	Vegetation	Moderately suitable
	Bare land	Highly suitable

**Figure 3.7:** Land-use/land-cover type map (a) and reclassified land-use/land-cover suitability map (b)

3.6.5 Lithology

In Landfills site selection, the geological characteristics and structures of the regions are very important. Generally, there are five major geological characteristics in in the study area. These are Stratoid Basalt shows and forming mountain chain. Its grain size is ranging from fine to medium. Aphanitic basalt with quartz vein filling some joints and also has vesicular texture at the top. This rock is not suitable due to the slope and affected by fracture. Trap or flood basalt is fine-grained, extrusive igneous rock covering gentle to flat topography of the area. It is highly fragmented and less thickness underlying with alluvial deposited or mud flat. Because of these natures it is moderately good for landfill site. Rhyolitic rock is occurred by lava flow of felsic composition forming dome shape. It shows flow banding at the top and loose pinkish color at the bottom. Flow basalt is formed by fissure or central eruption and covers large areas of central to north western

part. This rock is highly affected by faults and joints; mostly it overlies layered bed of vesicular basalt. Mudflat is the large plain area which contains clay, silt and sand deposition of thick layers. This unit is the most important for waste disposal site, because of its mud nature fluid is not transmitting through the layer.

From the above five units only two of them are preferable, the rest of them are not due to their topography and texture. The constant characteristic of the 3 lithology types is that they all contain fracture, meaning that they allow water percolation (Table 3.7 and Fig 3.9).

Table 3.7: Solid waste dump site selection using lithology as criteria

Factor	Classes Type	Classification suitability
Geology	Stratoid Basalt	Unsuitable
	Rhyolitic	Less suitable
	Flow basalt	Moderately suitable
	Trap or flood basalt	Suitable
	Mud flats	Highly suitable

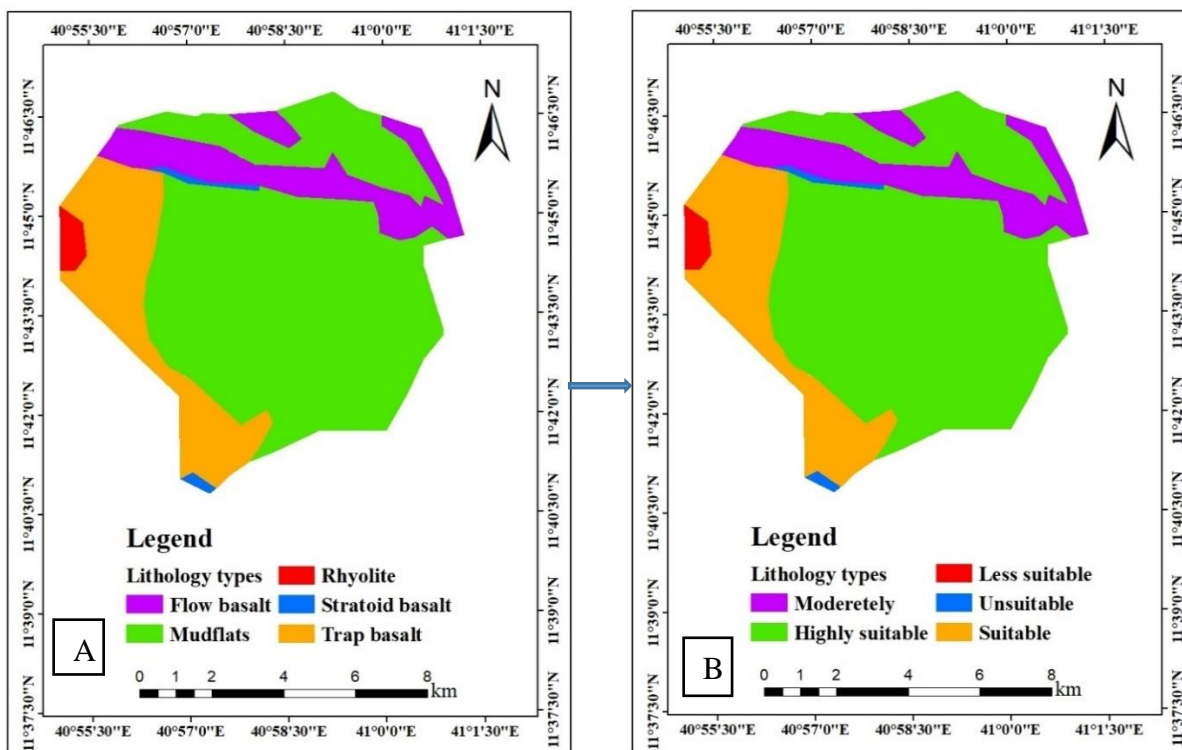


Figure 3.8: Lithology type map (a) and reclassified Lithology suitability map (b)

3.6.6 Fault and soil

The fault is one of the criteria considered for solid waste disposal site selection. The fault of the study area was generated from Digital Elevation Model of Logia town. To generate faults of the

study area the following methods were followed. First preprocess the digital elevation models that are sink or fill calculation and projection transformation, similar to the study area to overlay and clipping by the study area extents. The next process was to find fault area using geomatics software by increasing and decreasing the edge gradient threshold value (change pixel value) to create the minimum and maximum faults included in the study area. The file was saved as shapefile format, compatible to ArcGIS software for further analysis and/or buffer distance calculation for the thematic layer, constraint map preparation and to check the fault result by overlaying on hill shade of the study area. The study area of fault buffer distance was performed based on Rafiee *et al.* (2011). According to the literature, areas found within 1000 m buffer distance from faults were considered as unsuitable for solid waste disposal site due to high permeability of soil near the fault and groundwater contamination. Waste disposal area should be far from faults and have a minimum distance of 1000 m was used for site selection processes due to the waste can pollute the groundwater or damage the surrounding engineering structures in case of an earthquake (Rafiee *et al.*, 2011). Areas which do not have faults or have a safe distance from the faults are appropriate for dump site selection. Accordingly, buffer tools were used to prepare a proximity map distance (Table 3.8, Fig.3.10 and 3.11). Soil characteristics promote a safe and more economically feasible implementation and operation of a dump site. Permeability, effective porosity, and workability are important soil characteristics which were considered for dump site selection. In the present study area, there were two classes of soil types used for solid waste disposal site selection analysis (Table 3.9, Fig. 3.12). These are orthic solonchaks and lithosol soils were classified (Mohammed *et al.*, 2009).

Table 3.8: Solid waste dump site selection using fault as criteria

Factor	Criteria value (m)	Classification
Fault	0–500	Unsuitable
	501–1000	Less suitable
	1001–1500	Moderately suitable
	1501–2000	Suitable
	>2000	Highly suitable

Table 3.9: Solid waste dump site selection using soil as criteria

Factor	Classes	Classification suitability
Soil	Orthic solonchaks	Unsuitable
	Lithosol	Suitable

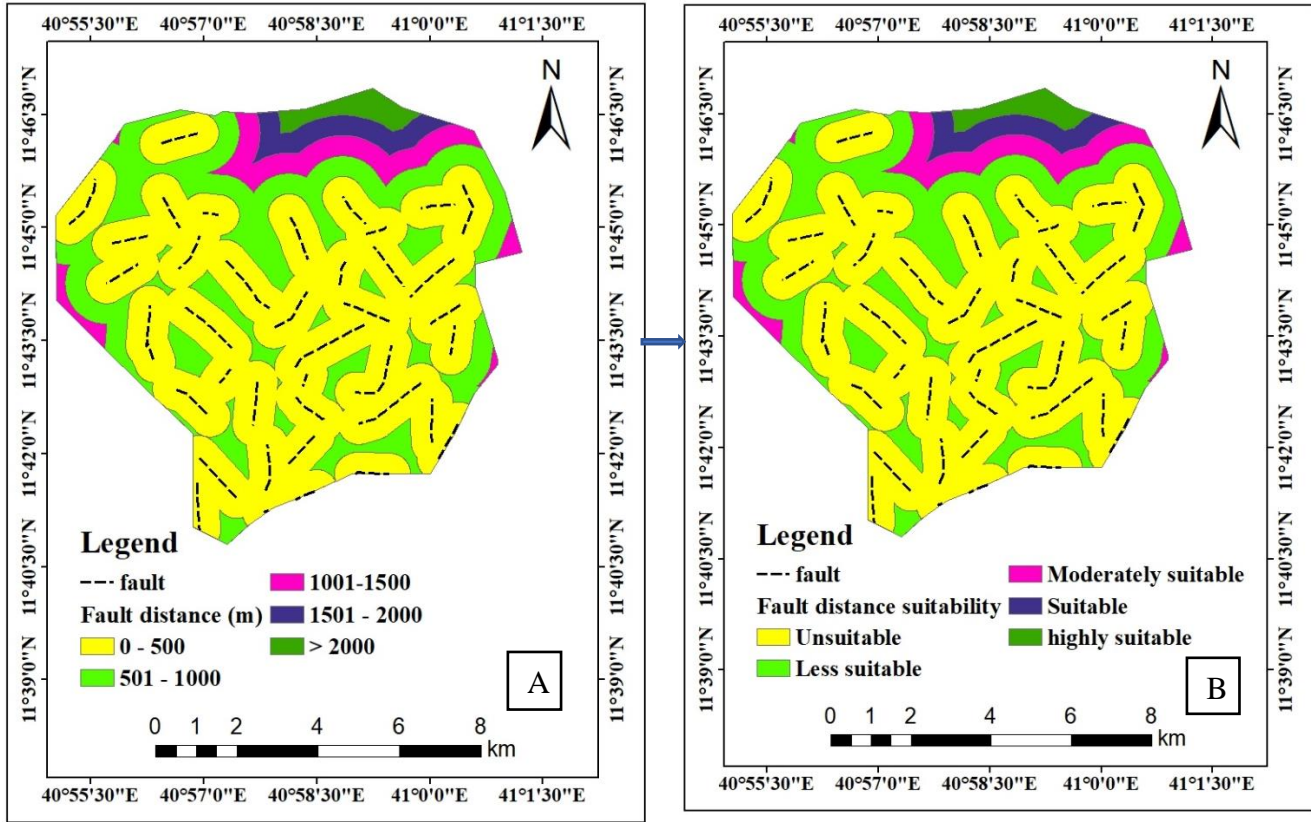


Figure 3.9: Fault buffer distance map (a) and reclassified fault buffer distance suitability map (b)

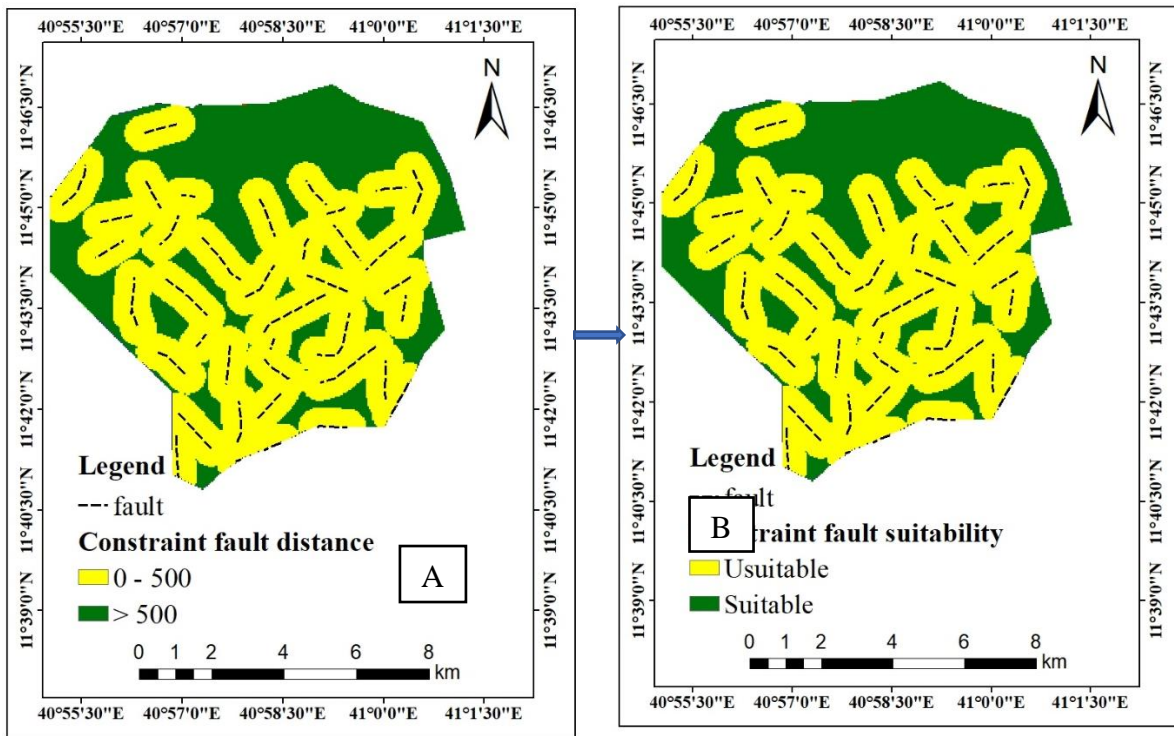
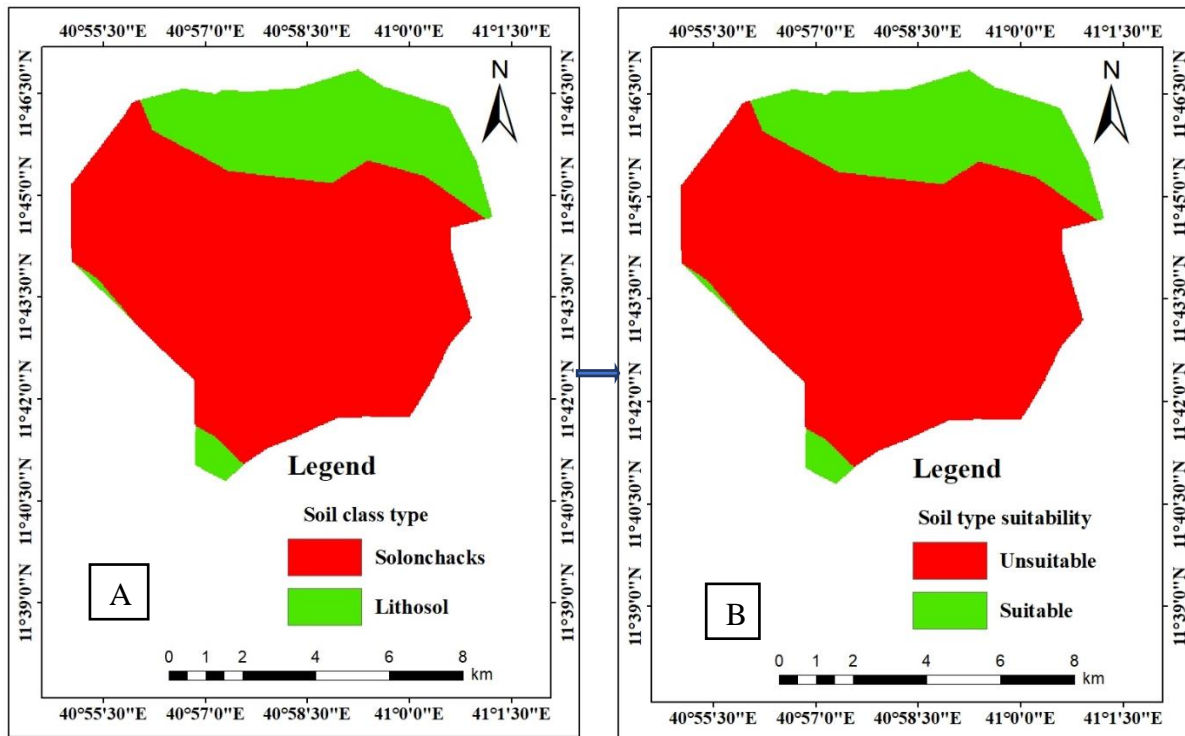


Figure 3.10: Fault constraint buffer distance map (a) and reclassified fault constraint map (b)**Figure 3.11:** Soil type map (a) and reclassified soil type suitability map (b)

3.6.7 Road networks and built-up area

Road network is one of the important criteria for solid waste disposal site selection processes. A solid waste site, especially close to roads may have a public health problem, as dump site can have the hazardous effect on human health. Moreover, dump site very far from road network is also not suggested due to high transportation cost. The existing road network was obtained from GIS environment. The road network of the study area was measured by buffer distance created in the ArcGIS environment using analysis tools. Based on the road network proximity standard (Sam and Steven, 2017), areas found below 700 m and above 700 m were considered and less than 700 m unsuitable but the above of 700 m was suitable. Therefore, for this study road network were reclassified into four classes (Table 3.10, Fig.3.13 and 3.14). Built up area is an important viewpoint of the environmental criterion in the solid waste disposal site selection. It also includes different services in the study area such as commercial area, settlement, school, religious institutions, educational institutions, health centers, governmental and private institutions and other social service areas. Solid waste disposal site should be far from such locations to avoid any pollution. The built-up area was generated from the structural plan of the study area. Set built up

with a distance greater than 700 m as the best site for solid waste disposal (Sam and Steven, 2017). In this study built-up area was classified into four classes (Table 3.11, Figs.3.15 and 3.16).

Table 3.10: Solid waste dump site selection using road network as criteria

Factor	Criteria Value (m)	Classification suitability
Road Network	0 –700	Unsuitable
	701–2100	Suitable
	2101–3500	Highly suitable
	3501–4900	Moderately suitable
	>4900	Less suitable

Table 3.11: Solid waste dump site selection using built-up as criteria

Factor	Criteria Value (m)	Classification
Built-up area	0–700	Unsuitable
	701–2100	Suitable
	2101–3500	Highly suitable
	3501–4900	Moderately suitable
	>4900	Less suitable

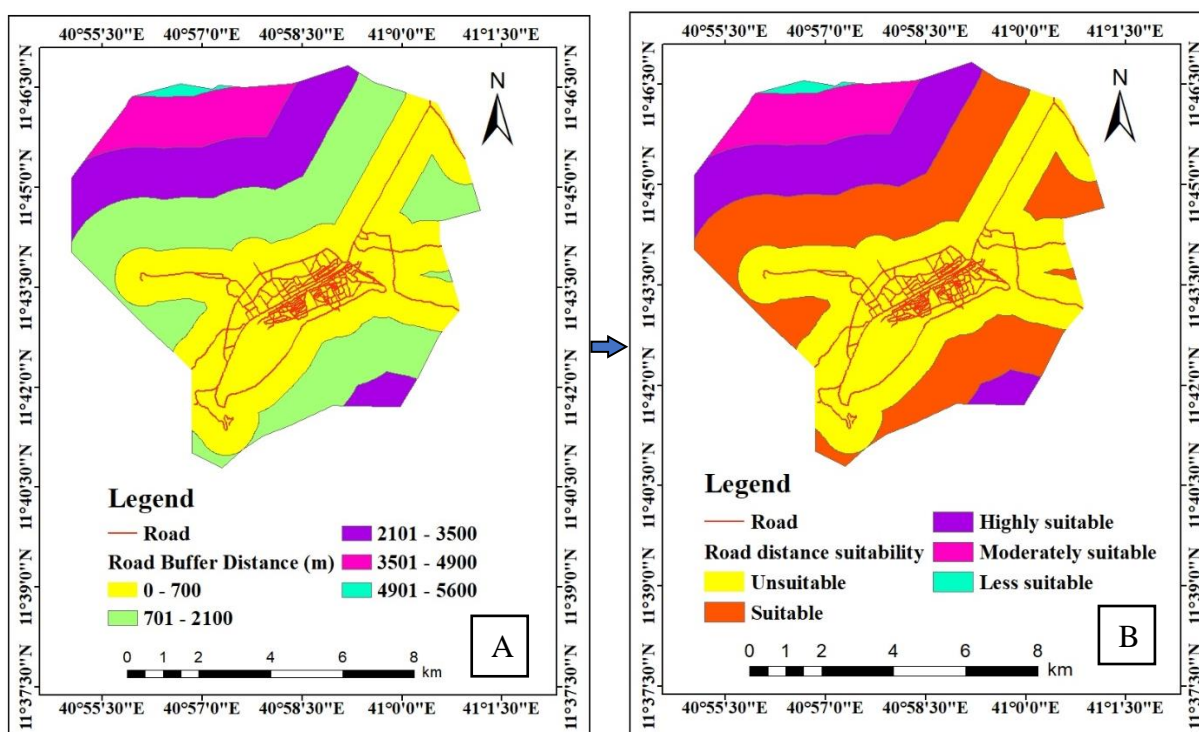


Figure 3.12: Road buffer distance map (a) and reclassified road buffer suitability map (b)

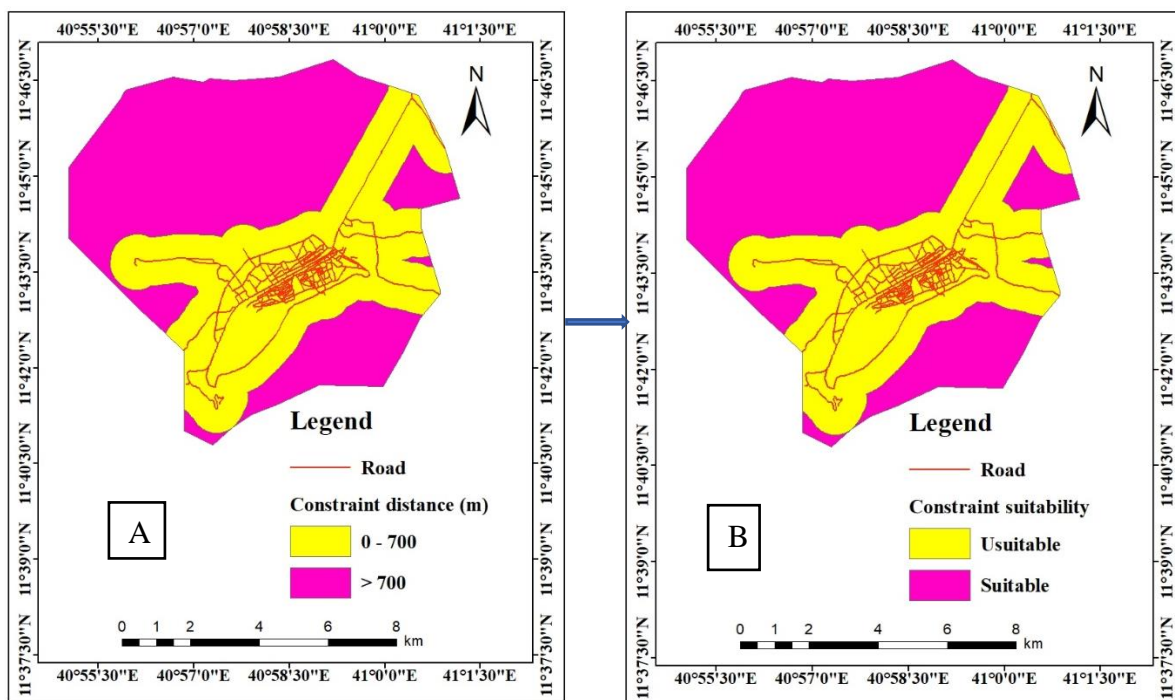


Figure 3.13: Road constraint buffer distance map (a) and constraint buffer reclassified road distance map (b)

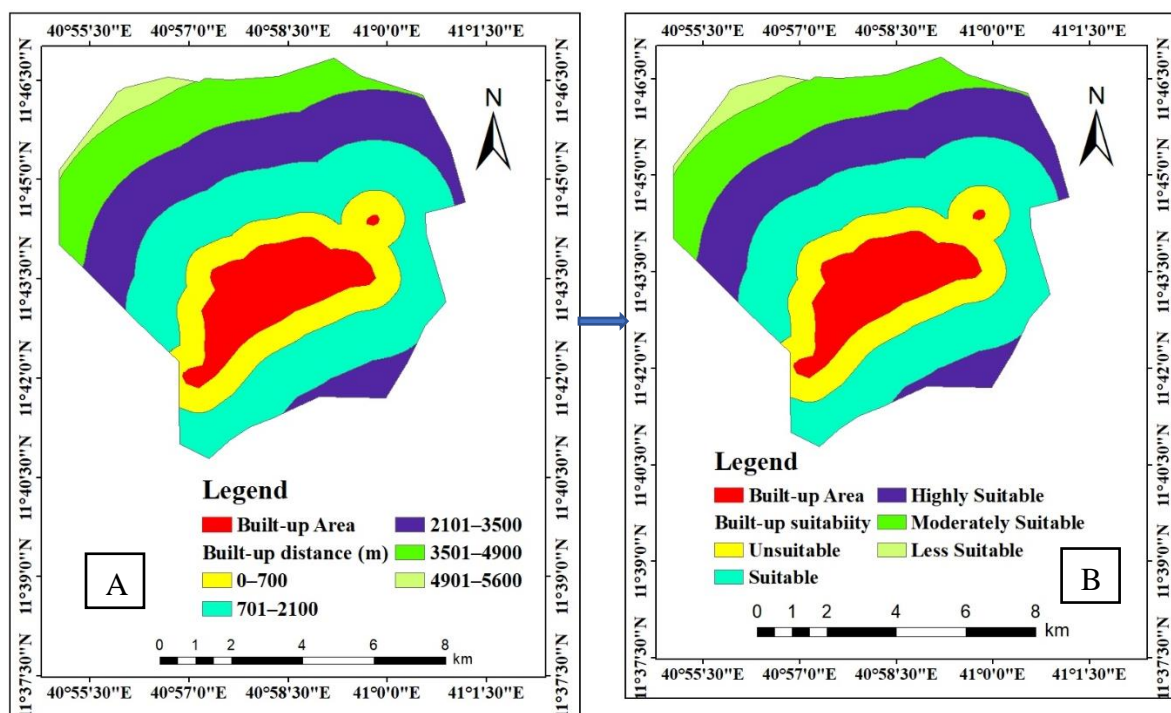


Figure 3.14: Built-up area buffer distance map (a) and reclassified built-area buffer distance map (b)

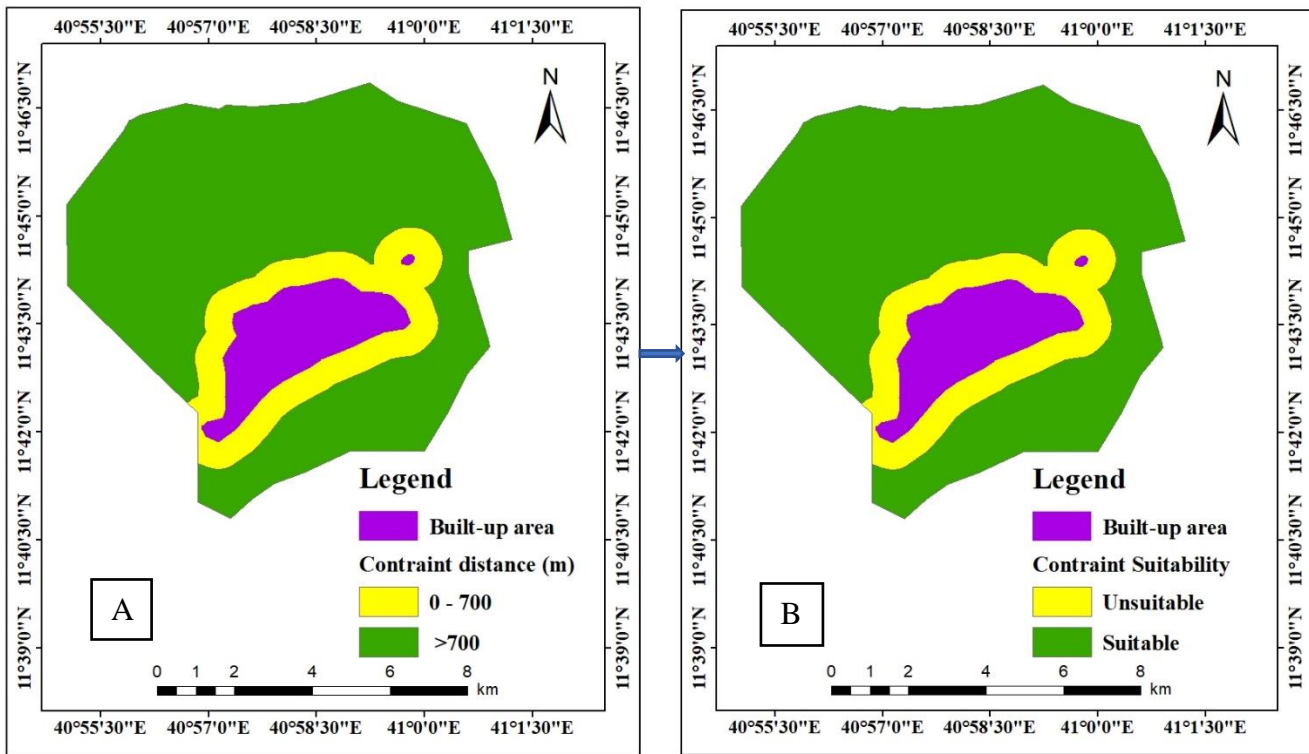


Figure 3.15: Built-up constraint buffer distance map (a) and reclassified built-up constraint buffer distance map (b)

CHAPTER FOUR

4 Results

4.1 Present Waste disposal sites in Logia town

Due to lack of appropriate solid waste dumping site and management system, the town is characterized by poor waste management practices. As a result, most of the solid wastes generated from (supermarkets, café, hotels and homes) dumped along street sides, nearby river, with communal spaces and other transportation route like bus terminal and highway Ethiopia to Djibouti roads. The present trends of waste disposal in Logia town is dumping near the Awash (Tendaho canal), Logia river, and built-up. Some of the observations from fields in the study area are shown in Figure 4.1a, b, c and d. These figures show that the municipality of Logia town is not providing proper solid waste management services.



Figure 4.1: Open dump site of solid waste disposal along different features.

4.2 Groundwater well points and river rank suitability

Solid wastes are being disposed near the river, which can cause health problems, with an extended impact on human and animal health as water is used for various purposes. Therefore, dump site should be placed away from groundwater sources (Table 4.1, Fig 4.2a). Based on (Table 4.1), 5.2% of the area was unsuitable, 56.8% was less suitable, 17.8% was moderately suitable, 9.3% was suitable, and 10.9% was highly suitable for a solid waste disposal site in Logia. Based on the above standards, suitability map of groundwater well point was prepared as shown in Figure 4.2a. Solid wastes disposed near the river cause ecological, agricultural and health problems. Considering these problems, the suitability of solid waste dump site map was produced (see Table 4.1 and Fig 4.2b). Table 4.1 indicates that 37.34%, 18.38%, 25.94%, 12.45% and 5.9% of the total area are unsuitable, less suitable, moderately suitable, suitable and highly suitable, respectively, for solid waste disposal site in Logia. Based on these findings suitability map for waste dumping site using river as a factor was prepared.

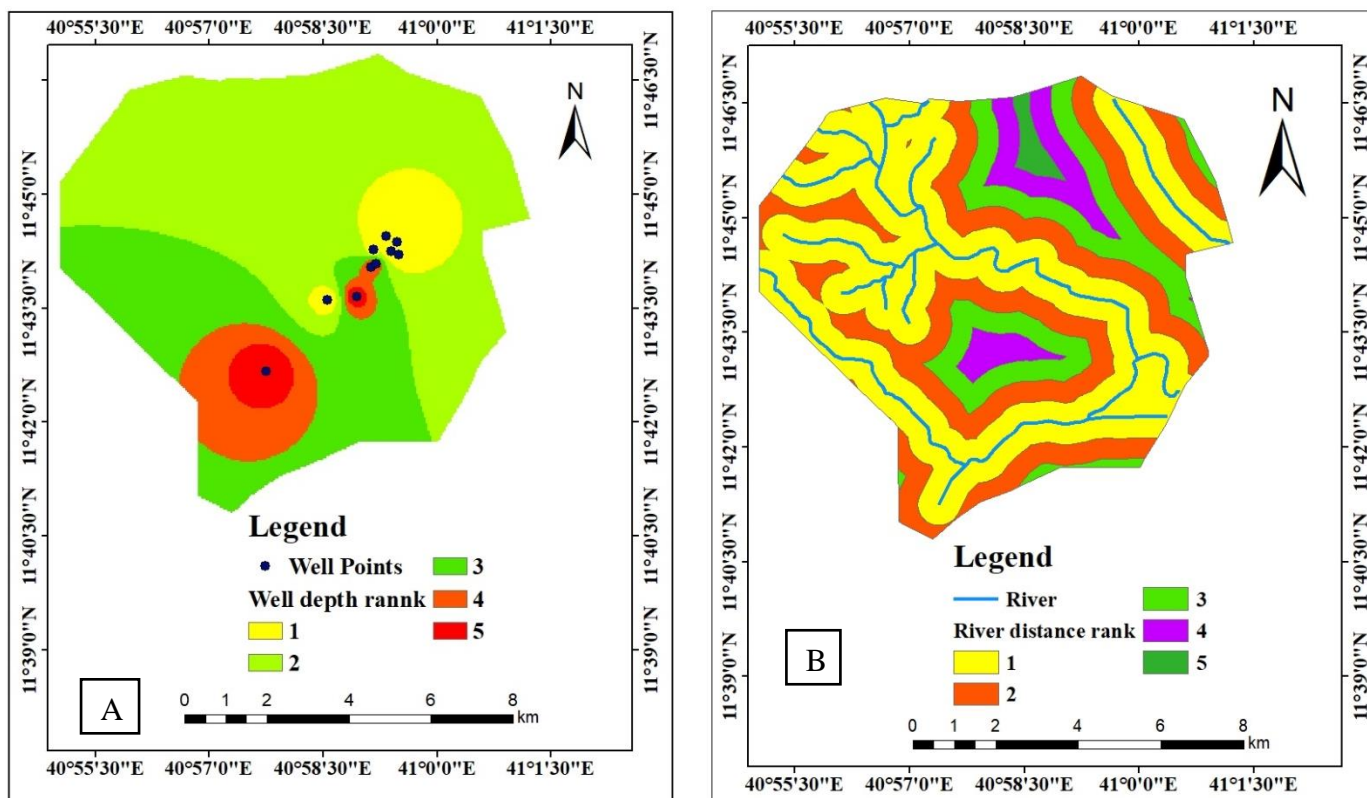


Figure 4.2: Wellpoint rank suitability map (a) and river rank suitability map (b)

Table 4.1: Criteria accepted for dump site selection suitability and their rank

Factors	Parameter (m)	Suitability class	Rank	Weight	Area (ha)	Area (%)
Road	0–700	Unsuitable	1	0.0344	3704.8	44.3
	701–2100	Suitable	4	0.2486	2644.2	31.4
	2101–3500	Highly suitable	5	0.5469	1352	16.1
	3501–4900	Moderately suitable	3	0.1088	665.5	7.6
	>4900	Less suitable	2	0.0613	51.5	0.6
Built-up	0–700	Unsuitable	1	0.0428	2227.7	26.5
	701–2100	Suitable	4	0.2242	2812.9	33.4
	2101–3500	Highly suitable	5	0.6158	1916.9	22.8
	3501–4900	Moderately suitable	3	0.1232	1282.9	15.2
	>4900	Less suitable	2	0.0940	177.6	2.1
River	0–500	Unsuitable	1	0.0202	3144.1	37.34
	501–1000	Less suitable	2	0.1124	1547	18.38
	1001–1500	Moderately Suitable	3	0.1423	2183.3	25.94
	1501–2000	Suitable	4	0.2131	1046.4	12.45
	>2000	Highly suitable	5	0.5120	497.2	5.9
Fault	0–1000	Unsuitable	1	0.0682	5398	64
	1001–2000	Less suitable	2	0.1664	1984	23.5
	200–3000	Suitable	4	0.2968	871	10.6
	>3000	Highly suitable	5	0.4686	165	1.9
Well depth	92–96	Unsuitable	1	0.0221	427.7	5.2
	96–101	Less suitable	2	0.0390	4753.9	56.8
	101–105	Moderately suitable	3	0.1136	1485	17.8
	105–110	Suitable	4	0.2431	779.4	9.3
	>110	High suitable	5	0.5822	917	10.9
Geology	Stratoid Basalt	Unsuitable	1	0.0346	67.1	0.80
	Rhyolitic rock	Less suitable	2	0.0663	104.0	1.24
	Flow basalt	Moderately Suitable	3	0.1408	1131.0	13.44
	Trap or flood basalt	Suitable	4	0.2950	1530.9	18.19
	Mud fats	Highly suitable	5	0.4634	5585.0	66.35
Soil	Orthic Solonchaks	Unsuitable	1	0.4284	2024	75.9
	Lithosols	Suitable	4	0.5716	0.7	24.1
LU/LC	Water Body	Unsuitable	1	0.0389	88	1
	Built-up area	Less suitable	2	0.1035	1131	13.4
	Vegetation	Suitable	4	0.3255	442	5.3
	Bare-land	Highly suitable	5	0.5320	6757	80.3
Slope	>20°	Unsuitable	1	0.1481	3	0.03
	11–20°	suitable	5	0.2703	68	0.87
	0–10°	Highly suitable	4	0.5816	8347	99.1

4.3 Slope and Land-use/land-cover rank suitability

The topography of the study area is dominated by a slope of 0–10°, which is 99.1% of the total study area is highly suitable, because it is flat plane. The second most dominant topography of the study area is 10–20° found in most parts the study area of Logia town, covering 0.87% of total area is suitable and the remaining 0.03% of the area is unsuitable with slope >20° (see Table 4.1). Based on Table 4.1, the slope suitability coverages of Logia, the extent of highly suitable, suitable, and unsuitable areas were demarcated and the suitability map was prepared (Fig 4.3a). Based on the land-use/land-cover suitability (Table 4.1), from the land-use suitability point of view, the largest part of the study area (80.3%) was highly suitable for solid waste disposal sites, whereas, 5.3% and 13.4% of the area were suitable and less suitable, respectively. The remaining 1% of the study area was unsuitable for the solid waste disposal site. Accordingly, the waste dump site suitability map was prepared and given in Figure 4.3b.

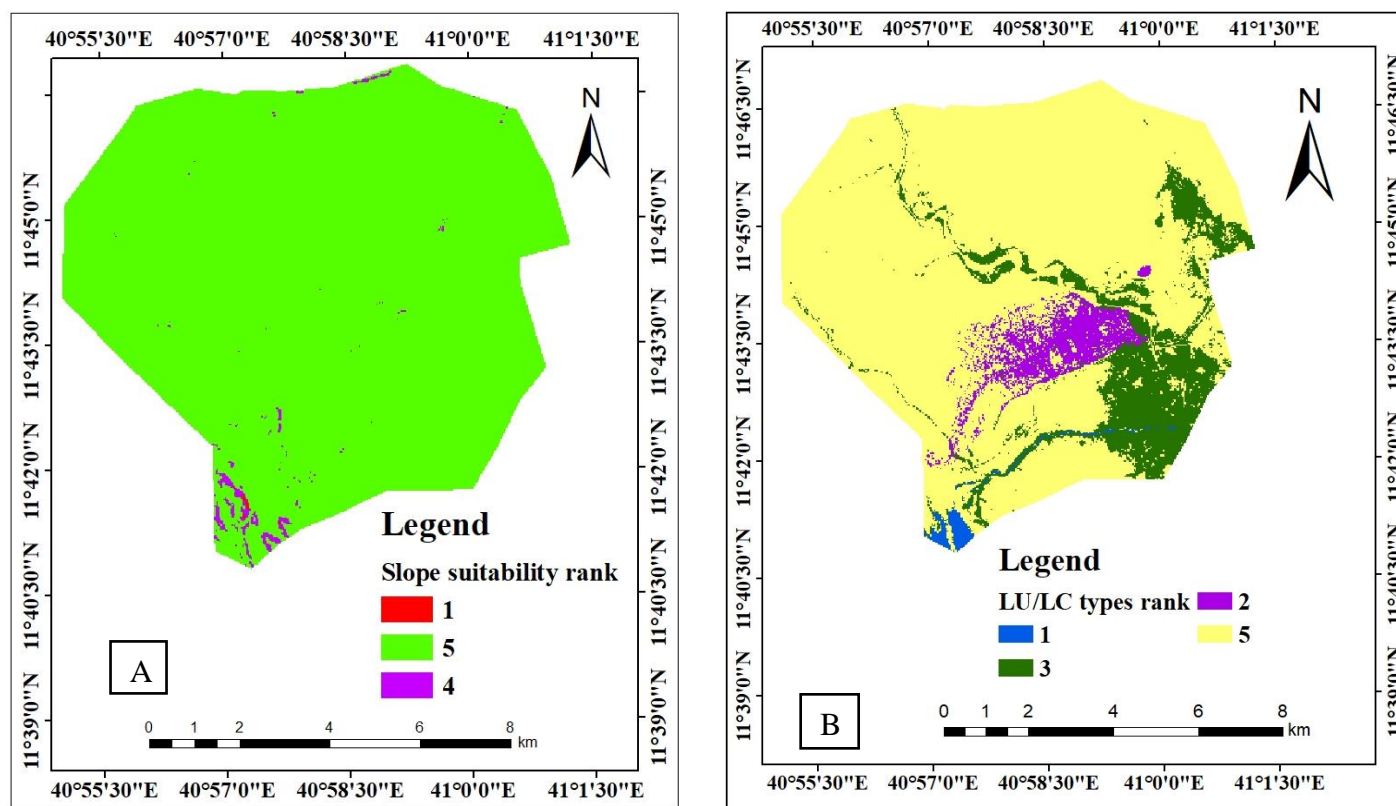


Figure 4.3: Slope rank suitability map (a) and Land-use/land-cover rank suitability map (b)

4.4 Geology and Fault suitability

The present study area contains five geological types such as stratoid basalt, rhyolite, flow basalt, trap basalt and mudflats. Stratoid basalt area has 66.35% extent as highly suitable for the solid waste disposal site, rhyolite covers 18.19% as suitable, and 13.44% as moderately suitable. The remaining trap basalt and mudflats 1.24% and 0.80% of the total study area are less suitable and unsuitable, respectively for solid waste disposal sites (Table 4.1). The suitability map prepared is presented in Figure 4.4a. The reclassification of fault was to identify the safety site for dumping waste with reference to fault as a factor. The more distance from fault, the more suitable the area for waste disposal to minimize the negative effect of dump site (Table 4.1). Based on fault proximity suitability, only 1.9% of the extent of the study area is highly suitable and 10.6% of the area is suitable, whereas 23.5% and 64% of the study area are less suitable and unsuitable, respectively for solid waste disposal sites. During suitability reclassification phase, the highest rank was assigned to a buffer distance greater than 3000 m and the lowest rank 1000 m was given to unsuitable areas (Fig.4.4b).

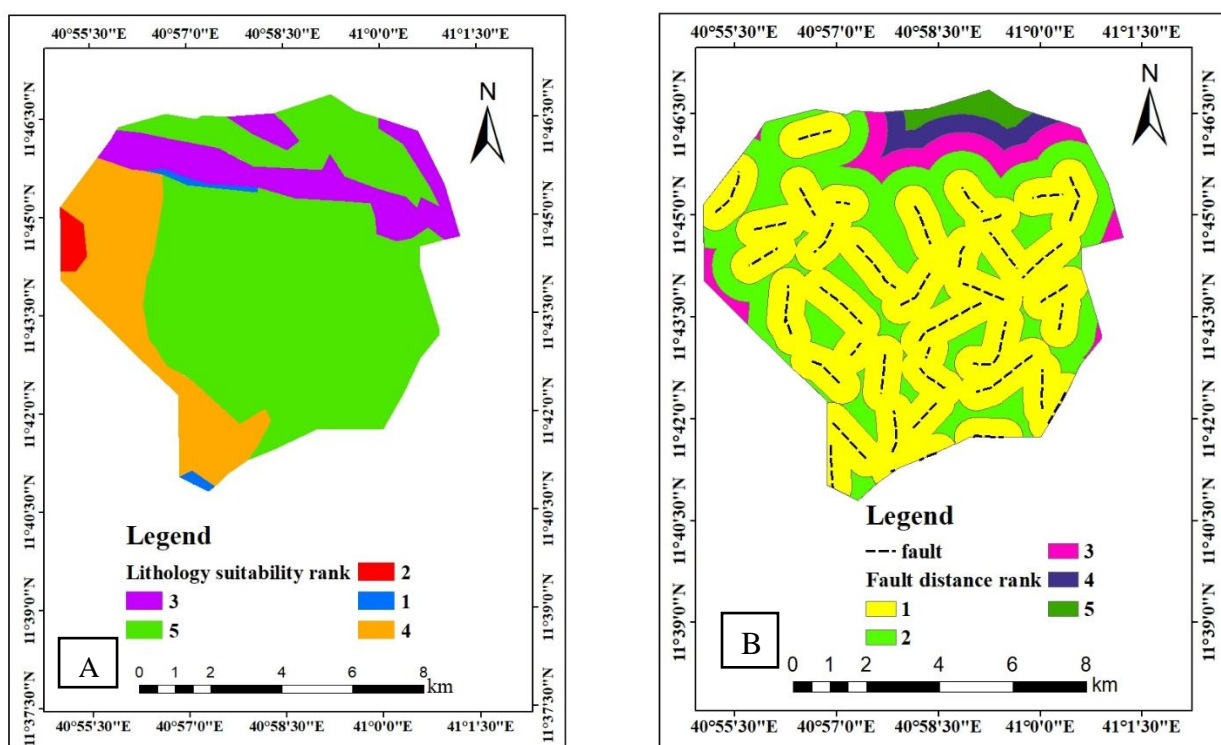


Figure 4.4: Geological type suitability map (a) and fault suitability map (b)

4.5 Soil suitability

Soil is one of the factors for solid waste dumping site selection processes depending on the texture. In Logia town, there are two types of soils contains such as lithosols (clay) and orthic solonchak (saline). Based on Table 4.1 about 24.1% of the total area is suitable and 75.9% of the area is unsuitable for solid waste disposal sites. Accordingly, the suitability map prepared is given in Figure 4.5.

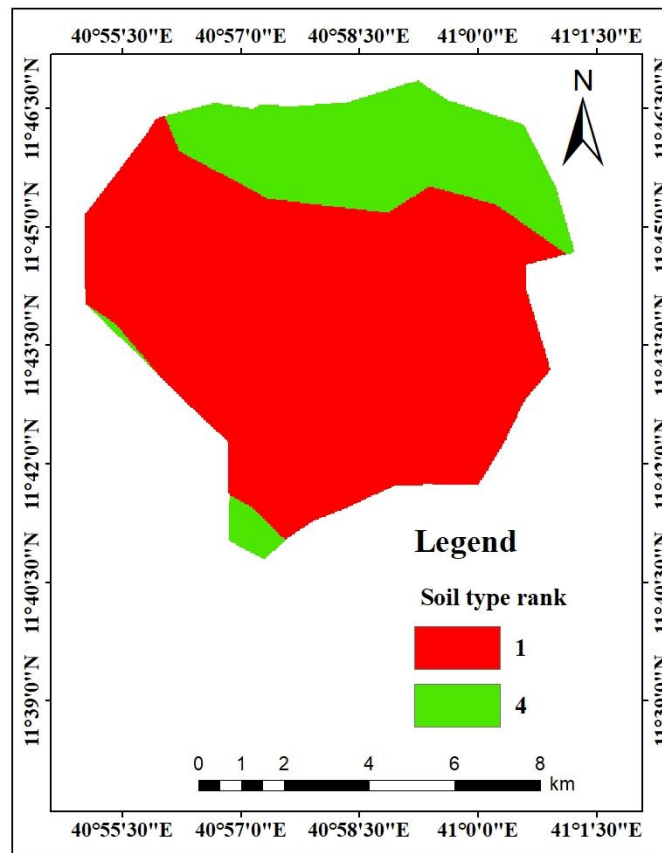


Figure 4.5: Soil rank suitability map

4.6 Road network and built-up area suitability

Solid waste dumping site should be located at a suitable distance from roads to facilitate transportation and to reduce relative costs. Based on the standards, the road network suitability distance calculated is shown in Figure 4.6a. In the study area, 0.6% and 7.6% of the area are highly suitable and suitable, respectively, while 44.3%, 31.4% and 16.1% of the area is unsuitable, less suitable and moderately suitable, respectively for waste disposal sites. Road proximity in the remaining study area are moderately suitable and less suitable, respectively, for solid waste disposal sites. Man-made or developed areas are important as a factor for solid waste disposal.

Disposal site should be away from built-up areas to reduce uncomfortable effects such as bad odors and health problems. The dump site should also be far from commercial buildings, urban green spaces, service area and industries. By considering these health problems, waste disposal sites calculated for Logia town is presented in (Fig 4.6b). As presented in (Table 4.1), 26.5% of the total area is unsuitable for solid waste disposal, while 33.4% is less suitable. The other 22.8%, 15.2%, and 2.1% were moderately suitable, suitable and highly suitable, respectively, for solid waste disposal in Logia town.

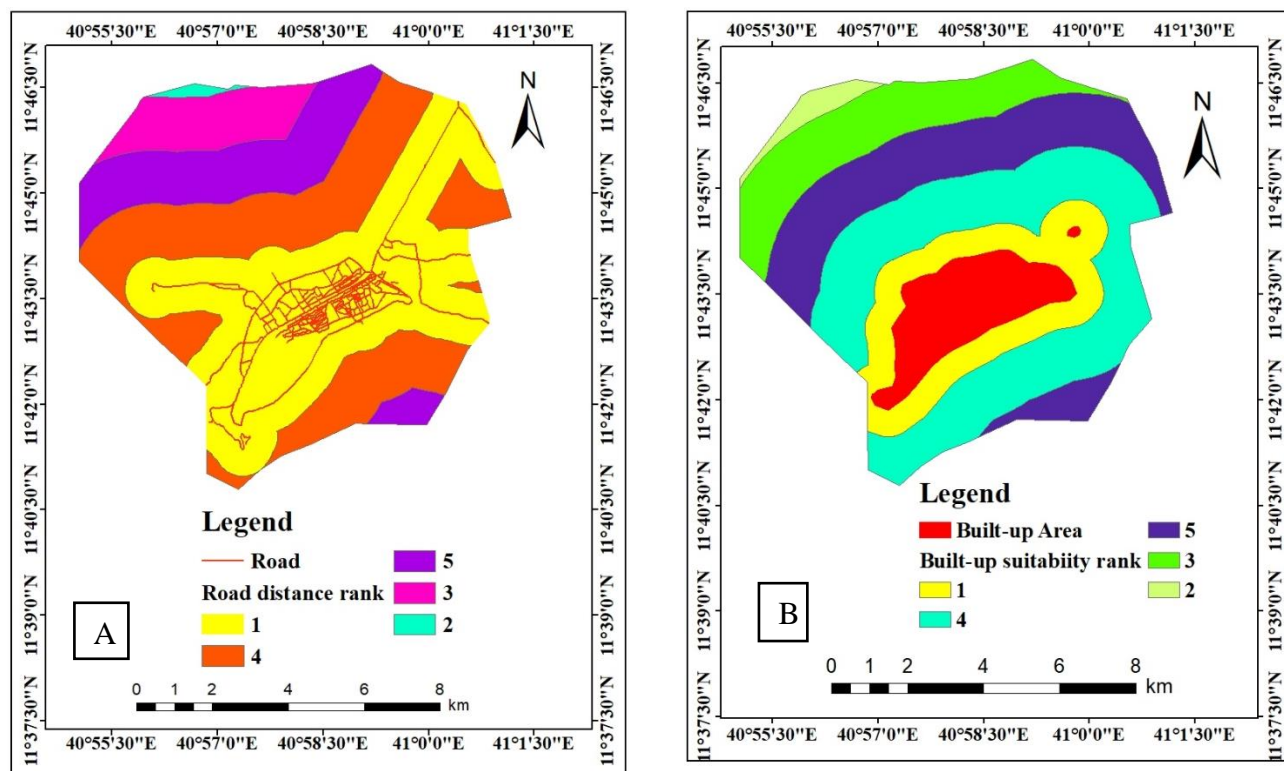


Figure 4.6: Road network rank suitability map (a) and built-up rank suitability map (b)

4.7 Constraint criteria

Constraints are limitations or restrictions, which prohibit certain elements to be taken into account. Constraint maps are used to distinguish between lands suitable and restricted for dump sites. A constraint map for each theme contains 1's for suitable land and 0's for unsuitable land. Thus, five constraint maps were generated, for factors such as groundwater well points, river, road network, fault and built-up area.

4.8 River and road constraint buffer distance suitability map

To locate waste-based facility, surface water contamination is a major consideration. The river constraint map had a buffer zone less than 500 m as the desired location for the dump site. The

constraint map created using the buffer distance less than 500 m are given 0 is (unsuitable) and greater than >2000 m as suitable (Fig 4.8a). Distance from existing roads is an important factor in locating waste conversion facilities. A restricted buffer zone was considered in this study in order to minimize odor and health problems. Beyond this restricted buffer zone, the facility location must be close to a road network in order to reduce transportation costs. Multiple buffer rings were created around the roads, and grading values were assigned to these buffer rings in such a way that grading values increase with a decrease in the buffering distance from roads. The road constraint map of buffer distance <700 m was made and areas as 0 m (unsuitable) and 1 (suitable) on the road network proximity standard. Locating the dump site not far away from a road would help reduce costs related to transportation (Fig 4.8b).

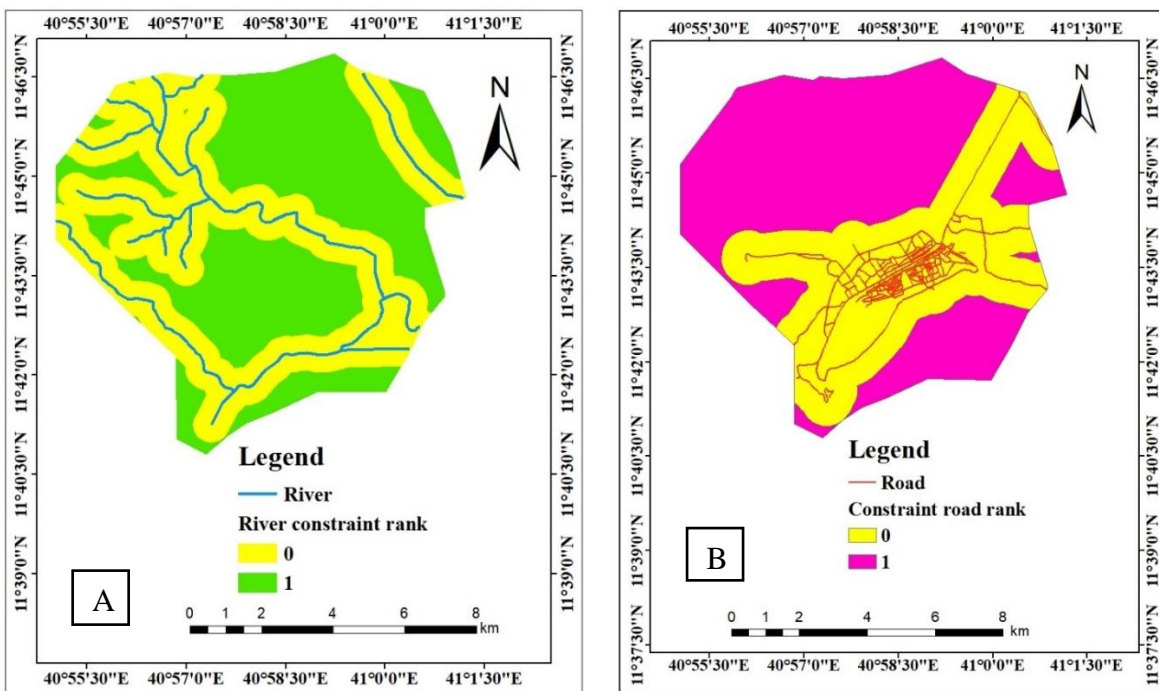


Figure 4.7: River buffer constraint suitability rank map (a) and road buffer constraint suitability rank map

4.9 Fault and built-up area constraint buffer distance suitability map

Based on fault distance suggested for solid waste disposal site selection, a minimum distance of 1000 m should be kept. Also, for the current study, less than 1000 m buffer distance from faults were considered as 0 (unsuitable) for solid waste disposal site due to high permeability of soil near the fault. Areas >1000 m buffer distance of fault was considered as 1 or suitable (Fig 4.9a). The built-up area constraint map was created in order to define dump site hazards, such as scavenging animals and unfavorable odor and noise. The buffer zone of built-up area distance <700 m was

assigned 0 (unsuitable), while > 700 m the considered to be 1 (suitable) for locating a solid waste disposal location (Fig 4.9b).

4.10 Constraint map

Constraint maps were produced by merging individual theme factors into the study area. This procedure created a constraint map for each theme containing only two classes represented by 1's (for the suitable site) and 0's (for the unsuitable site). four constraint maps were produced, such as well points, river, road, fault and built-up area were combined using overlay function (using direct multiplication of binary integer values) to create the final constraint map. Finally, from the total area of the study unsuitable area cover of 7176.8 ha (85.2%) and suitable area cover of 1241.2 ha (14.8%) were recognized (Table 4.2 and Figure 4.10).

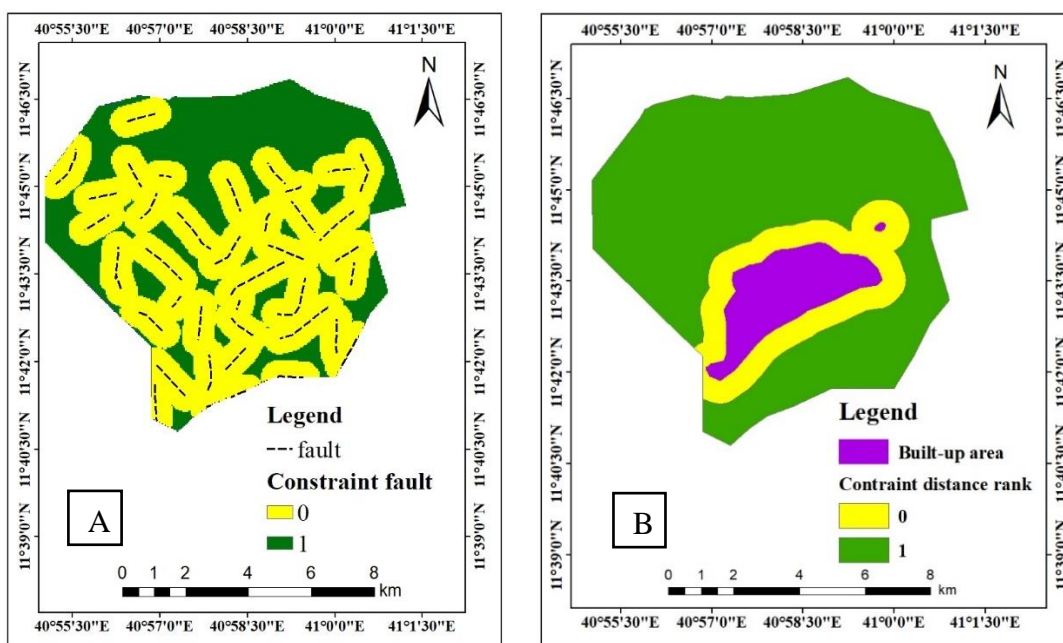


Table 4.2: Constraint criteria accepted for dump site selection

Criteria	Parameter (m)	Suitability	Rank	Weight	Area (ha)	Area (%)
River	0–500	Unsuitable	0	0.2471	427.7	5.08
	>500	Suitable	1	0.7520	7990.3	94.92
Road Networks	0–700	Unsuitable	0	0.4531	3704.8	44.02
	> 700	Suitable	1	0.5469	4713.2	55.98
Fault	0–1000	Unsuitable	0	0.4686	5398	64.12
	>1000	Suitable	1	0.5314	3020	35.88
Built-up area	0–700	Unsuitable	0	0.3842	3704.8	44.02
	>700	Suitable	1	0.6158	4713.2	55.98

4.11 Assigning criteria weights

One of the components of GIS-Based Multi-Criteria Evaluation (MCE) methodology is assigning criteria weights for each factor maps. The purpose of weighting in the landfill site selection process is to express the importance or preference of each factor relative to another factor effect on landfill siting. A number of criterion-weighting procedures based on the judgments of decision makers have been proposed in the multi-criteria decision literature. One of the most promising is pair-wise comparison developed in the context of a decision-making process is known as the Analytical Hierarchical Process (AHP). In MCE using a weighted linear combination, it is necessary that the weights sum to 1. Accordingly, in IDRISI, the weight module utilizes the pair-wise comparison technique to help develop a set of factor weights that will sum to 1.0 (Table.9). In AHP, weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved at a time, in determining suitability for the stated objective. Accordingly, all possible combinations of two factors were compared based on expert judgment to prepare a pair-wise comparison matrix from which the module calculates a set of weights and consistency ratio. This ratio is very important as it shows any inconsistencies that may have arisen during the pair-wise comparison process (Table 4.3 and 4.4).

Table 4.3: Preference matrix for the solid waste site selection in Logia town.

Factors	LU	LI	RO	BU	FA	RI	Wd	SO	SL
FA	1								
SO	1/2	1							
LI	1/3	1/2	1						
LU	1/4	1/3	1/2	1					
RO	1/5	1/4	1/3	1/2	1				
BU	1/6	1/5	1/4	1/3	1/2	1			
RI	1/7	1/6	1/5	1/4	1/3	1/2	1		
Wd	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	
SL	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1

Table 4.4: Normalized comparison matrix for solid waste dump site selection Logia town.

Factors	LU	LI	RO	BU	FA	RI	Wd	SO	SL	Weight	Weight (%)
FA	0.3534	0.4237	0.3953	0.3493	0.3071	0.2717	0.2428	0.2192	0.2000	0.3058	30.58
SO	0.1767	0.2119	0.2635	0.2620	0.2457	0.2264	0.2081	0.1918	0.1778	0.2193	21.93
LI	0.1166	0.1059	0.1318	0.1747	0.1843	0.1812	0.1734	0.1644	0.1556	0.1542	15.42
LU	0.0883	0.0699	0.0659	0.0873	0.1229	0.1359	0.1387	0.1370	0.1333	0.1088	10.88
RO	0.0707	0.0530	0.0435	0.0437	0.0614	0.0906	0.1041	0.1096	0.1111	0.0764	7.64
BU	0.0601	0.0424	0.0329	0.0288	0.0307	0.0453	0.0694	0.0822	0.0889	0.0534	5.34
RI	0.0495	0.0360	0.0264	0.0218	0.0203	0.0226	0.0347	0.0548	0.0667	0.0370	3.7
Wd	0.0459	0.0297	0.0224	0.0175	0.0154	0.0149	0.0173	0.0274	0.0444	0.0261	2.61
SL	0.0389	0.0275	0.0184	0.0148	0.0123	0.0113	0.0114	0.0137	0.0222	0.0190	1.9
Total										1.00	100

Consistency index = $0.07 < 0.1$

(Note: LU= Land-use/land-cover, LI=Lithology, FA=Fault, RI=River, SO= Soil, RO= Road, BU= Built up area, Wd= well depth and SL= Slope).

4.12 Dumpsite Suitability map

In order to select appropriate solid waste disposal site selection for the study area comparison of the different positions based on environmental, social and economic impacts were done. From the weight calculation, the relative importance of each parameter was determined for all criteria land-use/land-cover, lithology, fault, river, soil, road, built-up area, slope, and well maps. Out of the total study area, about 5.93 % (499.43 ha) fall under highly suitable categories due to the area satisfies environmental, social and economic criteria such as fault, built up area, surface water, geology, land-use/land-cover, soil, slope, and road network. Highly suitable landfill site was found in the northern part of the study area. The suitable area covers an area of 6.4% (537.5 ha), moderately suitable class covers 3.23 % (272 ha), less suitable area covers 1.02% (86.10 ha) and the remaining 84.99 % (7154.61ha) falls under unsuitable for solid waste disposal sites. The red point indicates the existing open dump sites surrounding in Logia town (Table 4.17 and Fig. 4.11).

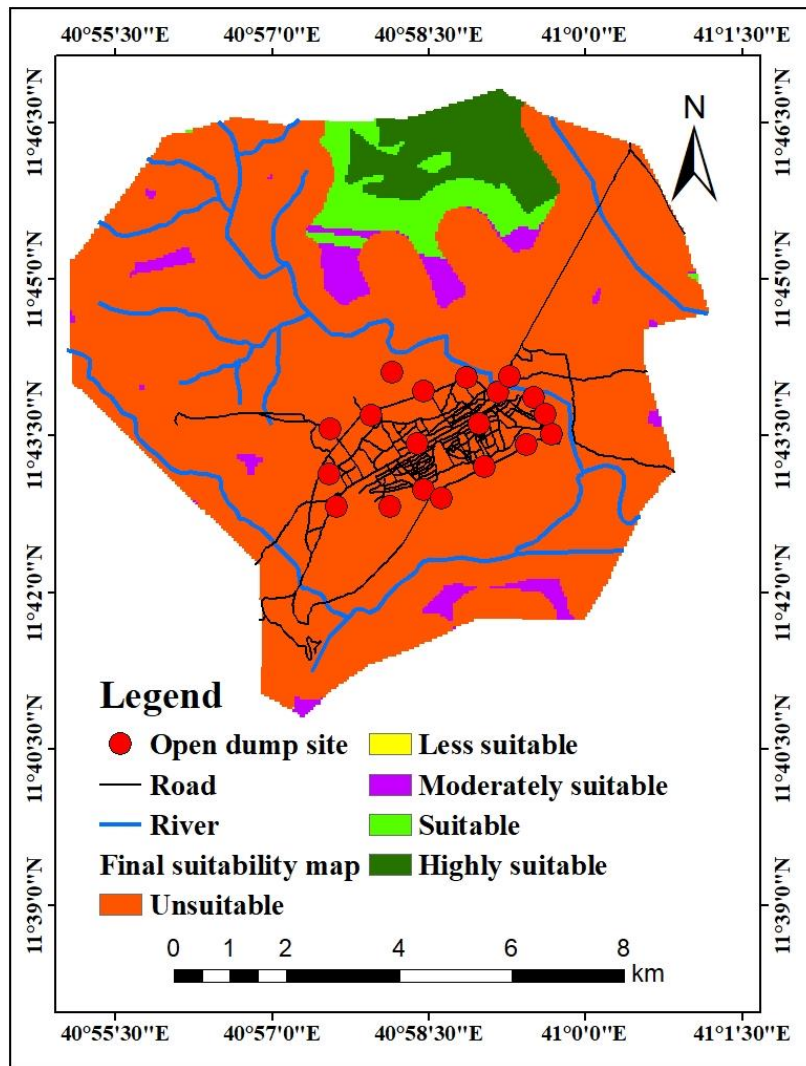


Figure 4.8: Overall solid waste dump site suitability map for Logia town.

CHAPTER FIVE

5 Discussion

In GIS and Remote sensed data and data analysis techniques to monitor and map solid waste disposal sites that are currently incomplete. The present study would represent an important first step in addressing a critical gap in the detection of illegal waste disposal sites and enhance the cost-effectiveness and efficiency of waste management efforts. Due to their ability to manage large volumes of spatial information from various resources, GIS is ideal for site selection studies (Kao *et al.*, 1997).

Existing landfill site is clearly unsuitable beyond the scope of public health, hygiene, public reactions, noise, dust, and odor. The overall dump site suitability selection showed five dump site suitability classes *viz.* unsuitable (restricted), less suitable, moderately suitable, suitable and highly suitable. Bare-land, water body, built-up areas and vegetation lands used for the dump site selection processes due to their land-use/land-cover effect and values. Bare land in the study area was identified as the best option for the solid waste dump site. Areas with slope $>20^\circ$ were excluded as they are unsuitable whereas areas with slope $0-10^\circ$ were found to be the best for dump site (Akbari *et al.*, 2008). Areas within 700 m radius and >4900 m were excluded to minimize public health effects (Sam and Steven, 2017).

Area-wise calculation of these suitability classes showed 7154.61 ha (84.99%) of the study area is unsuitable (restricted) for waste dump site in Logia town. This restricted area included well points, river/streams, fault, road, built-up area in the first order followed by permeable locations, faults, lithology, areas with a steep slope ($>20^\circ$), built-up and vegetation areas, areas close to roads. That means ground/ surface water related criteria, namely, the proximity of a dump site to rivers/ streams/ lakes/ swamps and groundwater wells are more influential than rest of the criteria as they need good protection against leachate contamination from dump site (Tyowuah and Hundu, 2017).

Based on the results the highly suitable, suitable and Moderately suitable areas are suitable for solid waste dump site due to the parameters or far from faults, river, built-up, road and suitable according to soil, slope, geology and land-use/ land-covers. Dump site in these areas is preferable over others because of the least effects that may cause on the environment and public. The south-eastern part of Logia town having high elevation was excluded from the selection of dump site as it comprises the recharge area for low-lying regions of the town. Similarly, the south-west part of

Logia is a potential source of groundwater for the town and its surroundings and hence excluded from the dump site. Therefore, a high suitable dump site should be identified most preferably from the northern part of Logia town.

The current open dump site and the final site selection results were compared. The current open dump site is located in an inappropriate or not suitable area due to lack of suitable dump site in Logia town but, the final results of site selection processes is properly suggested dump site location is based on scientific criteria. The final results of this study are considering on the factors used and the constraint area. Therefore, the current result is more preferable than the open dump site. It is placed surrounding the built-up area, roadsides and nearby river. Considering the effect of solid waste on health, economy and other aspects of human life, the properly selected site can be accessed by road.

They have been widely applied in the past for site selection studies (Curtis and Perry, 2000; Woodhouse *et al.*, 2000; Thomas, 2002; Nikolakaki, 2003; Haaren and Fthenakis, 2011). The integration of both GIS and multi-criteria techniques improves decision-making because it establishes an environment for transformation and combination of geographical data and stakeholders preferences (Malczewski, 1999). Among the Multi-Criteria Evaluation techniques, AHP has been widely used in solid waste dump site selection in the recent years. Pokhrel and Viraraghavan (2005) carried out an evaluation of solid waste management concerning the location of landfills in Nepal. Padmaja *et al.* (2006) identified a solid waste disposal site in Hyderabad city using AHP and GIS. Graphical information system and Multi-Criteria Evaluation tools have been used extensively to local suitable location for undesirable facilities (Tavares *et al.*, 2011; Eskandari *et al.*, 2012; Rikalovic *et al.*, 2014; Tsiko, 2016). An undesirable facility is one which people want to be located far away from their living and working area (Tang *et al.*, 2013).

Solid waste dumping site should be located at a suitable distance from roads to facilitate transportation and consequently to reduce relative costs. The trend in Logia is dumping most of the solid waste on the Djibouti roadside. According to Sam and Steven (2017), a minimum distance of 700 m buffer was used for road suitability dumpsite location. According to Kontos *et al.* (2005); Al-hanbali *et al.* (2011), and Irfan *et al.* (2012) used multiple buffer ring extents and the grading values for roads. Today Logia town has grown at an unexpected growth, the distance of the facility to the nearest residential area is reduced down to nearly a few kilometers.

Furthermore, the present site is also found in the excluded areas of this study, which indicates that in conventional siting procedures had not been considered.

Groundwater circulation and the downward flow of pollutants through rocks and soils depend on the hydrogeological condition of the materials, more specifically hydraulic properties such as porosity, permeability, and transitivity (Tsegaye Mekuria, 2006). The proximity of a solid waste dump site to a groundwater well point is an important environmental criterion in the dump site selection so that well points may be protected from the runoff and discharge. Therefore, solid waste disposal should be placed away from wells. Additionally, it can have irreversible human and environmental effects. Distance from groundwater well was considered as an important criterion for this research. In Logia town, the area totally 10 functional wells. But this is assumed to be an appropriate buffer distance with respect to previous literature (Sumathi *et al.*, 2008; Eskandari *et al.*, 2012).

According to Tyowuah and Hundu (2017), contamination of ground/surface water resources by leachate is a principal concern in relation to disposal sites. Deep groundwater areas are preferable as chances of groundwater pollution will be minimized with increasing depth (Augustin 2008). Waste disposal should also be away from faults (Rafee *et al.*, 2011). The fault is one of the criteria that was considered for solid waste disposal site selection. It is a better system for identifying fault area from Digital Elevation Model of Logia town (Rafee *et al.*, 2011).

CHAPTER SIX

6 Conclusion and Recommendations

6.1 Conclusion

This study examined problems of solid waste disposal sites in Logia town and its implications on the residents of Logia town. The study revealed that the town has grown in population as well as spatial extent over the years. The findings have shown a useful application of GIS and AHP methods as a viable tool for analyzing the criteria for decision making support. The analysis was taken well points, land-use/land-cover, fault, slope, geology(lithology), river, road, built-up area and soil type as determining factor in order to find an appropriate site for a solid waste dumping site. One area was selected as most suitable. This site is easy to access and manage for disposal of solid waste. The one more site away from water sources, and other variables put into the analysis. It is located in a west, northern and east part of the study area. The integration of multi-criteria decision analysis is a useful tool in solving solid waste dump site selection problem because it provides efficient spatial data manipulation and presentation. Hence, the capacity to use AHP with GIS and RS technology for identification of suitable solid waste dumping site will minimize the environmental risk and human health problems. The result of final suitability map shows that 2.2% of the study area is highly suitable for the solid waste disposal site, 6.4% suitable, 0.6% moderately suitable, less suitable 5.6% and 85.2% the total of the study area is under unsuitable station for waste disposal in Logia town.

6.2 Recommendations

For proper solid waste disposal systems and management are to be developed, and maintained in Logia town, for which the following recommendations were suggested.

- Multi criteria evaluation technique is very important technique for dump site selection, therefor the researcher will use this method is used to consider different criteria from different points of view.
- The selected dump sites by this study are only for non-hazardous solid wastes. Since the criteria for hazardous wastes area different from non-hazardous wastes, separate dump site should be selected.
- According to the results the highly suitable area is far from the built-up area, therefor, the government should put waste collection bins in a different part of the cities and arrange the

transportation with appropriate vehicles; also, the system will be developed for recycling wastes as plastics, metals and others.

- There should be public awareness in different ways like media, school symposium, workshops seminars which explored by the government and participation in the planning and implementation of solid waste management.
- The concerned body should formulate solid waste disposal sites by considering social, economic and environmental aspects to improve the status of the solid waste management system of the town.
- Using GIS approach to waste disposal and site selection has proven to be a powerful tool that enhances the sitting process. The GIS is a powerful tool for identifying suitable waste disposal sites. The major benefit of a GIS is that once a GIS database exists, it can be enhanced into a complete waste disposal management GIS package.
- The selection of the final solid waste dumping sites requires further hydro-geological analyses to ensure conformity with the stringent standards required for design and construction of such facility.

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**Addis Ababa University
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Appendices**

Appendix 1: Format for thesis originality test report

Name of student	Ahmed Mussa Yimam
ID No	GSR/4818/09
Stream	Remote sensing and Geo-informatics
Thesis title	Solid Waste Dumping Site Suitability Selection Using Geographic Information System and Remote Sensing: A case study of Logia Town, Afar Region Ethiopia
Online site used for originality test	http://www.paperrater.com/plagiarism_checker

No	particulars	Test I		Test II		Test II		Test IV		Test V		Average	Remark
		Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)		
1	Abstract	100	0	-	-	-	-	-	-	-	-	100	
2	Introduction	100	0	100	-	-	-	-	-	-	-	100	
3	Literature review	100	0	100	0	100	0	100	0	100	0	100	
4	Methodology	100	0	100	0	99	1	100	0	100	0	99.8	
5	Result and discussion	100	0	100	0	100	0	100	0	-	-	100	
6	Conclusion	100	0	-	-	-	-	-	-	-	-	100	
	Overall Thesis	100	0	100	0	99.67	1	100	0	100	0	99.97	

	Name	Signature
Student		
Advisor (1)		
Advisor (2)		

Appendix 2: Open dump sites current location in Logia town

Code	Easting	Northing	GPS accuracy (m)	Area Name
Point 1	40.9688	11.7137	±3	Near to awash river
Point 2	40.9838	11.7200	±3	Abuser mesgid
Point 3	40.9946	11.7251	±3	Selama sefer
Point 4	40.9860	11.7319	±3	Delala genda
Point 5	40.9810	11.7343	±3	Delala genda
Point 6	40.9658	11.7283	±3	Ayer tena
Point 7	40.9591	11.7189	±3	Wuhana fisash
Point 8	40.9917	11.7311	±3	Meneharia
Point 9	40.9905	11.7235	±3	piasa
Point 10	40.9742	11.7321	±3	Delala genda
Point 11	40.9732	11.7237	±3	Nazret hotel side
Point 12	40.9831	11.7268	±3	Gulet tera
Point 13	40.9603	11.7137	±3	Kella
Point 14	40.9742	11.7163	±3	Moter genda
Point 15	40.9880	11.7344	±3	Logia river
Point 16	40.9937	11.7284	±3	Logia river
Point 17	40.9771	11.7150	±3	Moter genda
Point 18	40.9594	11.7261	±3	Tefenakay

Appendices 3: Functional ground water well points

Code	Easting	Northing	GPS accuracy (m)
well point1	40.9855	11.7339	±3
well point2	40.9865	11.7348	±3
well point3	40.9861	11.7379	±3
well poin4	40.9889	11.7409	±3
well point5	40.9913	11.7395	±3
well point 6	40.9899	11.7375	±3
well point 7	40.9916	11.7367	±3
well point 8	40.9824	11.7275	±3
well point 9	40.9759	11.7269	±3
well point 10	40.9625	11.7112	±3

Appendix 4: Point data for filed verifications of land-use/land-cover

Code	Shape	Easting	Northing	GPS accuracy (m)	LU/LC
Fp1	Point	717206.49	1295601.30	±3	Vegetation
Fp2	Point	718084.91	1294553.55	±3	Vegetation
Fp3	Point	718476.49	1296416.22	±3	Vegetation
Fp4	Point	713911.10	1298879.49	±3	Vegetation
Fp5	Point	715873.25	1298407.21	±3	Vegetation
Fp6	Point	718205.93	1300642.71	±3	Vegetation
Fp7	Point	718466.28	1300306.16	±3	Vegetation
Fp8	Point	718580.58	1299912.45	±3	Vegetation
Fp9	Point	718796.48	1300204.56	±3	Vegetation
Fp9	Point	718796.48	1300204.56	±3	Vegetation
Fp10	Point	717162.42	1296738.16	±3	Vegetation
Fp11	Point	713645.04	1292884.23	±3	Vegetation
Fp12	Point	714858.88	1295016.57	±3	Vegetation
Fp13	Point	713159.06	1293482.64	±3	Vegetation
Fp14	Point	713013.01	1294290.35	±3	Vegetation
Fp15	Point	713015.51	1294294.26	±3	Vegetation
Wp16	Point	713126.26	1292819.50	±3	Water body
Wp17	Point	713271.78	1292621.06	±3	Water body
Wp18	Point	714420.41	1293900.88	±3	Water body
Wp19	Point	714794.79	1294303.05	±3	Water body
Wp20	Point	714046.02	1293824.91	±3	Water body
Wp21	Point	712690.21	1292762.17	±3	Water body
Wp22	Point	716720.18	1294783.22	±3	Water body
Wp23	Point	715660.79	1294735.33	±3	Water body
Wp24	Point	717992.04	1294861.15	±3	Water body
Wp25	Point	713488.03	1293249.15	±3	Water body
Bp26	Point	717563.08	1298554.56	±3	Built-up
Bp27	Point	716078.69	1297668.52	±3	Built-up
Bp28	Point	716808.94	1297497.07	±3	Built-up
Bp29	Point	716129.49	1297293.87	±3	Built-up
Bp30	Point	716466.04	1297033.52	±3	Built-up
Bp31	Point	716085.04	1296735.07	±3	Built-up
Bp32	Point	715678.64	1296817.62	±3	Built-up
Bp33	Point	715151.59	1296385.82	±3	Built-up
Bp34	Point	714878.54	1296258.82	±3	Built-up
Bp35	Point	714707.09	1296754.12	±3	Built-up
Bp36	Point	714491.18	1296957.32	±3	Built-up
Bp37	Point	715684.99	1297382.77	±3	Built-up

Bp38	Point	717291.54	1297027.17	±3	Built-up
Bp39	Point	713562.87	1295596.30	±3	Built-up
Bp40	Point	714168.10	1296743.94	±3	Built-up
Bp41	Point	713388.90	1295305.53	±3	Built-up
Bp42	Point	713223.54	1294945.03	±3	Built-up
Bp43	Point	713025.10	1296198.50	±3	Built-up
Bp44	Point	715021.30	1297403.37	±3	Built-up
Bp45	Point	717348.32	1297327.30	±3	Built-up
Brp46	Point	716687.41	1299231.76	±3	Bare-land
Brp47	Point	716604.73	1301265.75	±3	Bare-land
Brp48	Point	715612.54	1299562.49	±3	Bare-land
Brp49	Point	715099.91	1300753.11	±3	Bare-land
Brp50	Point	713876.20	1300852.33	±3	Bare-land
Brp51	Point	714818.78	1298090.74	±3	Bare-land
Brp52	Point	713760.45	1297908.84	±3	Bare-land
Brp53	Point	712702.11	1297594.64	±3	Bare-land
Brp54	Point	712420.99	1296404.02	±3	Bare-land
Brp55	Point	711428.80	1296900.11	±3	Bare-land
Brp56	Point	712602.90	1298140.35	±3	Bare-land
Brp57	Point	715612.54	1295593.73	±3	Bare-land
Brp58	Point	715182.59	1293741.64	±3	Bare-land
Brp59	Point	713722.75	1295416.95	±3	Bare-land
Brp60	Point	713897.37	1294496.20	±3	Bare-land
Brp61	Point	714556.19	1295313.77	±3	Bare-land
Brp62	Point	713302.06	1296091.64	±3	Bare-land
Brp63	Point	715047.52	1297695.81	±3	Bare-land
Brp64	Point	710404.07	1299062.39	±3	Bare-land
Brp65	Point	712565.72	1301671.19	±3	Bare-land
Brp66	Point	719616.88	1300309.11	±3	Bare-land
Brp67	Point	718392.48	1297502.76	±3	Bare-land
Brp68	Point	716394.87	1294010.25	±3	Bare-land
Brp69	Point	714146.30	1293323.79	±3	Bare-land
Brp70	Point	715082.93	1293411.10	±3	Bare-land
Brp71	Point	716083.72	1295166.28	±3	Bare-land
Brp72	Point	712772.10	1293385.93	±3	Bare-land
Brp73	Point	712496.93	1294022.92	±3	Bare-land
Brp74	Point	712457.24	1294218.05	±3	Bare-land
Brp75	Point	714111.42	1295059.59	±3	Bare-land

Appendix 5: Land-use/land-cover accuracy assessment

classification	Bare-land	Built-up	Vegetation	Water body	Row total	User accuracy
Bare-land	27	2	1	0	30	90
Built-up	1	18	1	0	20	90
Vegetation	0	1	11	2	14	78.8
Water body	0	0	2	8	10	80
Column total	28	21	15	10	74	
Producer accuracy	96.4	85.7	73.3	80		