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**ADDIS ABABA UNIVERSITY
COLLEGE OF SOCIAL SCIENCE DEPARTMENT OF
GEOGRAPHY AND
ENVIRONMENTAL STUDIES**

**GIS BASED MULTI-CRITERIAL EVALUATION OF SUITABLE SOLID
WASTE DISPOSAL SITE SELECTION,
THE CASE OF HOSANA TOWN, HADIYA ZONE, ETHIOPIA**

BY: DEBEBE JAKAMO

JUNE, 2017

ADDIS ABABA UNIVERSITY, ETHIOPIA

GIS BASED MULTI-CRITERIAL EVALUATION OF SUITABLE SOLID
WASTE DISPOSAL SITE SELECTION,
THE CASE OF HOSANA TOWN, HADIYA ZONE, ETHIOPIA.

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GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

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Declaration

I hereby declare that a project entitled “GIS based multi-criterial evaluation of Suitable Solid Waste Disposal Site Selection, the case of Hosanna town, Hadiya zone, Ethiopia” has been carried out by me under the supervision of Dr. Tebarek Lika, Department of Geography and Environmental Studies, Addis Ababa University during the year 2016/17 as a part of Master of Art program in Geography and Environmental Studies with specialization GIS, Remote Sensing and Digital Cartography. 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

Date: June 16, 2017

Debebe Jakamo -----

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Lists of Abbreviations and Acronyms

AHP:	Analytic Hierarchy Process
a.m.s.l:	above mean sea level
CSA:	Central Statics Authority
DEM:	Digital Elevation Model
EMA:	Ethiopian Mapping Agency
ERDAS:	Earth Resource Data Analysis System
ETM+:	Enhanced Thematic Mapper+
FOA	World food and Agriculture Organization
GIS:	Geographic Information System
GLCF:	Global Land Cover Facilities
GPS:	Global Positioning System
GSE:	Geological Survey of Ethiopia
LU / LC:	Land Use/ Land cover
MCDA:	Multi Criteria Decision Analysis
MCE:	Multi Criteria Evaluation
MWIE:	Ministry of Water, Irrigation and Electricity
MUDC:	Ministry of Urban Development and Construction
NUPI:	National urban plan institution
UTM:	Universal Transverse Mercator
3D:	Three Dimensional

Abstract

Solid waste management system is the most difficult task that many countries, both developing and developed, are facing. Landfill method is one of the easy and cheap management systems which are always needed for sustainable management of solid waste. The main objective of the study was to select landfill site for the town that is environmentally sound, socially acceptable and economically feasible in Hosanna town. To achieve the objectives, the present study was conducted by integrating Geographic Information System (GIS) and remote sensing for selecting suitable solid waste disposal sites. All the factors were represented with map outputs which were reclassified and standardized in GIS environment followed by preparation of their suitability map. Analytical Hierarchy Processes pair-wise comparison module was used to derive weights for all factor parameters.

Accordingly, 89% of the study area is unsuitable, 1.6% of the total study area is less suitable, 2.9% is moderately suitable and 6.5% is highly suitable for landfill based on pre-defined criteria (based on their area, distance from the center and nearby settlements due to their minimum environmental and social negative effects). The final output of the study shows that 4 selected landfill sites in relation to those evaluating criteria. Therefore, landfill sites 4 which are chosen as highly suitable sites arranged based on their area size from large to small area size, site1(97.1ha), landfill site,2(45.7ha), landfill site,3(29.2)and landfill site4(23.1ha). In general, landfill site selection has been required appropriate data set, consideration of responsible persons and other concerned bodies.

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Waste was an early problem of mankind, and a growing one that is of major concern to every nation of the world (Genemo, *et al*, 2015). It is an issue mostly witnessed in urban areas as a result of high surge in population growth rate and increase per capita income thus posing a danger to environmental quality and human health. Waste is a material discharged from each stage of daily human life activities which lead to impose impact on human health and the environment, whereas solid waste refers to leaves/twings, food remnants, papers/cartons, textile materials, bones ash/dust/stones dead animals, human and animals excreta, construction and demolished debris, biomedical debris, household hardware (electrical appliances, furniture etc...) (Babatunde *et al.*, 2013).

Solid waste is a global environmental problem in today's world both developed and developing countries due to rapid population growth, economic activities growth and the rise of community demand accelerated solid waste generation in the world(Tirusew, 2013). The most common problem associated with improper management of solid waste includes disease transmission, fire hazards, odour nuisance, atmospheric and water pollution, aesthetic nuisance and economic loss (Jilani *et al.*,2002).

For many underdeveloped nations municipality solid waste management has thus become a major issue of concern, especially as population increase. For instance, in most developing countries 30-50% of the population is urban, and in many African countries the growth rate of urban areas exceeds 4% (Senkoro, 2003).

When the government of African countries were asked by the World Health Organization to prioritize the environmental health concern, result revealed that solid waste was identified as the second most important problem (next to water quality), less than 30% of urban population have access to “proper and regular garbage removal (Senakoro, 2003). The issue of solid waste management in developing countries, either not efficient or still at the elementary stage, that is why solid waste generated has become a threat to the environment.

Solid waste disposing is an important part of waste management system, which requires much attention to avoid environmental pollution and health problem. However, most solid waste dumping sites in developing countries are found on the outskirts of the urban areas where there are water bodies, crop fields, settlement and road. These are a suitable site for the incubation and proliferation of flies, mosquitos and rodents. They transfer diseases that affect human health (Abul, 2010). Inappropriate disposal of solid waste can be manifested by contamination of surface and ground water through leachate, soil contamination through direct waste contact, air pollution by burning of waste, spread of diseases by different vectors like birds, insects and rodents, or uncontrolled release of methane by anaerobic decomposition of waste (Visvanathan and Glawe, 2006).

There are various techniques that are currently being used for solid waste management. These include thermal treatment, biological treatment, land filling and recycling (Kontos *et al.*, 2005). However, in today's society, finding a suitable site is becoming a significant problem (Erkut and Moran, 1991).

The various factors such as socio-economic, environmental and land use should be considered along people well-being for developing suitable solid waste disposal site. Today advancement in remote sensing and Geographic information system (GIS) techniques has made waste disposal site selection more accurate and convincing (Kontos, *et al.*, 2005).

GIS undoubtedly provide better data management, high quality analysis and improve the efficiency. The use of GIS reduce the time, cost and enhance accuracy (Akbari *et al.*, 2008).GIS is a tool that not only reduce time and cost of the site selection, but also provide digital database for further monitoring program of the site.

1. Statement of the problem

Waste management is a major issue of the global environmental agenda, as population and consumption growth result in increasing quantities of wastes. In developing countries, the population of towns is increasing due to both natural increase and migration from rural areas. This high population growth and the activities of development result in the generation of large amount of solid wastes, that its composition includes paper, vegetable peelings, onion seed coats, broken plastic and festal, soil and dust, animal dung, grasses, pieces of cloth, small bottles, soot, etc.(Mekonin, 2012). Those solid wastes are face problem of their disposal and have potential effect to pollute the environment like water, soil and air. The pollution of these and other resources of the environment affects public health. In Ethiopia, most of the diseases related to poor environmental sanitation and water contamination (Kumel, 2014).

Due to the fact that, rapid population growth and developmental activity, the Hosanna town has been experiencing high amount of household and municipal solid wastes which are not properly managed (Mekonin, 2012). These high rates of wastes are facing problem of their disposal and have very high potential effect to pollute environment such as surface and ground water, soil and air. The pollution of water could aid the transmission of water-borne infections such as typhoid, gastro enteritis and the pollution of soil can aid the spread of food-borne diseases like salmonellosis (Nair, 2010). The existing solid waste management of the town is improper and uncontrolled, where people dump wastes on the road street, market areas, water drainages and so on. Uncontrolled solid waste disposal can also cause environmental problems: -like traffic congestion on the streets and roads, municipal floods when dumped on water ways (Nair, 2010).

There are economic and social drawbacks for the existing inefficient waste management system of the town, such as absence of waste collection bins, lack of awareness and the habit of waste collection centers proximity and open nature, unplanned existing dumping location site problem and absence of transportation facilities. This leads to introduction of illegal dumpsites that became fertile ground for breeding flies and other vectors which have in effect become health hazard, obstructing traffic flow, causing environmental degradation and general unsightliness (Hauwa, 2003). Therefore, the increased wastes from the growing population and development activities have to be reduced via waste reduction, recycling and reuse techniques.

Despite the fact that, it is impossible to manage all solid wastes through waste reduction, recycling and reuse system, collecting and depositing in proper sites by landfill techniques is another means of waste disposal (Kummel, 2016). The landfill sites should be environmentally sound and socially accepted so as to protect environment and safeguard public health. Even if it is more difficult to selecting appropriate site and managing solid waste dumping in developing countries like Ethiopia with limited finance and rapid population growth rate, the use of GIS and RS provide appropriate method to select landfill site more accurate, cost and time efficient (Minalu,2016). However, in most part of our country the GIS and RS techniques had been already using to conduct research on land fill site selection, but not including Hosanna town.

The current waste disposal system of the town is open dumping system where there are river, stream, settlement and agricultural areas and the sites are filled out which causing social and environmental problems. That is why, the research needed to conduct in order to select suitable solid waste disposal site for the town by considering physical and social factors. Therefore, the study employs Geographic information system (GIS) and remote sensing techniques for appropriate solid waste disposal site selection for Hosanna Town.

1.2. OBJECTIVE OF THE STUDY

1.2.1 General Objective

The main objective of the study is to select suitable solid waste disposal sites which are environmentally sound, economically feasible and socially acceptable in the study area.

1.2.2. Specific objective

1. To assess if the existing dumping sites fit the standards,
2. To examine the physical and social factors that are necessary to select landfill site and prepare their suitability map in GIS environment, and
3. To determine potential solid waste disposal site by using multi-criteria analysis and produce its thematic map.

1.3. Research questions

1. What does the present solid waste disposal system of the study area look like?
2. What are the solid wastes which dumped in outdoor in the study area?
3. What are the necessary factors to be considered to select suitable solid waste disposal site?
4. How would the final selected landfills be evaluated?

1.4. Significance of the study

This project is expected to ensure environmental safety of Hosanna town by selecting suitable site for solid waste disposal using GIS and remote sensing which will support different stakeholders like urban planners, local engineers in their activities to consider the importance of free spaces and bare lands when urbanization and rapid growth rate of population highly aggravates on the urban land.

In addition, there is no prior study in the study area; therefore, the final output of this study will be used as springboard for further research on the issue of urbanization and municipal solid waste management.

1.5. Scope of the study

This study is limited to the suitable solid waste disposal site selection for Hossana town. The issues under consideration in this study are only solid waste disposal site selection, but not the liquid waste and gaseous waste. Moreover, the study will be limited in technical aspects for selecting suitable solid waste disposal site for Hossana town, rather recycling, reduction and reusing waste management systems. In addition, the project conducting period is time bounded until June 30/2017 G.C.

1.6. Limitation of the study

This study compiled with the limitation of the followings:

- ❖ Lack of reliable data for some factors for the study area, even though the data collected at national level are collected in a very wide range therefore the data lack well description of the area. Hence, geology and ground water are not considered as suitable site selection.
- ❖ Absence of prior study with regarding to landfill sitting in the study area to use as comparative advantage.
- ❖ Lack of organized secondary data due to the absence of documentation and organized database system with regarding to the turnoff the officers in the study area.

1.7. Organization of the paper

The research paper has five chapters, the first chapter contains the introduction part with background of the study, statement of the problem, objectives of the study, project questions, scope, significance and limitation of the study. The second chapter is related to literature reviewed, which focus on explaining terms, concepts related to the subject matter and applications of GIS and RS in landfill sitting . This section is emphasized on different scholar's ideas about causes and consequences of landfill around the world. The third chapter deals with descriptions of the study area, methodology and materials employed in this study. The fourth chapter presents finding with the output representation of the study. The fifth chapter includes conclusion and recommendations of the research work.

CHAPTER TWO

Review of Related Literatures

2.1. General Concepts and Definition of Terms

Solid Waste includes all products discarded as useless or unwanted which arising from human and animal activities those are normally solid and discarded once. Similarly, solid wastes means any garbage, refuse, sludge and other discarded solid materials, including solid waste materials resulting from industrial, commercial, and agricultural operations, and from community activities, but does not include solid or dissolved materials in domestic sewage or other significant pollutants in water resources, such as silt, dissolved or suspended solids in industrial waste water effluents, dissolved materials in irrigation return flows or other common water pollutants (Tchobanoglou *et al.* 1977 cited in Genemo 2015).

2.2. Types of Solid Waste

According to 2012 world bank report solid waste can be classified into different types depending on their source:- municipal waste, hazardous waste and hospital waste.

2.2.1 Municipal solid waste

Municipal solid waste consists of household waste, construction and demolition debris, sanitation residue, and waste from streets. This garbage is generated mainly from residential and commercial complexes. With rising urbanization and change in lifestyle and food habits, the amount of municipal solid waste has been increasing rapidly and its composition changing.

2.2.2. Hazardous waste

Industrial and hospital waste is considered hazardous as they may contain toxic substances. Certain types of household waste are also hazardous. Hazardous wastes could be highly toxic to humans, animals, and plants. Household wastes that can be categorized as hazardous waste include old batteries, shoe polish, paint tins, old medicines, and medicine bottles. Hospital waste contaminated by chemicals used in hospitals is considered hazardous. These chemicals include formaldehyde and phenols, which are used as disinfectants, and mercury, which is used in thermometers or equipment that measure blood pressure.

1 [Municipal solid waste - www.epa.gov/epaoswer/non-hw/muncpl/index.htm](http://www.epa.gov/epaoswer/non-hw/muncpl/index.htm)

In the industrial sector, the major generators of hazardous waste are the metal, chemical, paper, pesticide, dye, refining, and rubber goods industries. Direct exposure to chemicals in hazardous waste such as mercury and cyanide can be fatal (Eberechi, 2016).

2.2.3. Hospital waste

Hospital waste is generated during the diagnosis, treatment, or immunization of human beings or animals or in research activities in these fields or in the production or testing of biological. It may include wastes like sharps, solid waste, disposables, anatomical waste, cultures, discarded medicines, chemical wastes, etc. These are in the form of disposable syringes, swabs, bandages, body fluids, human excreta, etc. This waste is highly infectious and can be a serious threat to human health if not managed in a scientific and discriminate manner

2.3. Solid waste management in developed countries

Shortage of land for waste disposal and inappropriate landfill site is one of the biggest problems in most of the large urban area in the world which has its negative impact on human and environment (Genemo, *et al*, 2015).

This extends wider than just the geographical boundaries of the town or municipalities. Solid waste management is in crisis in many of the world's largest urban areas as populations attracted to cities continues to grow and this has led to ever increasing quantity of domestic solid waste while space for disposal decrease (World Bank, 1999).

Solid waste management is the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations, and that is also responsive to public attitudes. Management of solid waste reduces adverse impacts on the environment and human health and supports economic development and improved quality of life (Sener, 2004).

2 Municipal solid wastes -www.epa.gov/epaoswer/non-hw/muncpl/index.htm, Ibid,

2.4. Solid waste management in developing countries.

In Africa rapid urban growth since 1960's has put pressure on land resources within the areas surrounding cities, and has led to increased generation of wastes. The problem is aggravated with the open dumping nature of disposing waste, especially in the slum areas of most African cities (Hammer 2003 cited in Genemo 2015).

The booming growth of cities of the developing world has outpaced the financial and man power resources of municipalities to deal with provision and management of services, of which solid waste is the major one. Lack of these services greatly affects the urban poor, women and children who are vulnerable to health hazards. Twenty two human diseases are related to improper solid waste management (World Bank, 1999). Moreover, its effects are also reflected in reduced productivity, low income and poor quality of life and deteriorated environment. Similar to cities of most developing countries, provision of required services lags behind the need and development of settlements in urban areas of Ethiopia.

Integrated infrastructure and housing development is not widely practiced. Provision of solid and liquid waste collection and disposal is low (moisture ban are as lack the service). In addition to this, deterioration of the immediate environment in the households and their surrounding is increasing. With the current growth rate of urban population in Ethiopia, it is estimated that the population of moisture ban are as especially small urban centers is doubling every 15-25 years (World bank, 1999).

As solid waste generation increases with economic development and population growth, the amount in these urban areas will double with in a similar time range. Municipalities in Ethiopia have to be prepared for this challenge (Yohannis et al., 2015) with no exception of Hossana Town.

2.5. Methods of Solid Waste Disposal

There are different methods used for waste management such as reuse, recycling, incineration, landfill etc. In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by land filling remains the most commonly employed methods (Debishiree, 2014).

2.5.1. Incineration

Incineration is a disposal method in which solid organic wastes are subjected to combustion so as to convert them into residue and gaseous products. This method is useful for disposal of residue of both solid waste management and solid residue from waste water management. This process reduces the volume of the solid waste to 20 to 30 percent of the original volume. Incineration and other high temperature waste treatment systems are sometimes described as “thermal treatment”. Incinerators convert waste materials into heat, gas, steam and ash. Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical wastes). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants. Combustion in an incinerator is not always perfect and there have been concerns about pollutants in gaseous emission from incinerator stacks. Particular concerns have focused on some very organics such as dioxins, furans, etc which may be created which may have serious environmental consequences (Eberechi, 2016).

2.5.2. Recycling

Recycling is a resource recovery practice that refers to the collection and reuse of waste materials such as empty beverage containers. The materials from which the items are made can be reprocessed into new products. Material for recycling may be collected separately from general waste using dedicated bins and collection vehicles are sorted directly from mixed waste streams and are known as kerb-side recycling, it requires the owner of the waste to separate it into various different bins (typically wheelie bins) prior to its collection (Lars, 1999).

The most common consumer products recycled include aluminum such as beverage cans, copper such as wire, steel and aerosol cans, old steel furnishings or equipment, polyethylene, glass bottles and jars, paperboard cartons, newspapers, magazines and light paper, and board boxes. These items are usually composed of a single type of material, making them relatively easy to recycle into new products. The recycling of complex products (such as computers and electronic equipment) is more difficult, due to the additional dismantling and separation requirement. The type of material accepted for recycling varies by city and country.

Each city and country has different recycling programs in place that can handle the various types of recyclable materials (Eberechi 2016 and Sener, 2004).

However, certain variation in acceptance is reflected in the resale value of the material on cities reprocessed. Methods of waste reduction, waste reuse and recycling are the preferred options when managing solid waste. There are many environmental benefits that can be derived from the use of these methods. They reduce or prevent greenhouse gas emissions, reduce the release of pollutants, conserve resources, save energy and reduce the demand for waste treatment technology and landfill space. Therefore, it is advisable to adopt and incorporated these methods as part of the solid waste management plan (Mekonin, 2012).

Both waste reduction and reuse are methods of waste prevention which eliminates the production of waste at the source of usual generation and reduce the demands for large scale treatment and disposal facilities. Methods of waste reduction include manufacturing products with less packaging, encouraging the public choose to reusable products such as cloth napkins, reusable plastic and glass containers, backyard composting and sharing and donating any unwanted items rather than discarding them (Mekonin, 2012).

Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus, from this definition recycling occurs in three phases: first the separation and collection of waste material (waste is sorted and recyclables collected), the preparation of these materials for reuse, preprocessing and remanufacturing of these materials (recyclables are used to create raw materials). (Lars, 1999 and Sener, 2004).

2.5.3. Source reduction

It involves diminishing waste amount, volume and toxicity at a source of generation. Source reduction is the most effective way which reduces the quantity of waste, the cost of associated with its handling and its environmental impact (Sener, 2004).

Waste reduction may occur through the design, manufacture and packaging of products with minimum toxic content, minimum volume of materials, or longer life and also at the

household, commercial or industrial facility through selective buying patterns and the reuse of products and materials (Tehobanoglous ,1993 cited in Sener, 2004).

2.5.4. Landfill

It is the process by which the solid waste that cannot be recycled nor further used; the residual material remaining after the recovery facility and after the recovery of conversion product and energy is placed in a landfill. Although there is a public opposition to landfills, it is necessary and there is no combination of waste management technique that does not require landfilling. Landfilling includes monitoring of the incoming waste stream, placement and the compaction of waste and installation of landfill environmental monitoring and control facilities (Sener,2004).

Disposal of waste in a landfill involves burying the waste, and this remains a common practice in most countries. Landfills are often established in abandoned or unused quarries, mining voids or borrow pits. A properly designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. In contrary, poorly designed or poorly managed landfills can create adverse of environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquid Another landfills products are gases that mostly composed of methane (CH₄) and carbon dioxide CO₂, which is produced as organic waste breaks down an aerobically. This gas can create dour problems and kill surface vegetation. A landfill site is also known as a tip dump, rubbish dump, garbage dump or dumping ground. Historically, landfills have been the most common method of organized waste disposal method and remains in many places around the world (Minalu, 2016 and Sener, 2004).

Landfill is an environmentally acceptable method of waste disposing on the ground. Many developing countries do not have criteria for landfill site selections and some have regulations of developed countries without modifying to their local conditions. But taking regulations of developed countries without considering local conditions is a problem because the development of engineered landfills involves complex engineering design and construction techniques. These sophisticated engineered landfills can occur where the local economy can afford the high level of expenditure required for construction and operation of the landfill and where the technical resources to achieve high standards of construction and operation

are made available. Therefore, in developing sitting criteria for new landfills sit it is important to ensure that the constructional and operational capabilities of the local communities. Additionally, available financial and human resources, the composition of the waste and the climate of the area should be considered (Laura, 2003 and Kumel, 2014).

Landfill has been recognized as the cheapest form for the final disposal of municipal solid waste and it has been the most used method in the world. However, sit ting landfill is an extremely complex task mainly due to the fact that the identification and selection process involves many factors and strict regulations. For proper identification and selection of appropriate sites for landfills careful and systematic procedures need to be adopted and followed. Wrong sitting of landfill many result in environmental degradation and public opposition. The sitting of solid waste landfill must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them,(Sumathi,2007).

GIS has been found to play a significant role in the domain of sitting of waste disposal sites. Many factors must be incorporated in to landfill sitting decisions and GIS is ideal for this kind of studies due to its ability to manage large volumes of spatial data from a variety of sources (Debishree, 2014).

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

The natural anaerobic decomposition of the waste in some landfills used to recover energy and produces landfill gases which include carbon dioxide, methane and traces of other gases. Methane can be used as an energy source to produce heat or electricity. These landfills present the least environmental and health risk and the records kept can be a good source of information for future use in waste management, however, the cost of establishing these sanitary landfills are high when compared to the other land disposal methods (Minalu 2016).

2.6. Landfill Sitting

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

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

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

Sitting a sanitary landfill requires an extensive evaluation process in order to identify the optimum available disposal location. Therefore, the sitting of a solid waste landfill must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them. GIS has been found to play a significant role in the domain of sitting of solid waste disposal sites. Many factors must be incorporated in to landfill sitting decisions and GIS is ideal for this kind of preliminary

studies due to its ability to manage large volumes of spatial data from a variety of sources. The integration of GIS and Analytical Hierarchy Process (AHP) is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and AHP supplies consistent ranking of the potential landfill areas based on a variety of criteria (Debishree et al., 2014 and Sener 2004).

2.7. Concept of dump sites

Dumpsites are places designated for disposal of normally solid or semi-solid materials, resulting from human and animal activities that are considered useless, unwanted or hazardous. In other words, they are essential part of any waste management system, dump sites are historically the most used method for waste disposal in the world. It has the longest history, the widest range of capabilities and in most instances, is the least expensive waste disposal method (Eberechi 2016). The final disposal in most developing countries is usually a matter of transporting the collected waste to the nearest available open space and discharging them. The environmental conditions from these sites are thus expected to be bad especially in terms of the contamination to the environment and lives or that open dumping has potential to reduce environmental quality in neighborhood and can also pose a threat to public health (Jung et al, 2005).

2.8. Common landfilling methods

The principal methods used for landfilling of municipal solid wastes are, excavated cell/trench, area, and canyon.

2.8.1. Excavated cell/ trench method

The excavated cell/trench method of landfilling is suitable for areas where an adequate depth of cover material is available at the side and where the water table is not near the surface. Typically, solid wastes are placed in cells or trenches excavated in the soil. The excavated soil from the site is used for daily and final cover. The excavated cells or trenches are usually lined with synthetic membrane liners or low permeability clay or a combination of the two to limit the movement both landfill gases and leachate (Tchobanoglous 1993 cite in Sener, 2004).

2.8.2. Area method

The area method is used when the terrain is unsuitable for the excavation of cells or trenches. High groundwater conditions necessitate the use of the area type landfills. Site preparation includes the installation of a liner and leachate control system. Cover materials must be carried by truck or earthmoving equipment from adjacent land or from borrow-pit areas. In locations with limited availability of material, compost produced from waste can be used as cover. Other techniques include the use of movable temporary cover materials such as soil and geo-membranes. Temporarily placed soil and geo-membranes over a completed cell, can be removed before the next lift is begun (Tchobanoglous 1993 cited in Sener, 2004).

2.8.3. Canyon/Depression method.

In this method, canyons, dry borrow pits, and quarries are used for landfills. The techniques to place and compact solid wastes in canyon/depression landfill vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of the leachate and gas control facilities to be used, and the access to the site.

Typically, filling for each lift starts at the head end of the canyon and ends at the mouth to prevent the accumulation of water behind the land fill. Canyon/depression sites are filled in multiple lifts, and the method of operation is the same as the area method. If a canyon floor is reasonably flat, the initial land filling may be carried out using the excavated cell/trench method. The availability of adequate material to cover the individual lifts and to provide a final cover over the entire land fill is very important. Cover material is excavated from the canyon walls or floor before the liner system is installed. Borrow pits and abandoned quarries may not contain sufficient soil for intermediate cover, so that it may have to be important (Tchobanoglous 1993 cited in Sener, 2004).

2.9 Landfill Site Selection Process

The major goal of the landfill site selection process is to ensure that the disposal facility is located at the best location possible with little negative impact to the environment or to the population. For a sanitary landfill siting, a substantial evaluation process is needed to

identify the best available disposal location which meets the requirements of government regulation that minimizes economic, environmental, health, and social costs (Sener 2004).

Landfill site selection is a significant step in implementing a waste management program. Proper siting can contribute to a diminution in design, construction, and operating costs, as well as help to minimize environmental impacts. From an environmental engineering perspective, an important objective of the process is to select a site that will provide the greatest public health and environmental protection in the event of landfill control failure by creating the best use of the land resource available. To insure that an appropriate site is chosen, a systematic process should be developed and followed. Unsuccessful landfill siting is typically the result of strong public opposition, and much research has been conducted to explore reasons for siting failures and to recommend changes in siting procedures (Laura,2003).

As such, it is important that an appropriate method be used so that the process results in the selection of a site that meets social, environmental and economic criteria. Lawrence (1996) in Tsegaye, 2006) identified three major siting approaches: the environmental suitability approach; the social equity approach and the community control approach. The basic idea behind each of these three approaches is as follows:

➤ **Environmental suitability approach**

This approach follows a rational planning process through which alternatives are recognized, screened and compared. The goal of the process is to minimize the negative and maximize the positive environmental effects of the project. There are typically three major stages in the process: area screening and identification, site screening and identification, and finally site comparison. There are many different qualitative and quantitative evaluation methods that can be used for screening and comparing site alternatives. The process and level of detail used can be designed to reflect project types and regional needs and characteristics (Tsegaye, 2006).

➤ **Social equity approach**

This approach focuses on fairness in the planning process, and a fair distribution of facilities, costs and benefits among stakeholders. Direct involvement of all interested and

affected parties is considered essential. Equity concerns have only recently been incorporated into the siting processes (Tsegaye, 2006).

➤ **Community Control Approach**

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

Steps in Landfill Siting

According to Tsegaye (2006) there are different steps in the landfill site selection process, such as identifying site requirements, objectives, criteria and constraints, area screening and identification using constraint mapping, Site Screening and Identification, Site Investigation and conceptual design and Site Comparisons and Selection. Each landfill site processing step is discussed below.

Step1: Identify site requirements, objectives, criteria and constraints

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

Step2: Area screening and identification using constraint mapping

Constraint mapping is a commonly used technique that involves creating a series of maps to show the areas identified as unsuitable for landfilling based on each of the constraints. When the maps are overlaid, the potential candidate sites can be easily identified. An important element of a successful landfill siting process is evaluating the basic suitability of all available land for landfilling to aid in the selection of a limited number of

potential sites for more detailed evaluations. The resources and constraints of the government agencies involved in the process should be taken in to consideration. The following are some of examples of typical constraints relating to water resource protection, as the current open field solid waste disposal site is affecting water resource the study area

- Water bodies (lakes, streams) are not suitable for landfill development.
- Areas with complex geology are not suitable as it will be difficult to monitor and remediate in the event of ground water contamination.
- Landfills should not be sited in protected areas such as forests and endangered species habitats.
- Landfills should not be close to urban landscapes.
- Landfill should not be constructed in the flood plain of a river or other areas susceptible to frequent flooding

Step3: Site screening and identification

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

Step4: Site investigation and conceptual design

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

Step5: Site comparisons and selection

This step involves a detailed evaluation and comparison of the candidate sites. This requires comparing data collected from site investigations and published sources, and conceptual designs to determine which site best fit the criteria. Often, this is achieved by weighting and rating criteria. The weight of each criterion is determined according to its relative importance and each site is rated for each criterion. The method used for rating does not necessarily need to be the same for all criteria. Numerical ranking such as a scale of 1to9, or a qualitative ranking such as high, medium or low can be used.

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

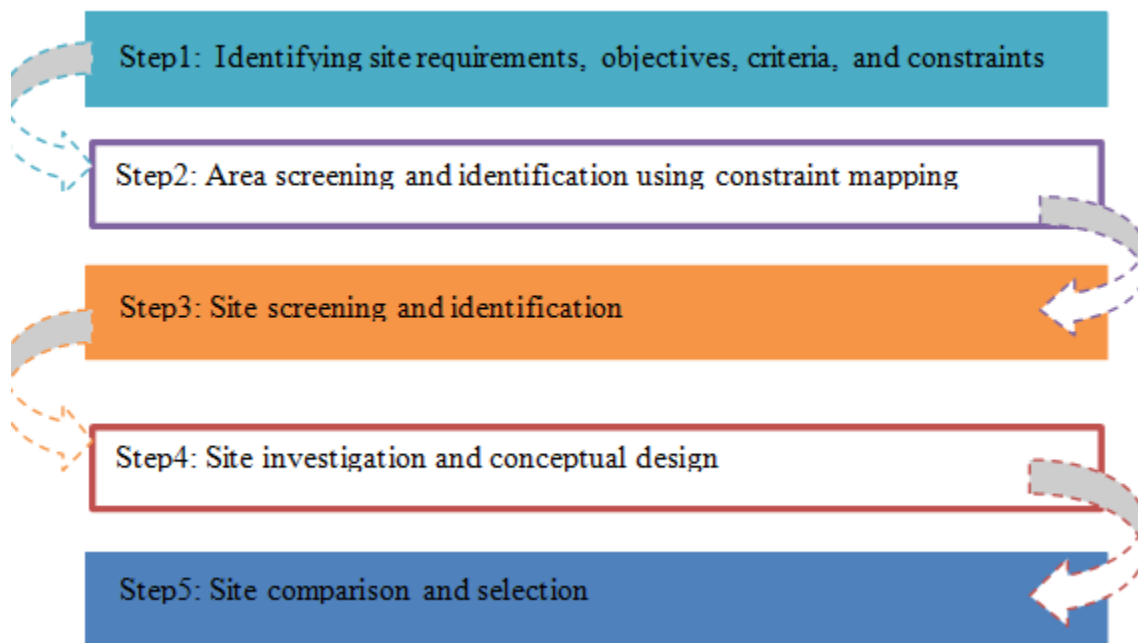


Figure2.1: Steps in the landfill sitting process (Tsegaye, 2006)

2.10. Criteria used for waste disposal site selection

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

Even if, the landfill site selection criteria vary from region to region, the following criteria are used for solid waste disposal site selection in most areas.

- ❖ **Distance from Settlement:** The landfill site should not be placed near a residential or an urban area, to avoid adversely affecting land value and future development and to protect the general public from possible environmental hazards released from landfill sites. In the same time, it should not be located too far to avoid extra transportation costs and environmental pollution. The safe distance from settlements is determined as 1500m (MUDC, 2012).
- ❖ **Land slope:** landfill site should have a gentle incline to avoid soil erosion and limit expenditure on cleaning and maintaining drainage system components. The land with a slope less than 10% is highly suitable for solid waste dumping (MUDC, 2012 and Tirusew *et al.*, 2013).
- ❖ **Proximity to Water bodies:** to maintain the environmental health of water sources at least 500 m buffered distance should be ringed through straight line calculation (MUDC, 2012).
- ❖ **Distance from roads network:** landfills shall not be located within 400 m of any major highways and city streets and also should not be placed too far from existing road networks, to avoid the expensive cost of constructing connecting roads (Issa, 2012 and MUDC, 2012).
- ❖ **Protected areas:** the landfill should not be located within 1000m distance of sensitive areas like churches, mosques, parks, schools and memorial sites (MUDC, 2012).

- ❖ **Land use and land cover type:** The land cover and use is the natural and human landscape that exposed by the threats imposed because of landfill adjacency and it is advisable to select land, which is occupied by bare and grass lands for solid waste disposal (MUDC,2012 and Tirusew *et al.*, 2013).
- ❖ **Soil type:** it is recommendable that the soil of the selected site has good nature of impermeability in order to reduce the possibility of aquifer contamination. The soil of the selected site should be clayey (MUDC, 2012)

2.11. Application of Remote Sensing for Landfill Site Selection

Remote sensing is defined as the science or art of obtaining information about an object, area or phenomenon through the analysis of the data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand *et al*, 2004).. According to Nishanth *et al* 2010, Remote sensing serves as a tool for environmental resources assessment and monitoring and an excellent tools for inventory and analysis of environment and its resources, owing to its unique ability of providing the synoptic view of a large area of the earth's surface and its capacity of repetitive coverage. One of the most important applications of remote sensing can be found in the case of solid waste landfill site selection where remote sensing data (satellite images) are used for extracting most of the site selection criteria used for siting landfill (Oštiretal.,2003) (example, mapping land use/land cover, geology and surface water), time and cost effectively. Moreover, remote sensing can provide digital data as an input for GIS.

2.12. Application of GIS for Landfill Site Selection

Technological development in computer science has introduced Geographic Information System (GIS) as an innovative tool in landfill process (Kontos *et al*, 2003).GIS combines spatial data (maps, aerial photographs, satellite images) with the other quantitative, qualitative and descriptive information databases. This technology offers an analytical framework for data synthesis that combines a system capable of data capture, storage, management, retrieval, analysis and display. When remotely sensed data are combined with other landscape variables organized with in a GIS environment provide an excellent framework for data capture, storage, synthesis, measurement and analysis. For assessing a site as a possible location for solid waste landfilling, several environmental and political factors and legislations should be

considered (Savage *et al.*, 1998). The GIS aided methodology presented here utilizes to create the digital geo-database as a spatial clustering process and easily understood way for landfilling process.

Landfill siting is a complicated process that requiring a detailed assessment over a vast area to identify suitable location for constructing a landfill subject to many different criteria (Chang *et al.*, 2007). Even though landfill sitting is complex, tedious and costly as it requires multiple criterions from environment, social and economic point of view, the development of technology in computer science provide an opportunity. GIS application can help in determining the landfill location in accordance with the technical requirements, with overlay the thematic map to get an appropriate landfill (Akbari *et al* 2008). Moreover GIS is a tool that not only reduces time and cost of the site selection but also provides digital databank for future monitoring program of the site. The procedure followed under the GIS framework rejects the unacceptable sites considering environmental factors exclusively, other than economic and political issues, contained in the form of multiple layers of attribute information to select the candidate sites for landfilling waste through an overlay analysis performed by GIS software (Basagaoglu, 1997). Therefore, GIS offers the spatial analytical capabilities to quickly eliminate parcel of land which is unsuitable for landfill site (Chang *et al.*, 2007) and hence reduce cost and time of siting processes.

2.13. Multi-Criteria Decision Analysis (MCDA)

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

Analytic Hierarchy Process (AHP), was introduced by Thomas Saaty in 1980, is a conventional land suitability analysis MCDA method that provides right decision-making approach for site selection. AHP has been integrated with GIS for land suitability modeling

when selecting the best alternatives from a pool of various possibilities in the presence of multiple criteria. This technique provides a means of decomposing the problem in to a hierarchy of sub-problems that can be more easily comprehended and subjectively evaluated. The subjective evaluations are converted in to numerical values that are ranked on a numerical scale (Debishree *et al*, 2014).

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

CHAPTER THREE

3. DESCRIPTION OF STUDY AREA AND RESEARCH METHODOLOGY

3.1 Geographical location

Hosanna, locally known as Wachemo is located at 232km south from the capital Addis Ababa via Alemgana-Butajira road. It lies on an elevation of 2158 -2400m above mean sea level, across the main high way leading from Addis Ababa via Butajira to Wolayita sodo. It is found 7°31` to 7°35` N latitude and 37°49` to 37°53`E longitude. It is surrounded by Lemo *werda*, one of the *weredas* of the Haddiya zone. It serves as a major business center for inhabitants in the area. It is one of the 22 modeled towns that is given emphasis by the regional state and among 19 selected strategic centers for development. Hosanna is the administrative center of the Haddiya zone, with the population of 133, 764. Out of which 65,132 are male and 68,632 are female (CSA, 2007).

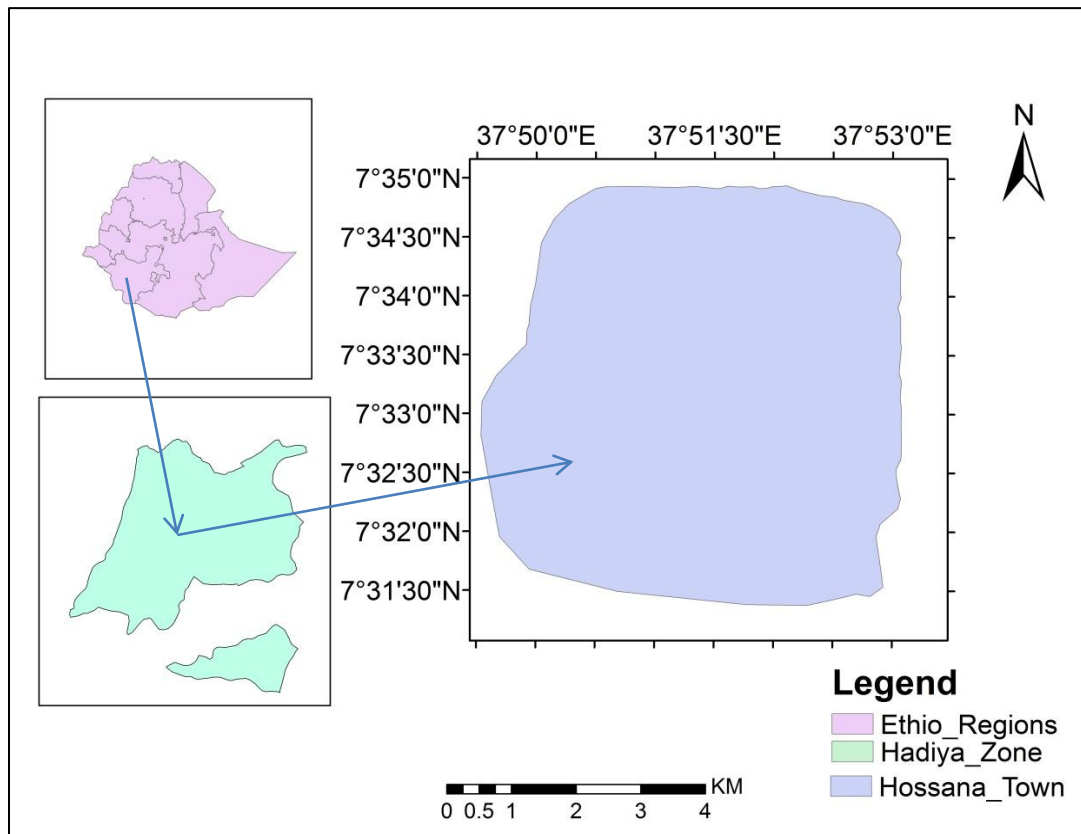


Figure 3.1: Location map of study area (Hosanna Municipality).

3.1.1 Climate

The whole study area is lying within a tropical climate as a humid region (Ethiopian meteorological Agency). The climate of Hossana town is characterized by four distinct seasonal weather patterns; that are the main wet season "kiremt" which extends from June to August, a minor rainy season (Autumn) "meker" extends from September to October, a little rainy season "belg" extends from March to May and more likely no rainy season "bega" extends from December to February. In general based on local climatic classification, Hossana town is grouped under "woeina-dega" climatic zones. As meteorological data has shown that the annual min average temperature of the town is around 17⁰c and the maximum temperature reaches up to 23⁰c as which is shown in the following graph.

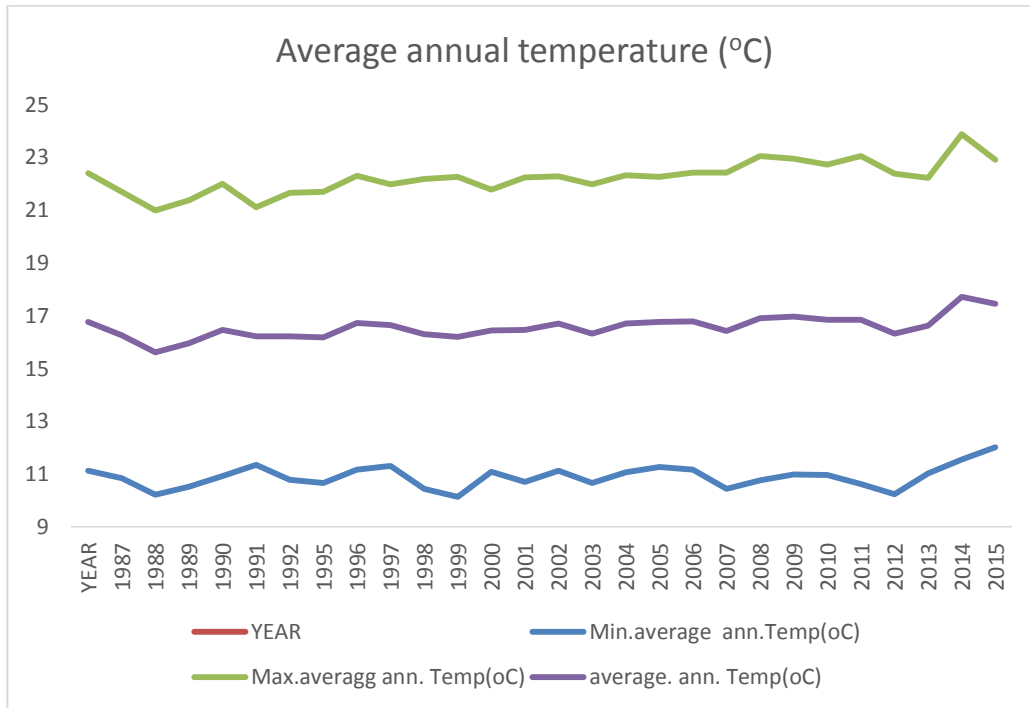


Figure 3.2: Average annual maximum and minimum temperature of study area (Ethiopian meteorological Agency, 2008/2016).

3.1.2 Rain fall

The variation in the seasonal distribution of rainfall in Ethiopia can be attributed by the reference to the position of the Inter-Tropical Convergence Zone (ITCZ), the relationship between upper and lower air circulation, the effects of topography and the role of local convection currents and the amount of rainfall. As meteorological data has shown that the highest average annual rainfall of the area was recorded in 1998 while the lowest was in 2015 as shown in the graph below.

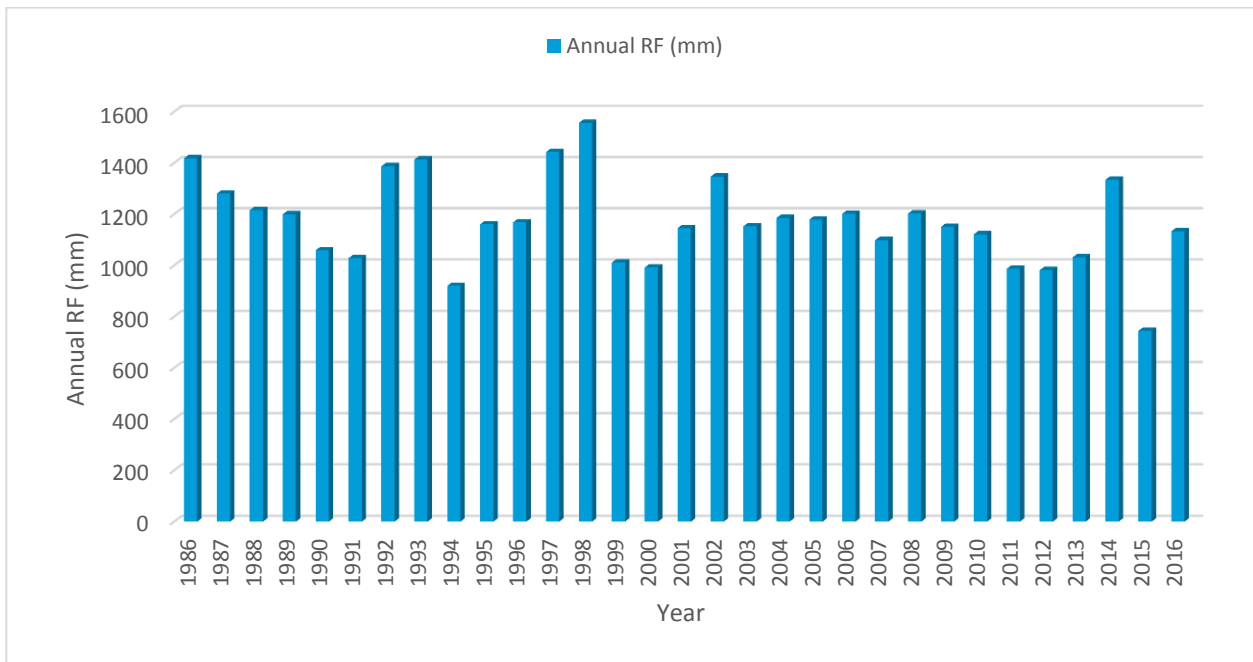


Figure 3.3: Annual rainfall distribution for the study area (meteorological Agency)

3.1.3 Physical characteristics

Physically, Hosanna Town covers about 37.13km² of land with alternatively changing horizontal and vertical landscape orientation. It includes several ups and downs, hills and plains which can commonly be said that the town is inclined dominantly from west to east. Tamirat (2005), the present day landscape of Hosanna owes its actual surface from the past volcano tectonic activities with the slight modification by local thick soil formation, soil erosion and to some extent by gully formation. Hosanna is found at the south eastern edge of the western plateau physiographic region which is very close to the left margin. Its location on a topographically higher area makes the town to serve as a divide for the Gibe-Omo and Rift-Valley lakes drainage basins (Mulugeta, 2000). Its elevation within the town ranges from

2200- 2400m asl around *Balewold Church* where the Hosanna hospital (currently Queen Elleni Mohammad Hospital) is situated to 2200m.asl around *TekleHaymanot Church*.

According to NUPI (2000), the slope characterizes the town, which gradually descends from the north to south elongated and highly elevated land mass to the east and west. Generally, about 75% of the town is with slope less than 10%, which is almost suitable for landfill site

The geology of Hossana town and its surroundings has been studied by researchers at the regional scale. The sequence of the rock units reveals the Precambrian gneiss, Mesozoic sediments, Paleogene (Late Eocene - Late Oligocene) fissural flood basalts with minor rhyolite, trachyte and pyroclastic flows Nazareth pyroclastic rocks type is the most dominant in the study area (Tamiru et.al, 2005).

3.1.4 Population:

Population is a key factor in carrying any plan in urban areas. According to central statistic Agency of Ethiopia total, population of Hosanna was 133,764 of which 65,132 are male and 68,632 are females. Currently, the total population size of the town is expected to be 168,764 of which 80,132 are male and 88,632 are female, if the growth rate (2.9%) is considered as constant (CSA, 2007).

3.1.5 Economic activity

The main economic activities of the town are trade, public services, transport, urban agriculture and the like. Among these activities trade, hotel and restaurants are the main ones. The physical characteristic of housing units in the town has revealed that the majority of them are dilapidated around “*Arada*” and without the requisite services; however, there are newly emerging housing units at the center and periphery of the town. Its proximity to Addis Ababa, Butajira and Wolaita Sodo towns creates good opportunity for future development of the town. Hosanna has access to asphalt road that links the town with Addis Ababa, Buttajira, Wolita Sodo and Wolikete town and other surrounding *woradas* with gravel road. Hosanna town is now administratively divided into three sub towns: Sech Duna, Gofer Meda and Addis ketema (Hosanna town administration finance and economy development office, 2017).

3.2 Methods and materials

The methods employed for this study involves consideration of important criteria for sitting solid waste dumping site. Even though the criteria will be considered, the reliability of the data affects the quality of any research. Therefore, in this project to collect data primary and secondary sources were applied as such to collect from field survey by using global positioning system (GPS), observation and interviewing the responsible persons and to gather data from internet, books, reports and journals respectively

3.2.1 Data sources:

To compile this project work different data sets were used to select suitable landfill site. These data were obtained from different sources as vector data and point data. In general, the sources were primary and secondary sources that all the factors (soil, settlement, road network, drainage and land use/land cover) obtained and further prepared in GIS environment.

3.2.2 Primary Data sources

The primary data obtained from field survey and observation of the study area to record, collect data that are not included in the structural plan and to record the exact location of the existing waste disposal site. Digital camera and GPS used to capture primary data like XY coordinates of important points and photography images. During field survey points to identify public facilities like schools and health centers as well as protected areas like churches and mosques should be collected using GPS. Photographs and field observations were applied to show the existing landfill site and the current waste disposal system of the town. Interviews with experts of environmental protection officers and residents who are near to the existing landfill have been taken to get more information. In addition to major factors, the results from interviews are used to identify the problem of existing landfill in the study area.

3.2.3 Secondary Data sources

Different factor maps such as road network map, land /use land cover type, slope, drainage map, of the study area that help to select suitable landfill site were used from recently updated land use/cover type map which was obtained from municipality of Hosanna town as polygon (vector) data with high scale was used after rasterized all in to equal cell size of 2m and coordinate system Adindan UTM zone 37N (UTM) to develop all factor maps by raster GIS spatial analysis which are very important for further analysis to select suitable landfill.

Table 1: Sources and types of secondary data

	Data type	Sources	Relevance
1	Land use map of the town	Municipality of hosanna town	To produce LU/LC
2	Structural map/master plan	Municipality of Hosanna town	To buffer the study area
3	Soil map	FAO	To extract soil map
4	Meteorological data	Meteorological Agency of Ethiopia	To generate climate and rainfall map
5	Contour map	Municipality of Hosanna town	To generate slope

3.3 Data analysis and presentation methods

There are different methods of GIS operation for suitability analysis (selection of suitable landfill site), like buffering, reclassify, overlay, spatial analyst and AHP are the major ones which were used in this study to select suitable landfill sites.

3.3.1. Buffering

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

3.3.2. Reclassify

The factors (road, river, slope and protected areas) were reclassified with the help of Euclidian distance function of spatial analyst tool operation of the GIS. The reclassified distances were ranked based on their suitability for landfill sitting.

3.3.3 Overlay

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

3.3.4. Multi-criteria decision making (MCDM)

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

3.3.5 Analytical Hierarchy process (AHP)

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

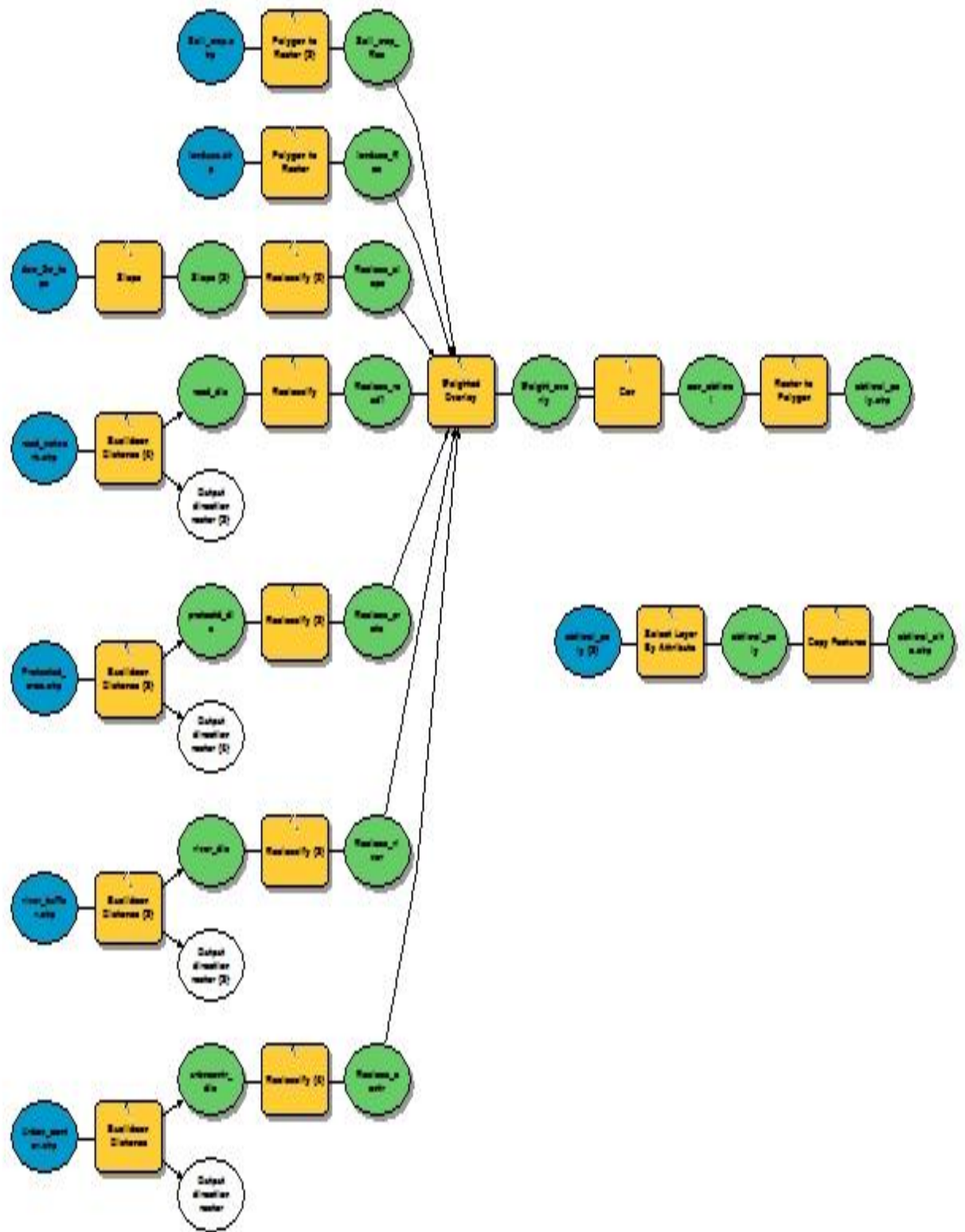


Figure3.4: Suitability model

3.3.6 Conceptual framework of the analyses

The general work flow of this study includes four major steps: identifying factors to be used to identify best location for solid waste landfill and producing maps for each, assigning weight for the selected factors, overlaying and generating landfill suitability map and finally, determining suitable areas for landfill.

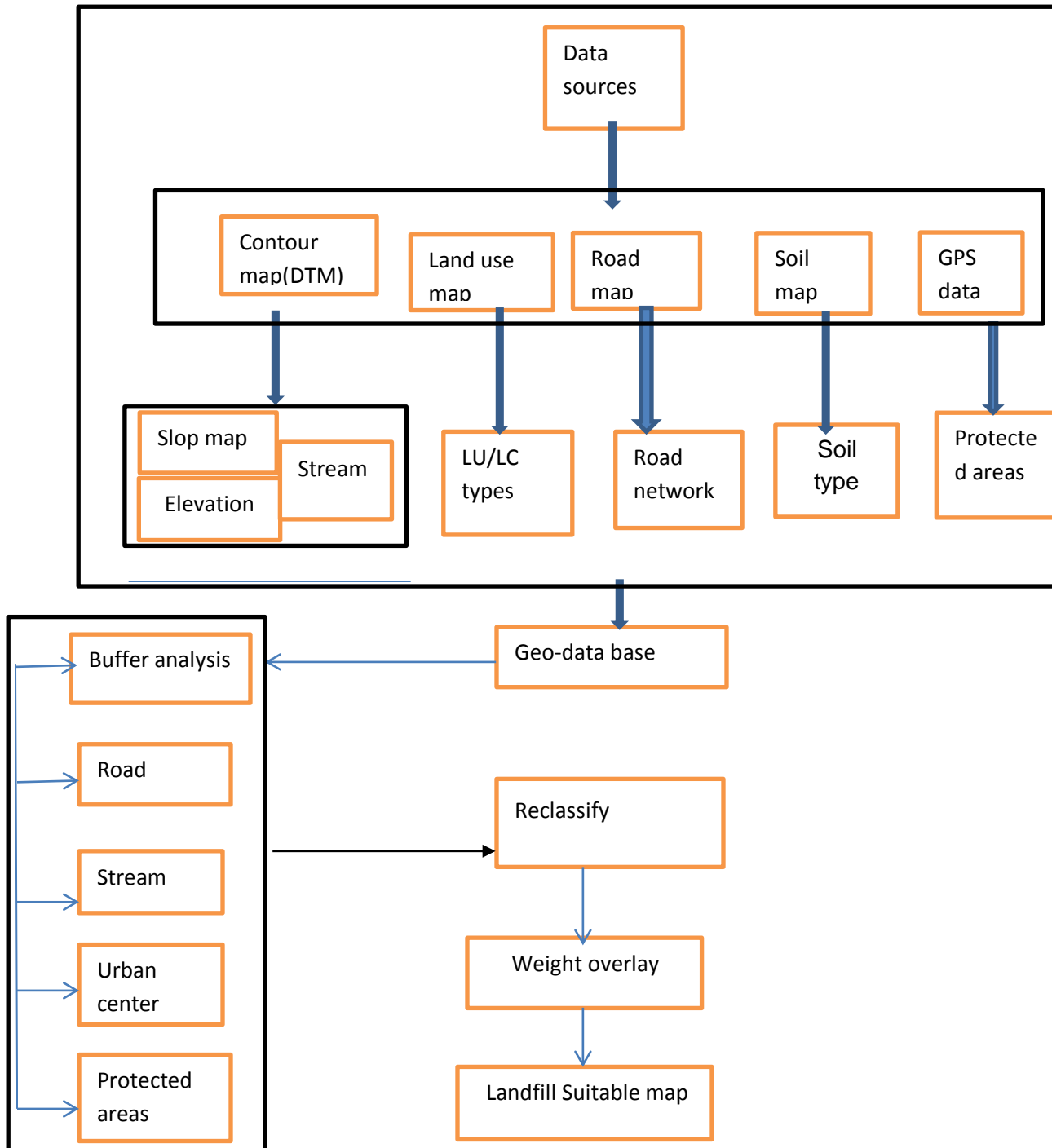


Figure 3.4: General Work flow of the study (Author, 2017)

CHAPTER FOUR

4. DATA ANALYSIS, RESULTS AND DISCUSSION

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

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

4.1 Solid Waste Management System in Hossana Town

The first objective of the research was to assess the present waste management strategies in Hossana town. This objective was achieved through field observation and interview with experts of Environmental Protection department of Hossana town. The result showed that the municipality of the town together with the land administration office

selected and prepared an existing open dumping site based on the criteria only distance from center of the town without consideration of other national or international criteria.

According to the observation and interview, the existing solid waste disposal system is not satisfactory, because the existing site does not consider major environmental and health factors, like distance from water bodies, agricultural fields and slope. The residents near to the existing open dump site are suffering from air pollution and due to pollution of the river they cannot use for animal feeding. The solid waste management system in Hosana town is a history of institutional trial with most issues unsolved, through collecting and transporting the solid wastes daily. The collectors gather the waste from houses and other institutions daily and transport it to dumping site using trucks. Unlike, many other towns of Ethiopia, Hossana town have no temporary garbage disposal site; therefore, households dump solid waste at any place outside their home. Since many of these are near to the settlement, road, drainage and public areas like market area which create a serious problem on human health, traffic flow and flood flow.

Although the town is one of the 22 modeled towns and among 19 selected strategic centers for development, the municipality did not give major attention to developing sustainable solid waste disposal site and management system. Solid wastes are generated from different sources due to fast growing nature of the town, however, it is possible to minimize and solve these problems through planning and implementing different municipal solid waste management components. Unsuitable and unmanageable site of landfill lead to serious contamination to the environment, for instance, surface water and air pollution, which have negative effect and considered as threat to residents. In the study area, surface water and air pollution are the main problems. However, the negative impacts from landfill can be minimized through selecting an appropriate site, which minimize potential environmental impact and GIS and RS techniques are effective for the purpose.

4.1.1 Open solid waste disposal at the study area

In the town majority of solid waste collected from residences, institutions and asphalt roads, hotels as well as commercial areas (chat barendas) is disposed in open field which is very close to the main river, crop field and major road. Solid waste that disposed in the open field close to the river contaminates the river highly because of runoff and wind.

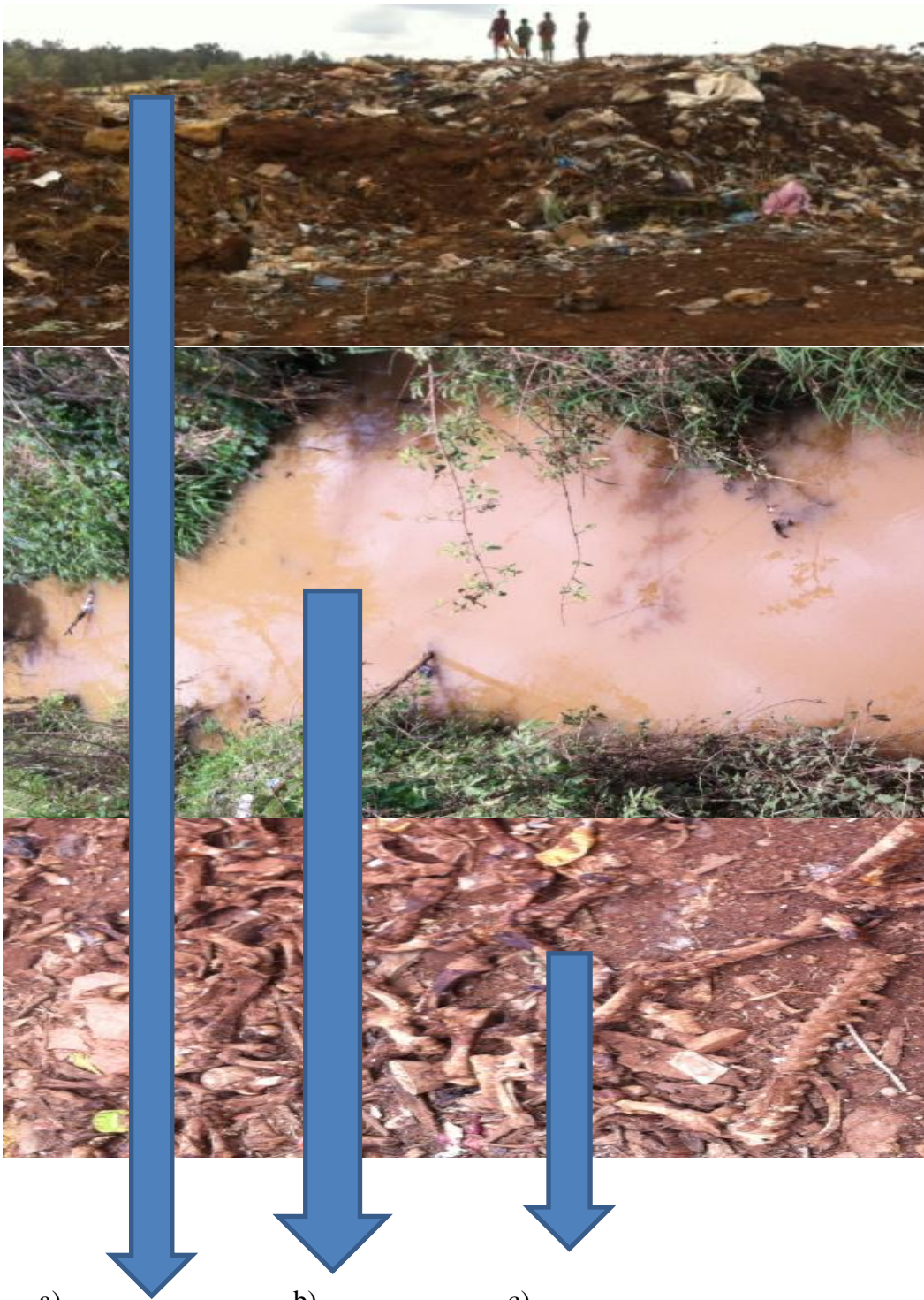


Figure 4.1 Open field solid waste disposal along a) agricultural field b) main river(Ajo wonz) c) near Hosanna to Gimbichu road (Author, 2017)

4.1.2 Illegal solid waste disposal in the town.

In the study area the waste disposal system is more or less without restriction; hence it contribute for enviromental contamination.



Figure 4.2 Illegal solid wastes dumped behind Woyeda condominium site (Gofermeda) and at shacha funeral site (along Hosanna to Hawasa asphalt road) (Author, 2017).

Figure 4.2 indicates that the solid waste management system in the study area is inefficient, even though the municipality is trying to collect solid waste from the source, it could be successful financially limitation and lack of committed persons.

4.2 Landfill site selection criteria

A Land fill site selection criterion setting is the first step to select suitable land fill site. Since the main objective of this project work is to select suitable land fill site by using criteria that minimize surrounding environmental, economic and social impacts.

Table 4.1: landfill site selection criteria

No	Spatial data	Layer name	criteria
1	Surface water	Stream	>1000m
2	Road network	Road	<2000m
3	Slope	Slope	<10%
4	LU/LC type	LULC	Bare land
5	Settlement	Settlement	>1000m
6	Soil type	Soil	Clay soil
7	Urban center	Urban center	>1000m

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

The overall national and international criteria used in this project are discussed as follows.

4.2.1. Geological criteria

It is essential to have an accurate understanding of the local geological setting in order to evaluate suitable waste disposal site and to control the site from contamination. This will include the type of rocks existing, details of the structure and characteristics of the rocks, composition and distribution of the subsoil, distribution and characteristics of the geology (Basak, 2004).

The rationale to study about the geology is to know the solid strata of the study area, which includes the type of rock, the state of weathering, the extent and distribution of structural features such as faults, joints, and bedding planes, the effect of leaches and the permeability of the strata. In addition to the geological information, it is important to know about the subsoil of the strata like its composition, the lateral and vertical continuity of the strata, the permeability, resistance to erosion and the stress of deformation behavior (Gizachew, 2011).

When we talk the geology of a given area, it is important to know geologically unstable or unsuitable areas of a given site. Geologically unstable areas are defined as locations where natural or manmade features create a considerable risk to the reliability of the landfill construction (Tsegaye, 2006).

Generally, landfills should not be sited within the following areas:-

- a) Area directly under karastified limestone
- b) Area prone to subsidence caused by previous mining activities
- c) Area underlain weak on unstable sub soils not capable of remediation, and
- d) Areas prone to land slide or slope failure

Generally, geological faults are areas most dangerous to site the landfills even though it is difficult to avoid being on or close geological faults. Because as majority of the faults increase the permeability of the bedrocks in the fault zone it would normally not be appropriate to roll out or down grade a site because of the presence of an absolute assurance that a site is geologically suitable. Because fault zones in permeable rocks are usually more significant than in low permeability rocks (Tsegaye, 2006). This literature gives detail emphasis how a given geology affects the landfill construction activity and how it can be suitable. Let us see the geological condition of the study area and examine how it can be suitable for this project site

Nazreth pyroclastic rocks: This is a name given to a group of rocks aged Miocene to Pliocene, Rhyolite trachyte flows and ignimbrites (Nar, Naq Nas), Makonnen Basalt (Pom) and “flood Basalts” PV. It is widespread over all of the study area covering most extensive regional exposure of the south west, southern, northern and southwestern parts of the study area. This type of rock is very similar with the Aiba basalt rock type except its low resistivity nature. The upper part of it is characterized by clayish sediment and black soil this corresponds to its low resistivity nature. The thickness of this sediment is more than 700 meters (Geological Survey of Ethiopia, 2011).

According to Tsegaye et al., (2005) and Efrem, (2010), Geology is one of the important environmental factors that should be considered during landfill site selection processes. Impermeable strata and consolidated material are suitable for landfill site as they do not allow

movement of leachate and hence to minimize the risk of groundwater contamination from landfill leachate (Centre for Advanced Engineering, 2000). For this study, the degree of porosity, thickness of the rocks and the presence of fracture are the factors or criteria to select the suitable rock type. The more weathered and fracture, the more permeable and unstable the rocks will be (Tameru et al., 2003). Hence, such formations are not suitable for solid waste landfill sitting because of the high probability of the underground water to be contaminated. To select the rock type that fulfill this criteria in the study area no need of any comparison, because only Nazret pyroclastic rock is the dominant type in the study area (Geological survey of Ethiopia 2011). Nazret pyroclastic rock is very suitable for landfill site because it has no porosity in addition to its thickness greater than 700 meters with less transitivity (Geological Survey of Ethiopia, 2011). Therefore, geology of the area was not taken for comparison like other landfill site selection criteria.

4.2.2. Urban land use criteria

The LU/LC is the natural and human made landscape that may be exposed by the threats imposed because of landfill adjacency. According to Tirusew *et al* (2013) it is advisable to select land, which was occupied by bare and grass lands for solid waste disposal site.

Land use map of the town was obtained from municipality of Hosanna town, that classified, residential area, urban recreational area, service area, commercial centers, Built up area, industry area, urban agricultural area, industry area, bare area and parking areas.

Accordingly, the land use types were ranked based on their importance to evaluate suitable site to locate landfills. Therefore, bare area was ranked as highly suitable, agricultural areas as suitable, parking areas as less suitable, industry area as moderately suitable and residential area and recreational area as unsuitable and the other areas was restricted because the residential areas are compactly settled and concentrated at central part of the town, where the protected areas exists (Table 4.2). Therefore, from the land uses of the town to select suitable land use for landfill site, only bare area(15.2%), agricultural area (4.4%), industry area , (1.9%) parking area(0.001%) and recreational areas(5%) were taken as highly suitable, suitable, moderately suitable, less suitable and unsuitable for comparison respectively as shown Table4.3.

Table 4.2: Land use suitability

No	Land use type	suitability	Area(ha)	Area (%)	rank
1	Recreational areas	Unsuitable	165.5	4.5	1
2	Built up areas	Restricted	122.6	3.52	restricted
3	Residential	Restricted	1547.66	41.4	restricted
4	General service areas	Restricted	473.8	12.7	restricted
5	Industrial areas	Moderately suitable	63.25	1.7	3
6	Agriculture	Suitable	144.78	3.9	4
7	Commercial areas	Restricted	3.07.41	8.2	restricted
8	Parking areas	Less suitable	6.55	0.2	2
9	Bare areas	Highly suitable	503	13.5	5
Total			3714.4	100	

Table 4.3: Land use suitability comparison for non-restricted land use type

No	land use/land cover type	suitability	Area (ha)	Area (%)	Rank
1	Recreational area	unsuitable	165.5	18.9	1
2	Industry area	Moderately suitable	63.25	7.2	3
3	Agricultural area	Suitable	144.78	16.5	4
4	Parking area	Less suitable	6.5	0.1	2
5	Bare area	Highly suitable	503	57.3	5

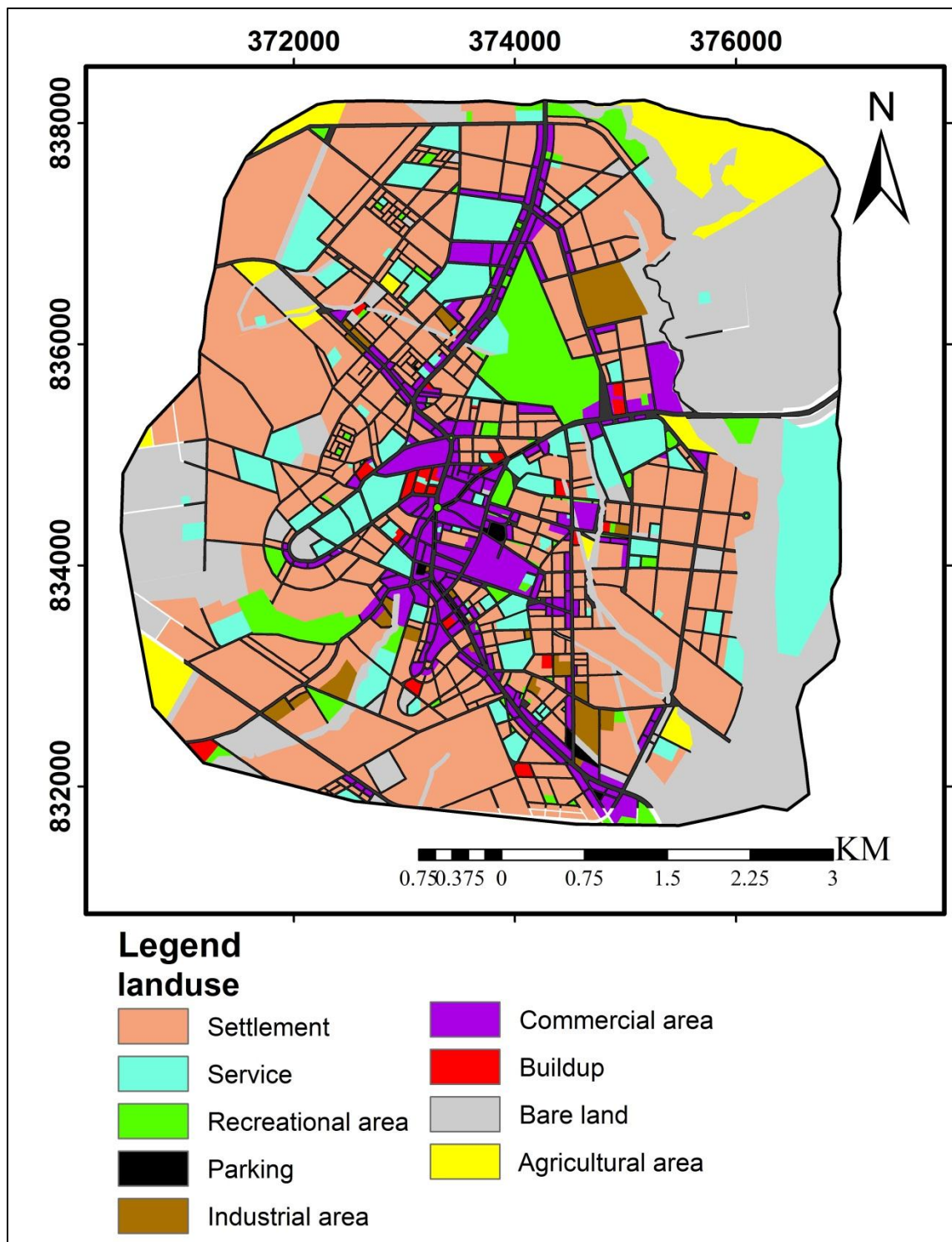


Figure 4.3: Major Land Use Categories Map of the town (Hosanna municipality, 2016)

4.2.3 Urban center criteria

The landfill site should not be placed near a residential or urban area at the same time it should not be located too far. Therefore, urban center is considered as land fill sitting criteria to minimize the transportation cost and to give equal opportunity for all residents and to protect the residents from pollution who use the site for dumping solid waste from the all peripheral part of the town .

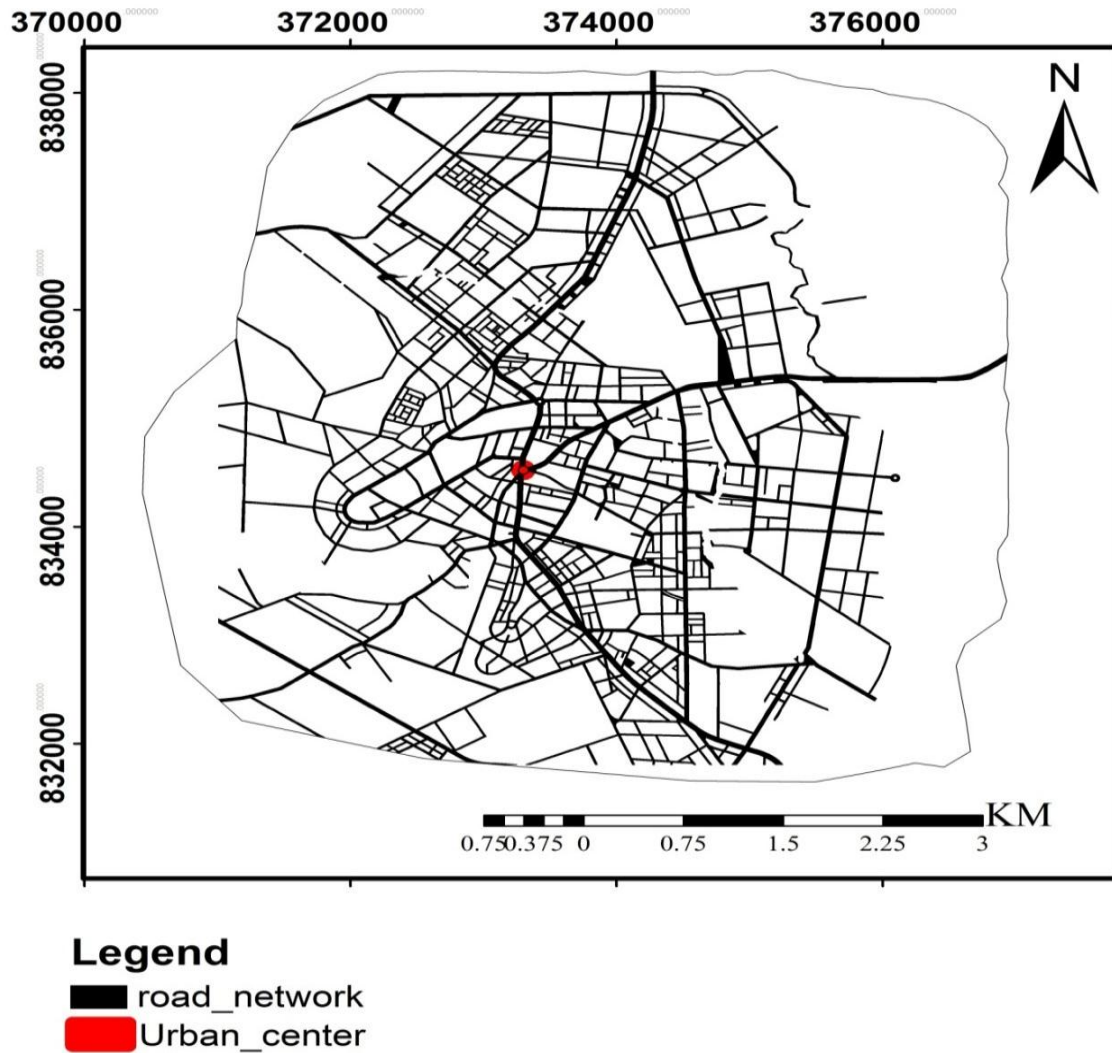


Figure 4.4: Urban center map of the hosanna town (Hosanna municipality, 2016)

According to Tirusaw *et al* (2013) the landfills site suitability increases with the increase of distance from the center of the town away 2500m buffer. Therefore, urban center was considered as factor with five buffer distance which refers 0-1500m unsuitable, 1500-2500m less suitable, 2500-3500m moderately suitable, 3500-4500m highly suitable and >4500 very highly suitable (figure 4.5).

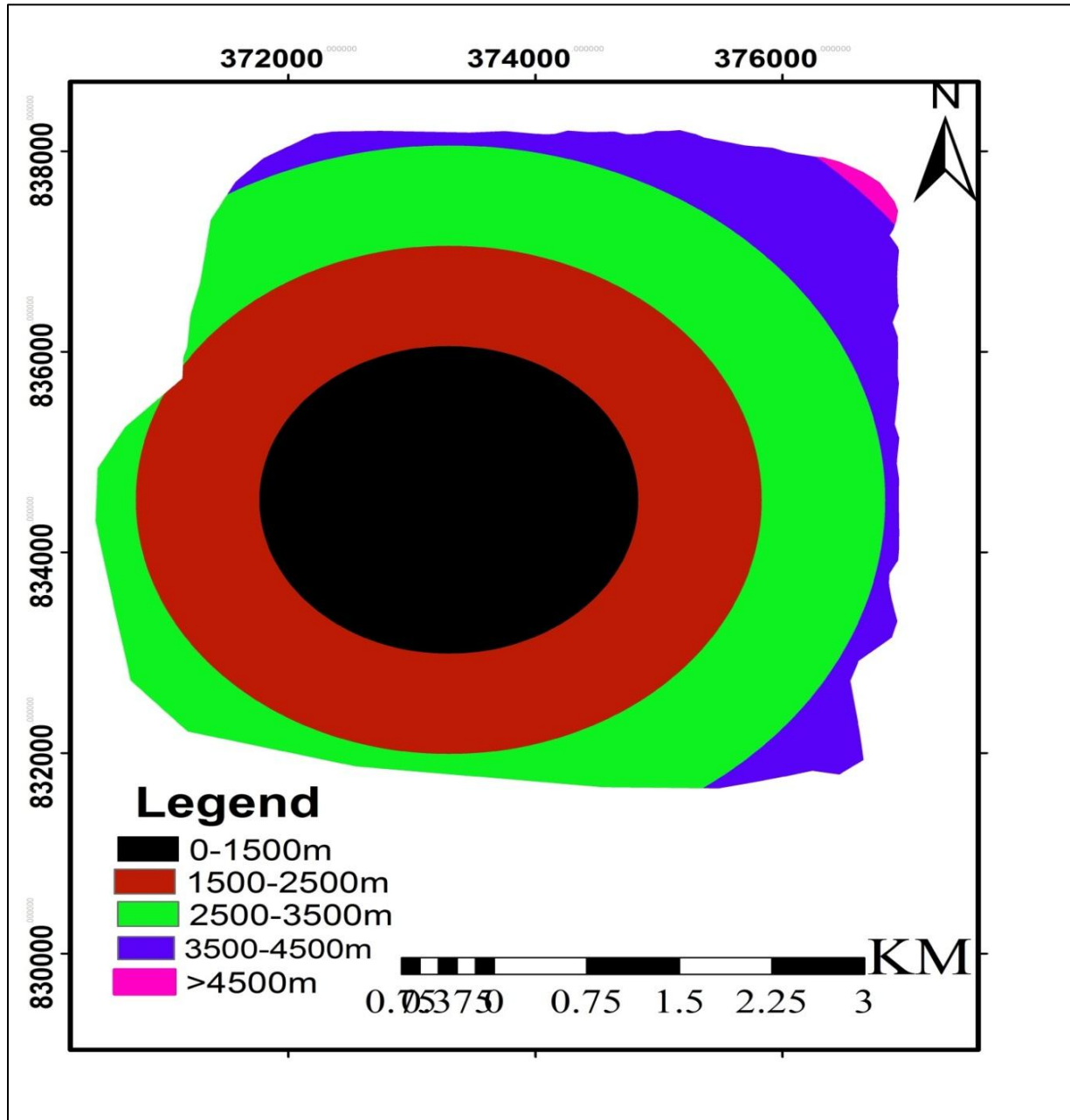


Figure 4.5: Urban center suitability map

4.2.4 Settlement

The protected area in this study includes the built up areas, service area (churches, mosques, schools and health centers) and commercial areas. Due to the concentration of residential settlement pattern with these protected areas special in the central part of the town, urban center was taken as factor rather protected area. The landfill should not be located in close proximity to sensitive areas listed above to a minimum limit of 1000 meter buffer surrounding. When the distance increases from these areas suitability also increases. In this study the XY coordinates for the above listed protected areas were gathered using GPS during the field survey and from land use map of the Hosanna town and buffered using the standards of MUDC (2012) to locate suitable sites for landfills. Accordingly, six different zones were specified: far buffers from protected areas are more suitable while near buffers are less suitable for landfill sitting. The study considered the reclassified distance as restricted from 0 to 200meter, restricted because it is very near 200 to 400, unsuitable, from 400m to 600m, less suitable from 600m to 800m moderately suitable 800 to 1000, highly suitable and above 1000m very highly suitable. Therefore, large part of the area fall under unsuitable class (61.4%) that is the concentrated nature of settlements with protected area of the town. Therefore, rather than protected area settlement was taken as one of the determinant factor for solid waste disposal site selection.

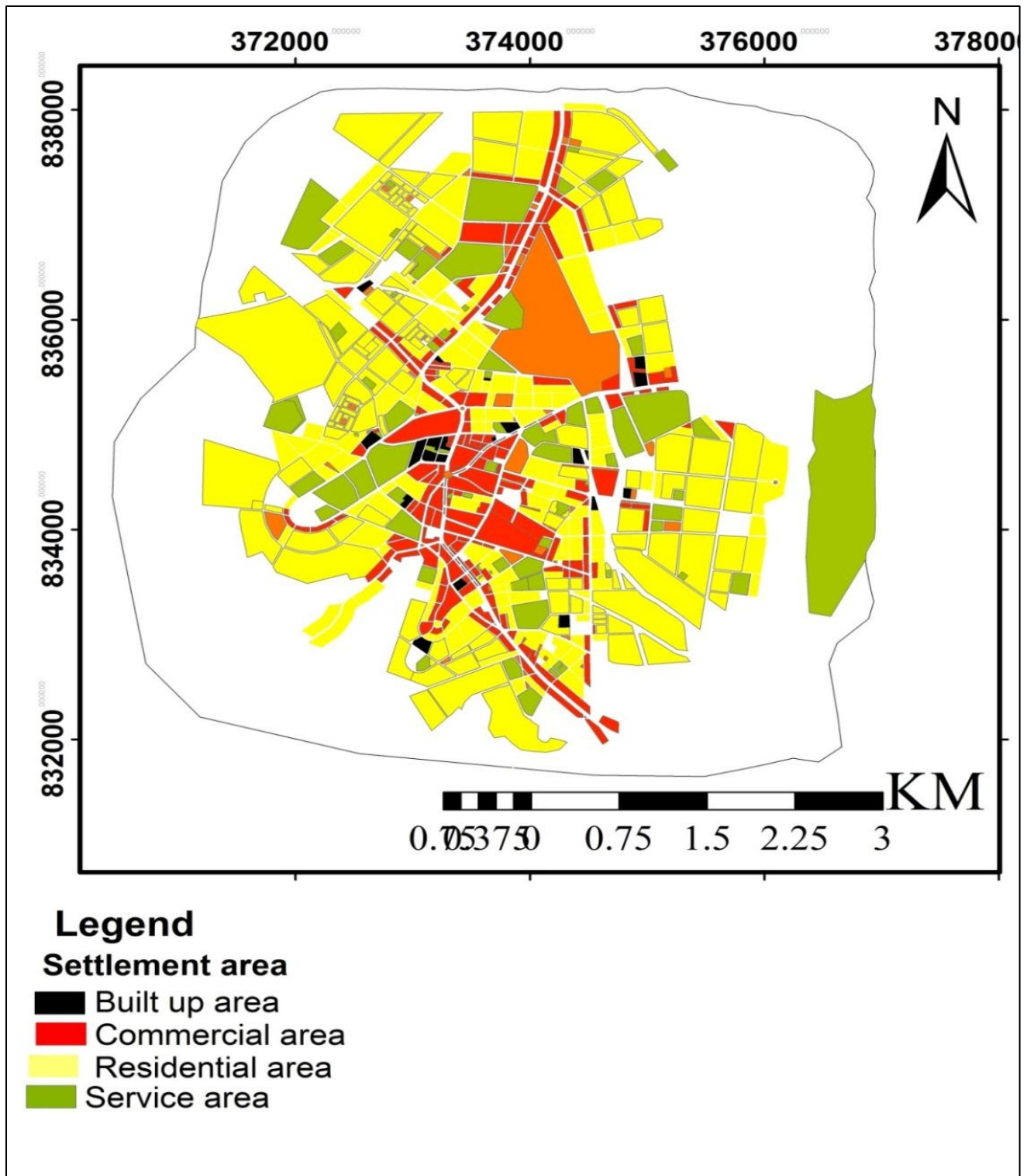
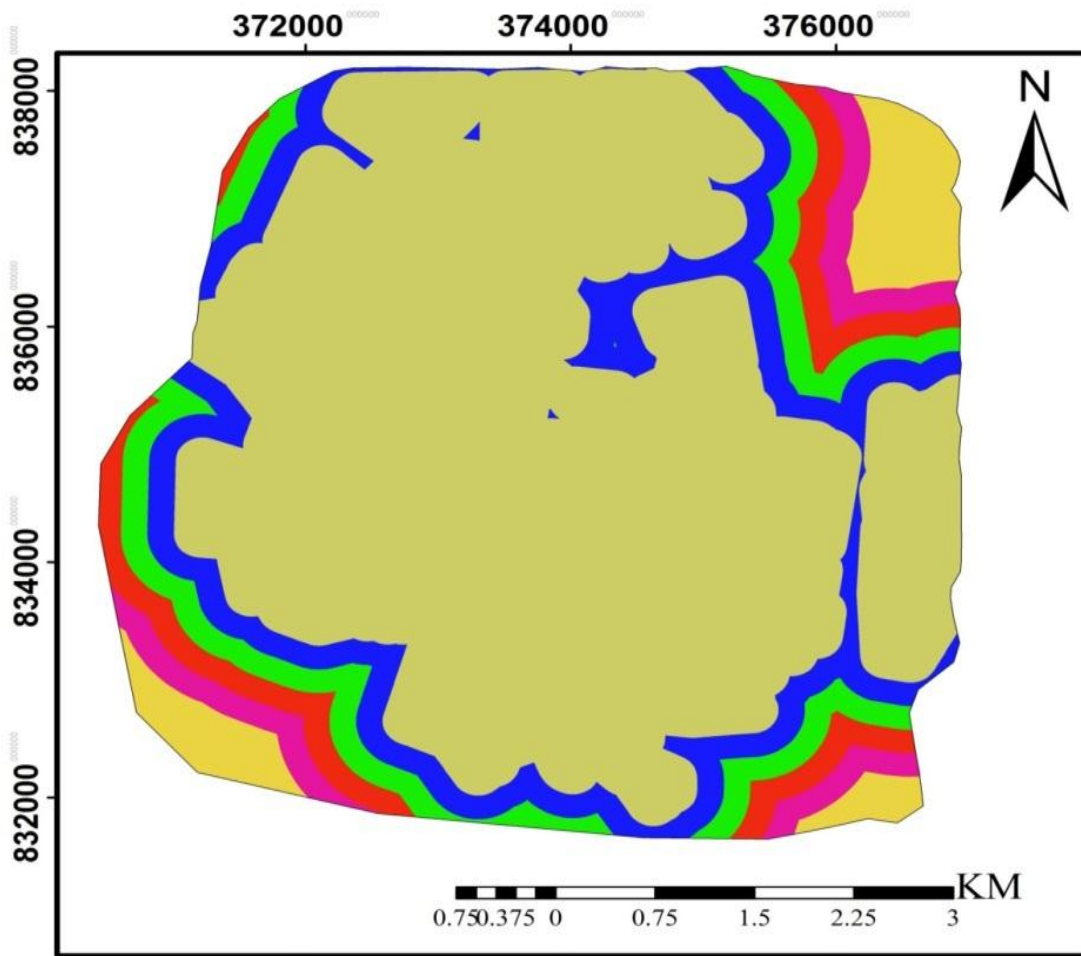


Figure 4.6: settlement area map (Hosanna municipality, 2016)

Table 4.4 settlement area suitability

No	Distance in meter	Suitability	Area(ha)	Area (%)	rank
1	0-200	restricted	2466.336	66.4	restricted
2	200-400	Unsuitable	436.0952	11.7	1
3	400-600	Less suitable	279.5436	7.5	2
4	600-800	Moderately suitable	197.8124	5.3	3
5	800-1000	Highly Suitable	134.8952	3.6	4
6	>1000	Very highly suitable	199.7076	5.4	5
Total			3714.4	100	



Legend

Suitable distance from settlement(M)

- 0-200m
- 200-400m
- 400-600m
- 600-800m
- 800-1000m
- >1000m

Figure 4.7: protected area suitability map

4.2.5 Proximity from road

A road is one of the criteria that should be considered from economic and social point of views during solid waste landfill site selection processes. This is because sitting landfill very close to roads may have public health problem as landfill can have hazardous effect to health. Moreover, landfill site very far from road network is also not recommended due to high transportation cost. Therefore, to minimize such problems, it must not be sited very close to and very far from roads (Issa, 2012 and MUDC, 2012). Therefore, the road network was reclassified roads with 0-200m, 200-400m, 400-600, 600-800m, 800-1000m and >1000m distance ranges as we see in the table 4.5

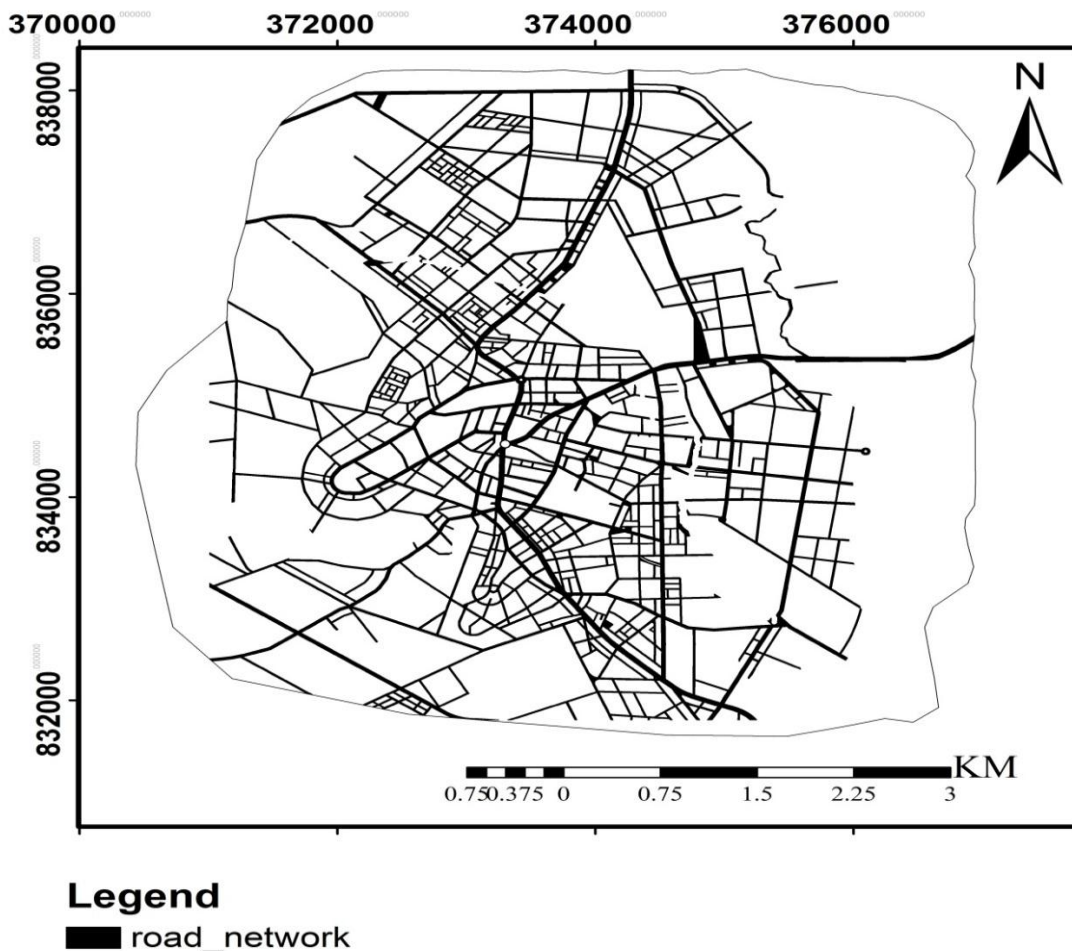


Figure 4.8: Road network of the study area map (Hosanna municipality, 2016)

The road network buffer map was reclassified and standardized based on the fact that very close and far away sites are unsuitable for landfill and hence excluded from the analysis. As the general concept, the landfills shall not be located within 400 meter of any major highways, city streets or other transportation routes. Solid waste dumping site must be located at suitable distance from roads network in order to facilitate transportation and it is preferred to locate landfills away 400 meter distance from roads (MUDC, 2012). Accordingly, 0-200m and >800m buffer distances were unsuitable due to their distance very closeness and far away from the road network respectively. But, the areas, from 200m to 800m, were given suitability according to their preference. The highly suitable site is 400-600m radius from the roads; moderately suitable site is 600-800m. Generally, for areas < 200m and above >800m suitability decreases with very nearness and increasing distance, which may result in pollution and increased transportation cost and inaccessibility of the area respectively.

In this study existing roads were developed from structural plan of the town, which was accessed from Hosanna town municipality in vector format. To locate landfills as suitable to the existing roads, buffer zones were categorized into five levels and standardized as very close and very far places from roads are not suitable for landfills, because of the pollution impact and additional transport and construction cost respectively. Accordingly, 0-200 and >800 meter buffer was assigned as unsuitable which cover about 90.8% of the total area.

Table 4.5 Road network suitability of the study area

No	Distance (meter)	Suitability	Area(ha)	Area (%)	Rank
1	0-200	unsuitable	2976.3	80	1
2	200-400	Less suitable	52.2	1.4	2
3	400-600	Highly suitable	103.0	2.8	5
4	600-800	Moderately suitable	181.3	4.9	3
5	>800	Unsuitable	401.6	10.8	2
			3714.4	100	1

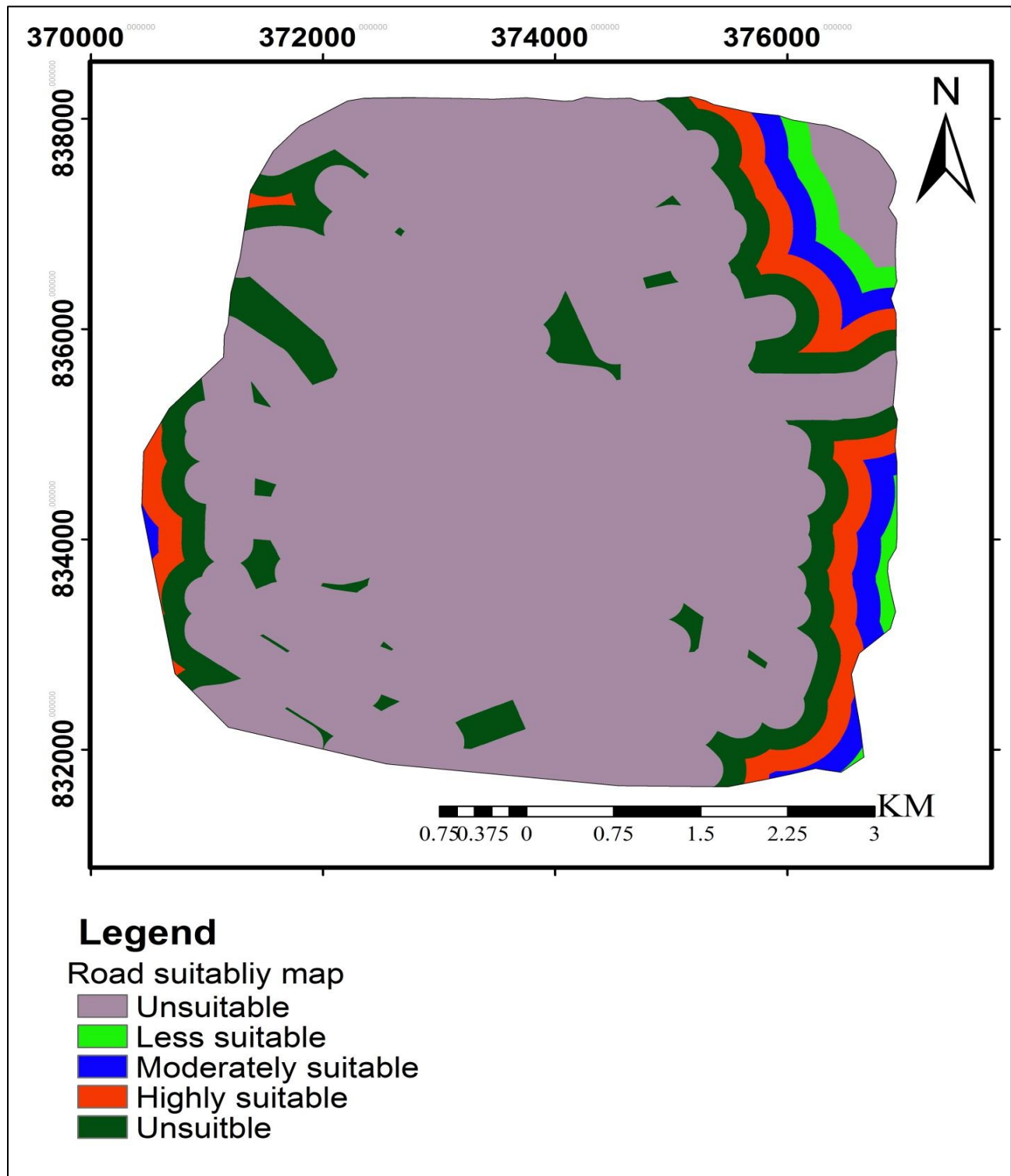


Figure 4.9: Road network suitability map

4.2.6. Slope criteria

Slope is an important factor in suitable site selection process, because slope determines the amount of runoff in the site. In this study, slope of the study area was generated from DEM which was generated from contour using Arc-GIS spatial analyst extension of surface tool. Then the slope raster was reclassified into six classes of slope percent. The reclassified slope was ranked from 1 to 5, and 5 is very highly suitable, 1 is for the unsuitable slope because water logging or flood plain and steep slope are not recommended for landfill siting.

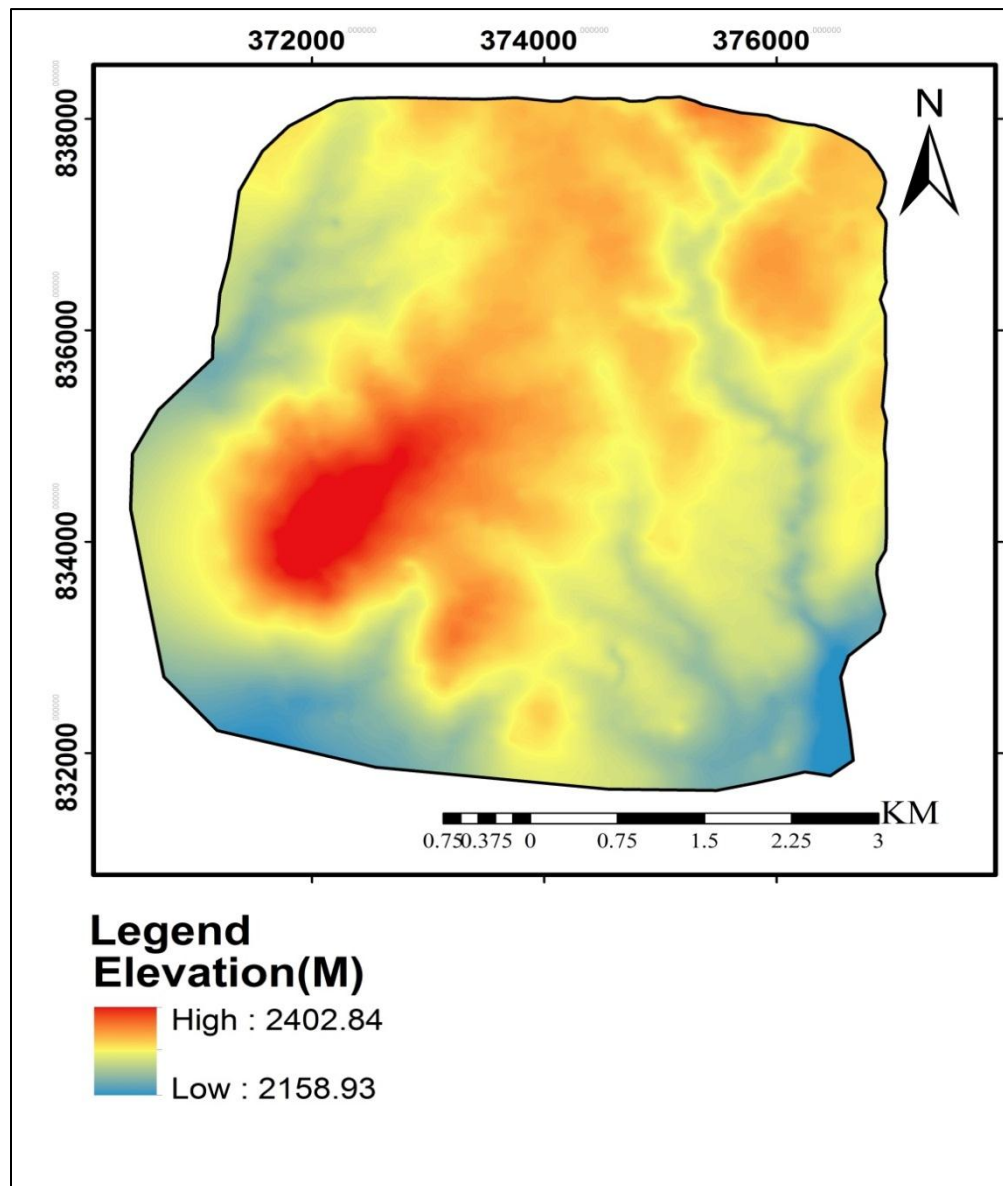


Figure 4.10: Digital Elevation model (DEM) of the study area

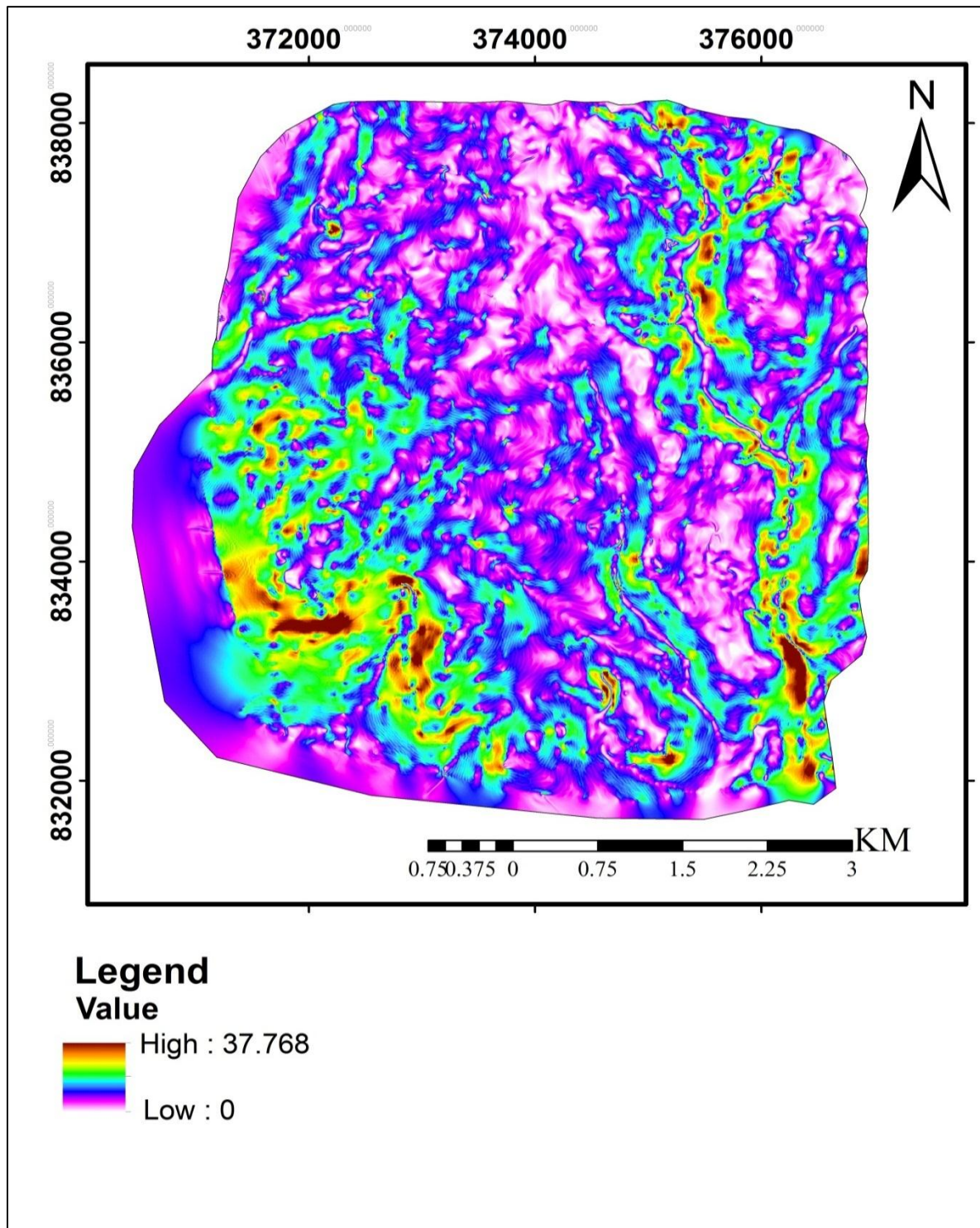


Figure 4.11: Slop map of the study area

Table 4.6 Slops Suitability Class

No	Percent rise (%)	Reclass	Rank	Suitability	Area cover (ha)	Area cover in (%)
1	0-2%	1	1	unsuitable	270.	7.3
2	2-10%	2	5	Very-highly suitable	2417.6	65
3	10-15%	3	4	highly Suitable	712.5	19.2
4	15-20%	4	3	Moderately suitable	258.8	7
5	>20%	5	2	Less suitable	55.5	1.5
					3714.4	100

This study considered the slope 2-10% as very highly suitable than the land with higher slope and 0-2% slop areas due to run off and water logging capacity respectively. Different research shows that areas with high slopes will have high risk of pollution and potentially not a good site for dumping (Ravindar J, 2014), therefore, the slope becomes steeper the area should be considered as least suitable. According Tirusew et al., (2013), the type of slope for landfill site should be gently, less than 10%. The majority of the study area falls under the slope class of 2-10% which covered 65% of the study area (Table4.6). Depending on this, most of the land is suitable for solid waste disposal site regarding to slop.

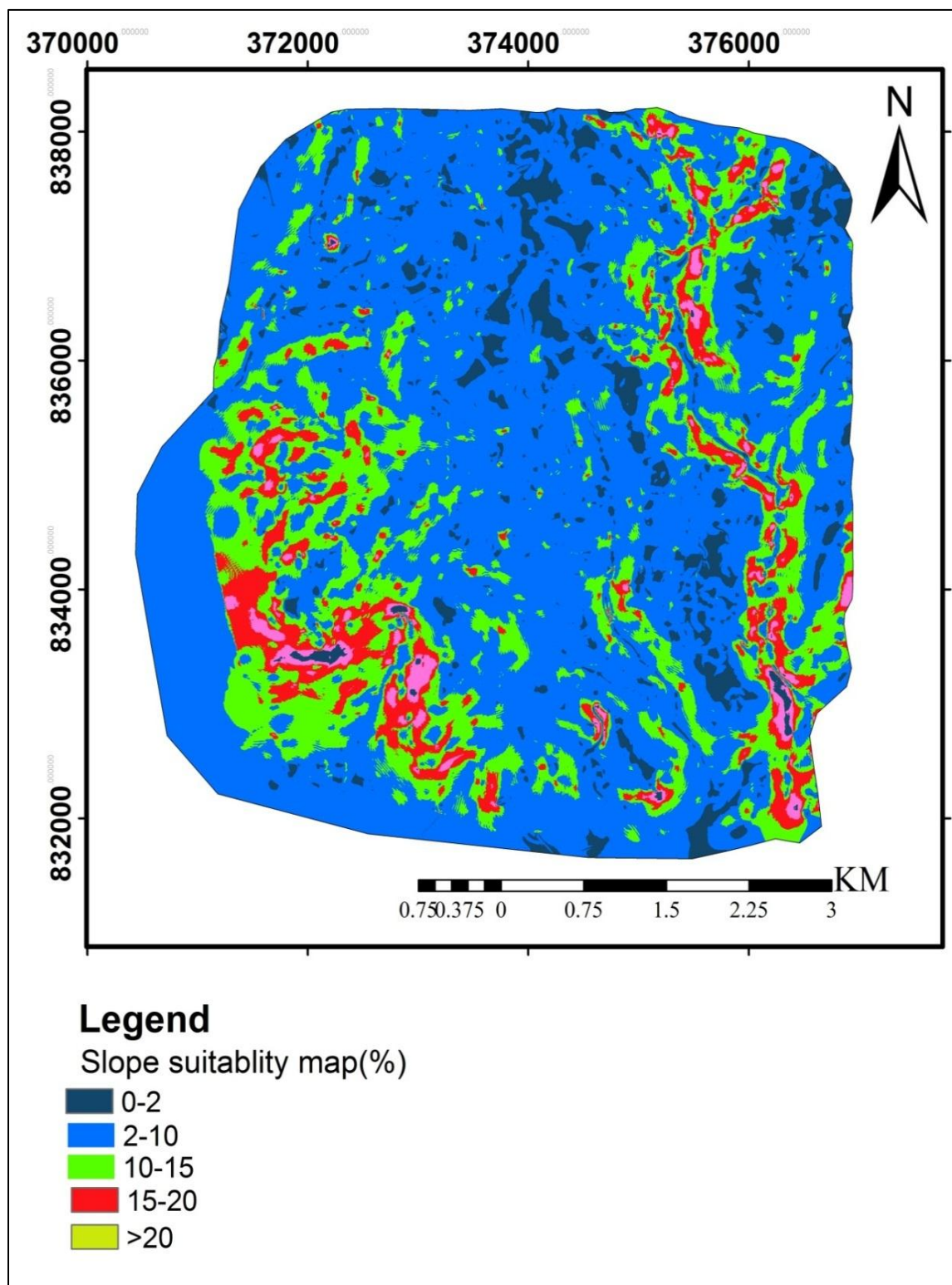


Figure 4.12: Slops Suitability map (Author, 2017)

4.2.7. Surface water criteria

The landfill site should not be placed within surface water or water resources protection areas to protect surface water from contamination by leachate. Safe distances from seasonal and permanent rivers should be maintained to prevent waste from eroding into rivers and major streams. A landfill should not be located within 100 feet (30.48 m) of any seasonal stream or river, and at least 300 feet (91.44 m) from any permanent stream or river. Large ponds, lakes, and reservoirs should have a buffer zone of land to prevent blown debris and runoff from harming aquatic habitats. Large water bodies (greater than 20 acres (80937.45 m²) of surface area should be at least 100 feet (30.48 m) from any landfill site. If the regional drinking water is supplied by surface water impoundments, it may be necessary to exclude the entire watershed that drains into the reservoir from landfill sites (Bagchi, 1994 in Basak, 2004). In case of a high velocity of the surface flow there will be more dilution of an eventually contamination. The potential landfill location with the highest velocity of the overland flow will get the highest consideration (Basak, 2004).

The major concern of sitting landfills within floodplains is the downstream effect from waste carried away during “episodes” of higher water levels. Since major rivers have a higher discharge and greater downstream influence, no landfill should be sited within the floodplains of major rivers (Bagchi, 1994 in Basak, 2004). In the study area the types of surface water exist are seasonal and permanent rivers that flow towards southwest and southeast of the town. These streams are used for humans and animals for drinking in peripheral part of the town. Perennial and intermittent rivers of the study area were generated from structural plan (land use map) of the town in GIS environment by rasterizing vector data to raster data.

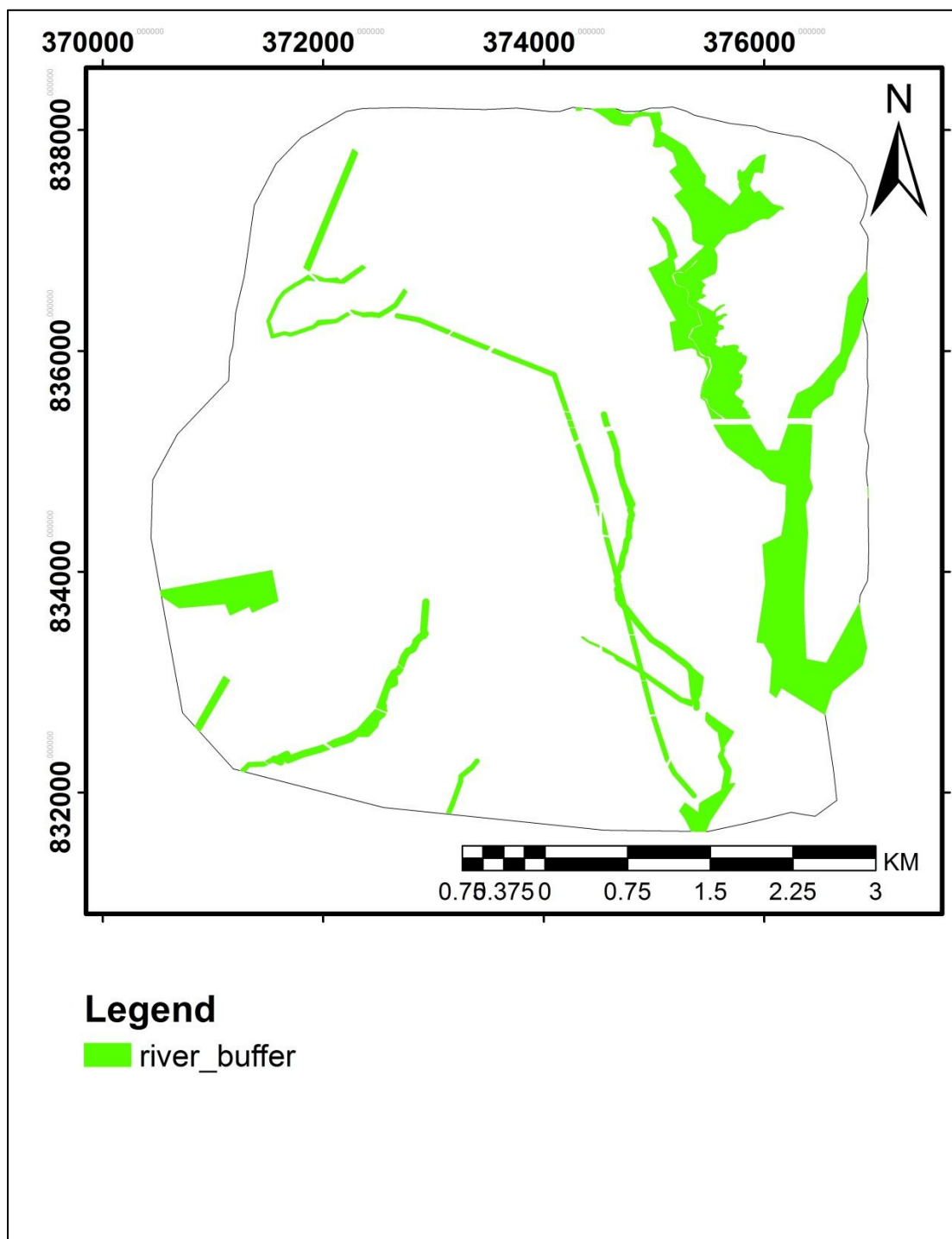


Figure 4.13: Drainage map of the study area (Hosanna municipality, 2016)

To protect surface water from pollution, landfill should not be located near streams and rivers. The contaminated runoff from landfill will have an adverse effect on surface water. Therefore, to minimize such pollution, different researchers set minimum buffer distance for landfill site selection. By using the standard of the Ministry of urban development (2012) the streams were buffered with the help of ArcGIS spatial analyst hydrology extension to locate suitable site for landfills. Furthermore, the further the distance from rivers and streams, the more preferable area for landfill (Gizachew, 2011).

Accordingly, Multiple Ring Buffer from Analysis Tools was used to prepare multiple buffer for distances:- 0-200,200-400, 400-600,600-800, 800-1000 and >1000m and rank were assigned for each buffer 1,2,3,4,5 and 6. To minimize the effect of landfill leachate on surface water pollution, 0-200 m buffer area were excluded from sitting process. The rest of the areas were analyzed based on the distance from the streams and rivers. Summary of suitability level with their respective areas are shown in Table 4.3.

Table 4.7 Rivers and streams proximity suitability

No	Distance in meter	reclassify	Suitability	Area cover (ha)	Area cover in (%)	Rank
1	0-200	1	Restricted	1492.4	40.2	Restricted
2	200-400	2	Unsuitable	879.0	23.7	1
3	400-600	3	Less suitable	619.9	16.7	2
4	600-800	4	Moderately suitable	369.7	9.9	3
5	800-1000	5	Highly suitable	228.4	6.1	4
6	>1000	6	Very highly suitable	125.0	3.5	5
Total				3714.4	100	

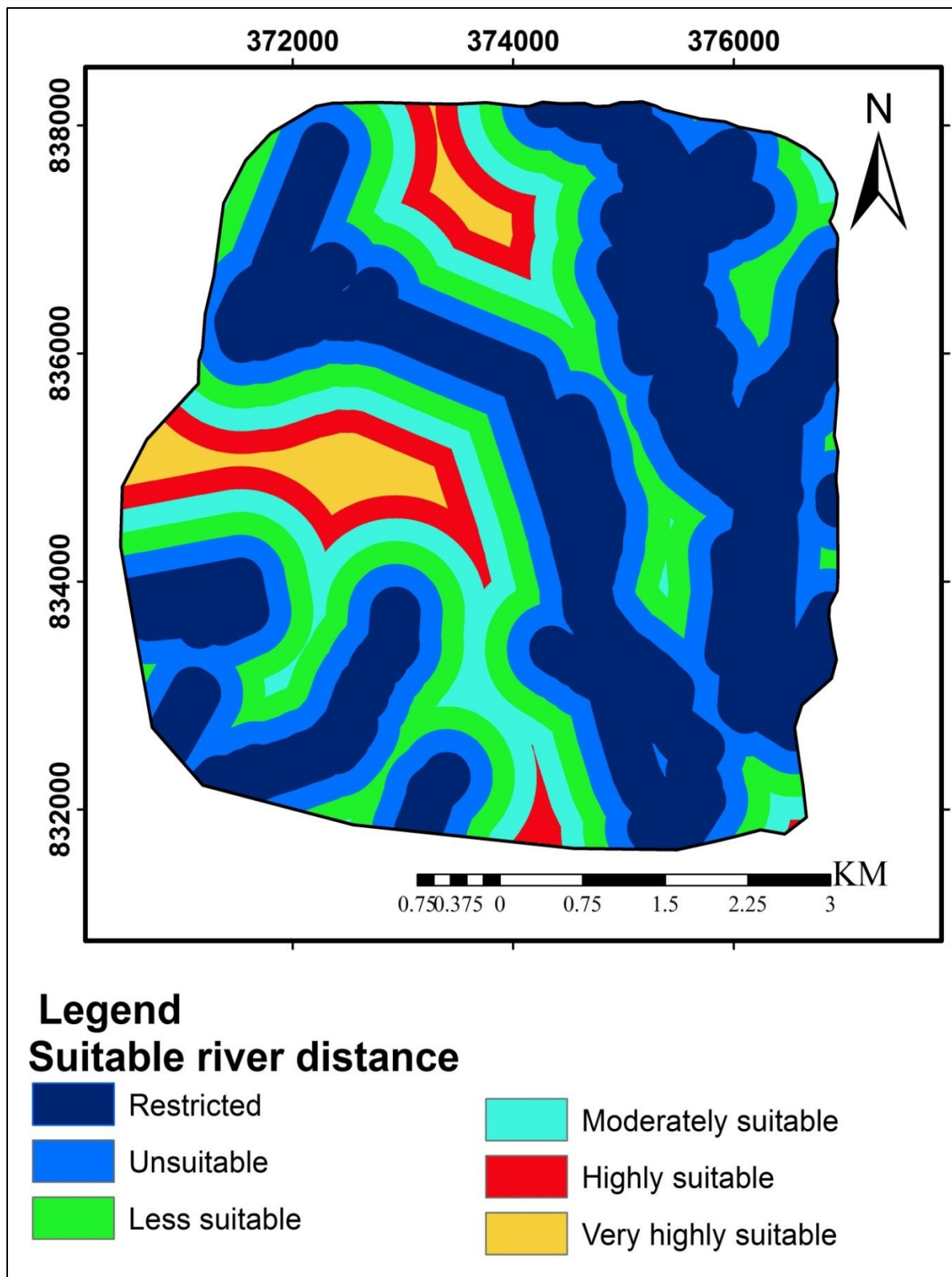


Figure 4.14: Rivers and streams proximity suitability

4.2.8. Soil criteria

In any place the existing soil type is the result of five soil forming factors namely climate (temperature and rainfall), topography, parent material, biological activities (flora and fauna) and time. As a result, soil can vary from place to place. The difference in the nature of soil results in the difference in water infiltration and holding capacity. The permeability and porosity of a given soil control the vertical as well as horizontal movement of contamination (Tsegaye, 2006). Accordingly, the soil type in the study area classified in to three major types namely Cambisols(11.44 km²), Luvisols(18.75 km²) and Nitisols(6.94 km²)(FOA, 2014).

Soil formation of the study area is directly related with weathering of the parent materials or rocks that exist in the area. The nature of the soil is varying from area to area in depth and content. The permeability and infiltration of each soil depends on its textural composition. The soil classes in the study area with different characteristics are presented below.

Cambisols: is combine soil with at least an incipient sub surface soil formation and its transformation of parent material is evident from structure formation and mostly brownish discoloration, incising clay percentage, and/or carbonet removal. Other soil classification system refers to many Cambisols as *Braunerden* and *Terrae fuscae* (Germany), *Sols bruns* (France), *burozems* (Russia) and *Tenosols* (Australia). The name *Cambisols* was coined for the Soil Map of the World (FAO-UNESCO, 1971-1981

This Soil is at least the beginnings of horizon differentiation in the subsoil, evident from changes in structure, colour, clay content or carbonate content; from Late Latin *cambiare*, to change. The parent material of this soil type is medium and fine textured materials derived from a wide range of rocks. Profile development of Cambisols is characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay, organic matter, Al and/or Fe compounds. Cambisols also encompass soils that fail one or more characteristics, including highly weathered ones (FOA, 2014). This type of soil is moderately suitable for land fill site, which cover the central and north east peripheral part of the Hosanna town.

Luvisols: have higher clay content in the subsoil than in the topsoil, as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. Luvisols have high-activity clays throughout the *argic* horizon and a high base saturation in the 50-100 cm depth. Many Luvisols are known as *Texturally-differentiated soils* and part of *Metamorphic soils* (Russia), *Sols lessivés* (France), *Parabraunerden* (Germany), *Chromosols* (Australia) and *Luvissoles* (Brazil). Connotation: Soils with a pedogenetic clay differentiation (especially clay migration) between a topsoil with a lower and a subsoil with a higher clay content, high-activity clays and a high base saturation at some depth; from Latin *eluere*, to wash. Parent material: A wide variety of unconsolidated materials including glacial till, and aeolian, alluvial and colluvial deposits (FOA, 2014). This type of soil is highly suitable for land fill site, which cover large portion of the Hosanna town (18.75 km²), found in the northern and north-western part of the town.

Nitisols: are deep, well-drained, red tropical soils with diffuse horizon boundaries and a subsurface horizon with at least 30 percent clay and moderate to strong angular blocky structure breaking into polyhedral or flat-edged or nut-shaped elements with, in moist state, shiny aggregate faces. Weathering is relatively advanced but Nitisols are far more productive than most other red tropical soils. Many Nitisols correlate with *Nitossolos* (Brazil), *Kandic* Great Groups of *Alfisols* and *Ultisols* and different Great Groups of *Inceptisols* and *Oxisols* (United States of America), *Sols fersialitiques* or *Ferrisols* (France) and *Ferrosols* (Australia)

It is deep, well-drained, red tropical soils with a clayey *nitic* horizon that has typical angular blocky structure breaking into polyhedral or flat-edged or nut-shaped elements with, in moist state, shiny aggregate faces; from Latin *nitidus*, shiny. The parent materials are finely textured weathering products of intermediate to basic parent rock, in some regions rejuvenated by recent and mixtures of volcanic ash. Nitisols are predominantly found on level to hilly land under tropical rainforest or savannah vegetation. Its profile development is red or reddish-brown clayey soils with a *nitic* subsurface horizon of high aggregate stability. The clay assemblage of Nitisols is dominated by kaolinite/ (meta) halloysite. Nitisols are rich in Fe and have little water-dispersible clay (FOA, 2014). This type of soil is less suitable for land fill site, which cover north eastern part to south west of the Hosanna town.

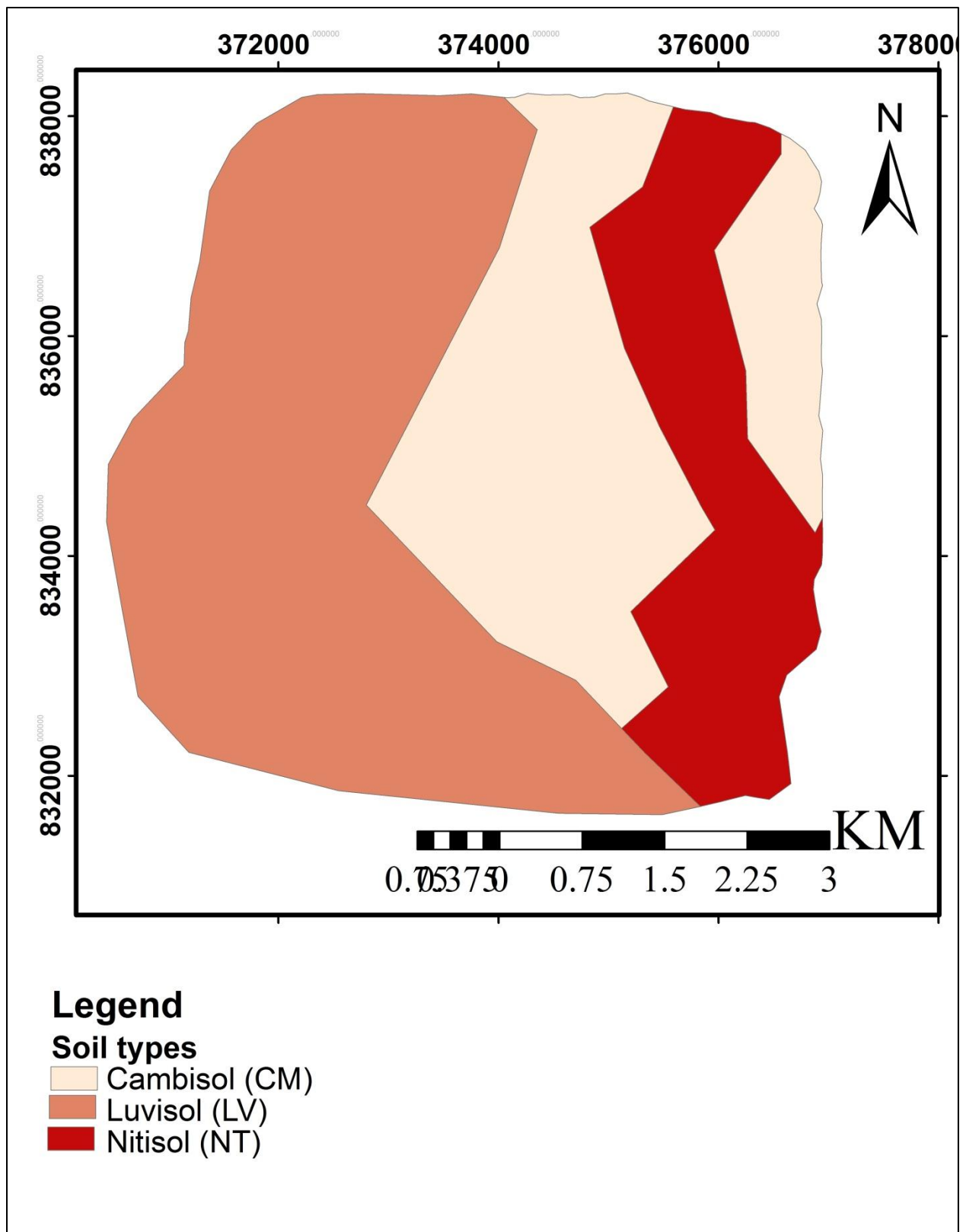


Figure 4.15: Soil map of the study area (Author, 2017)

Soil characteristics of the study area like texture and depth should also be considered for landfill site selection within the study area. This is due to availability of lining material and permeability depends on depth and texture soil, respectively. Clay textured soil is more preferred for landfill as it is impermeable to leachate and also used for lining the base of sanitary landfill. Moreover, area with deep soil is preferred as it provides soil for covering solid waste after each disposal to minimize air pollution from the landfill. The three dominant soil types of the study area were identified as highly suitable, moderately suitable and less suitable based on their dominant texture suitability for landfill. Luvisols were identified as highly suitable, Cambisols were identified as moderately suitable and Nitisols as less suitable (FOA, 2014). The three dominant soil types of the study area with their proportional area coverage represented in the table 4.8).

Table 4.8: Soil suitability of the study area

No	Soil type	Suitability	Area cover (Km ²)	Area cover in (%)	Rank
1	Nitisols	Less suitable	18.75	50.5	1
2	Cambisols	Moderately suitable	11.44	30.8	2
3	Luviso	Highly suitable	6.94	18.7	3
total			37.13	100	

4.3 Potential landfill site analyses

4.3.1 Calculating factor weight

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 landfill site selection process is to express the importance or preference of each factor relative to other 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. The procedures include ranking, rating, pair-wise comparison, and trade-off analysis. They differ in terms of their accuracy, degree of easiness to use and understanding on the part of the decision makers, and in the theoretical foundation (Hasan *et al.*2009). Accordingly, one of the most promising is pair-wise comparison developed in 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 100 %. 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 (Thomas L. Saaty, 2008). The scale shows the intensity of importance of two factors at a time (1=equal important, 2=equal to moderately important, 3= moderately important, 4= moderately to strongly important,5= strongly important, 6=strongly to very strongly important, 7=very strongly important, 8=very to extremely important and 9=extremely important.

Estimating the consistency ratio helps determine if the comparisons are consistent or not. The process uses a several phases. First, determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally, sum these values over the rows. Second, determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously.

Third, compute lambda (λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

$$CI = (\lambda - n) / (n-1)$$

Finally, calculation of the consistency ratio (CR) which is defined as follows:

$$CR = CI / RI$$

Where RI is the random index and depends on the number of elements being compared.

Table 4.9: Random indices

N	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Accordingly if the consistency ratio is less than or equal to 0.1, it indicates signifies acceptable reciprocal matrix (Saaty, 1980) and (Lawal et al, 2011). The consistency ratio of this study indicated that 0.04, which indicates that a reasonable level of consistency in the pairwise

comparison. So it is reasonable accepted and the weights which given for each criteria were reasonable. In order to combine all the layers to process overlay analysis, standardization of each data set to a common scale of 1, 2, 3, 4, 5 and 6 (value 1 = unsuitable, value 2 = less suitable, value 3 = moderately suitable, value 4= highly suitable and value 5= very highly suitable) was performed.

Table 4.10 .Pair wise comparison in 9 point continuous scale

	Land use/land cover	Urban center	Protected areas	Road	Slope	River	Soil
Land use/land cover	1						
Urban center	1/2	1					
Protected areas	1/3	1/2	1				
Road	1/4	1/3	1/2	1			
Slope	1/5	1/4	1/3	1/2	1		
River	1/6	1/5	1/4	1/3	1/2	1	
Soil	1/8	1/7	1/6	1/5	1/4	1/3	1

Table 4.11: Weights derived by calculating the principal eigenvector of pair wise comparison matrix

factors	weight	Percentage (%)
Land use/land cover	0.350077	35.0
Urban center	0.237442	23.7
Settlement	0.159437	15.9
Road	0.106666	10.7
Slope	0.071476	7.1
River	0.048780	4.9
Soil	0.026121	2.6

Consistency ratio=0.04

Table4.12 Weight of Suitable Solid Waste Dumping Site Selection Factors

Factor Influence (%)	Class	Value	Level of Suitability		
Urban Land use	Recreational area	1	Unsuitable		
	Industry area	2	Less Suitable	35.1%	
	Agriculture area	4	Suitable		
	Parking area	3	Moderately Suitable		
	Bare area	5	Highly suitable		
<u>Distance from Roads</u>	0-200 m	1	Unsuitable		
	200m-500m	2	Less Suitable	10%	
	500m-1000 m	5	Highly Suitable		
	1000m-1500m	3	moderately suitable		
Slope	0-2%		Restricted		
	2-10%	5	Very highly Suitable		
	10%-15%	4	Highly Suitable	7%	
	15-10%	3	Moderately Suitable		
	20-25%	2	Less suitable		
	>25%	1	unsuitable		
Distance from Streams	0-200m		Restricted		
	200m-400 m	1	Unsuitable		
	400m- 600 m	2	Less suitable	5%	
	600m- 800 m	3	Moderately Suitable		
	800m-1000 m	4	Highly Suitable		
	>1000m	5	Very highly suitable		
Distance from Protected area	<400m	1	Unsuitable		
	400m-800m	2	less suitable		16%
	>8000m	5	Suitable		
Soil	Nitisols	1	less suitable		
	Cambisols	2	moderately suitable	3%	
	Luvisols	3	highly suitable		
Urban center			24%		

Table 4.13: Suitability area level of suitability and the percent of total area coverage

No	Level of suitability	Landfill site	rank	Area(ha)	Area (%)
1	Unsuitable	1	1	2935.4	89
2	Less suitable	2	2	52.95	1.6
3	Moderately suitable	3	3	95.7	2.9
4	Highly Suitable	4	4	215.83	6.5
Total				3714.4	100

The above table shows the candidate landfill sites and their area with respective suitability. So, based on criteria like size of the site, distance from nearby settlements and distance from the center of the town are the determinant factors used to evaluate potential landfill site so as to choose the best suitable. Therefore, from sustainability and economical point of views, larger size of land that will serve for at least ten years are more preferable than small size to minimize the cost of site selection, design and closure. Accordingly as shown in figure 4.16 larger area covered by restricted and unsuitable as a result excluded from further comparison because it is not feasible economically as well as environmentally. Therefore, taking >12 hectars as preferable size of landfill site, landfill site 5(215.8ha) fall under highly suitable, landfill site 4(95.7ha) fall under moderately suitable and landfill site 3(52.7ha) less suitable (Table4.13). These, suggested areas as suitable for solid waste dumping site fall on the north east, south east and western direction from the town as indicated in Figure4.16.

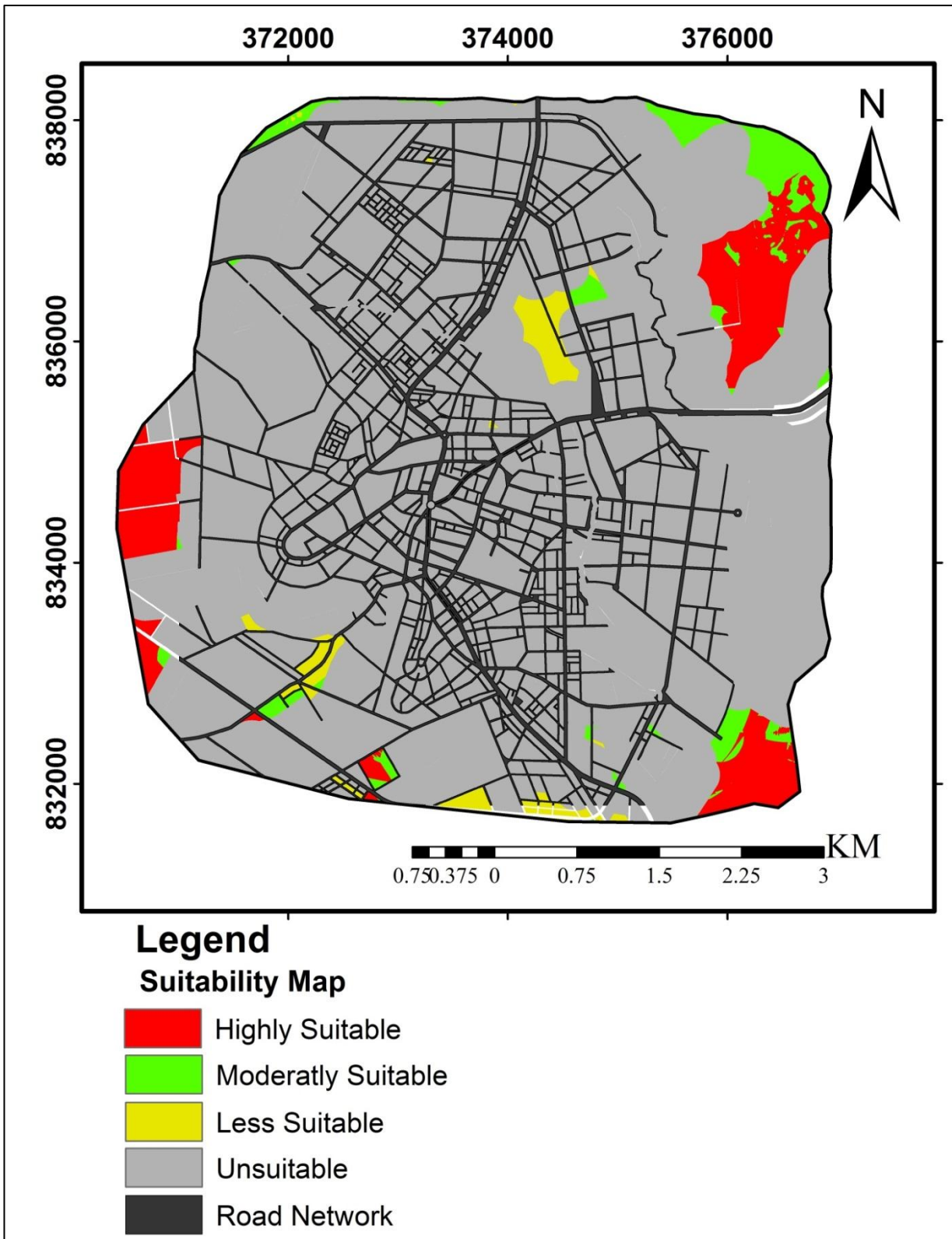


Figure4.16: Landfill Suitability Map

4.3.2: Evaluating selected landfill sites

Size of landfill is one of the determinant criteria for sustainable solid waste management as size of land selected for landfill determines the number of years for which the landfill will be used as waste disposal site. From sustainability and economical point of views, larger size of land that will serve for at least ten years are more preferable than small size (MUDC, 2012 and Gizechew, 2012). This is because selecting large sized landfill site can minimize the cost of site selection, design and closure that will be performed at the end of its lifespan. Accordingly, the analysis of the potential landfill sites in GIS environment, highly suitable sites with area ≥ 12.7 ha, and those sites occurred in protected area and built-up area as unsuitable for landfill sitting based on predefined factors and hence excluded from further analysis. The rest sites with area greater than 12.7ha preferable and selected to further evaluation with the previously set criteria. Accordingly, the result of the analysis shows 4 landfill candidate sites fulfill these area criteria and hence selected for further evaluation.

The analysis of selected landfill sites with the previously used criteria to select optimal site from the candidate landfill sites and landfill site with area 97.1 ha fall under very highly suitable and which is located north east of the town, landfill site with area 45.7ha as highly suitable, landfill site with area 29.2 ha as moderately suitable and landfill site with area 23.1ha as less suitable (fig 4.15).

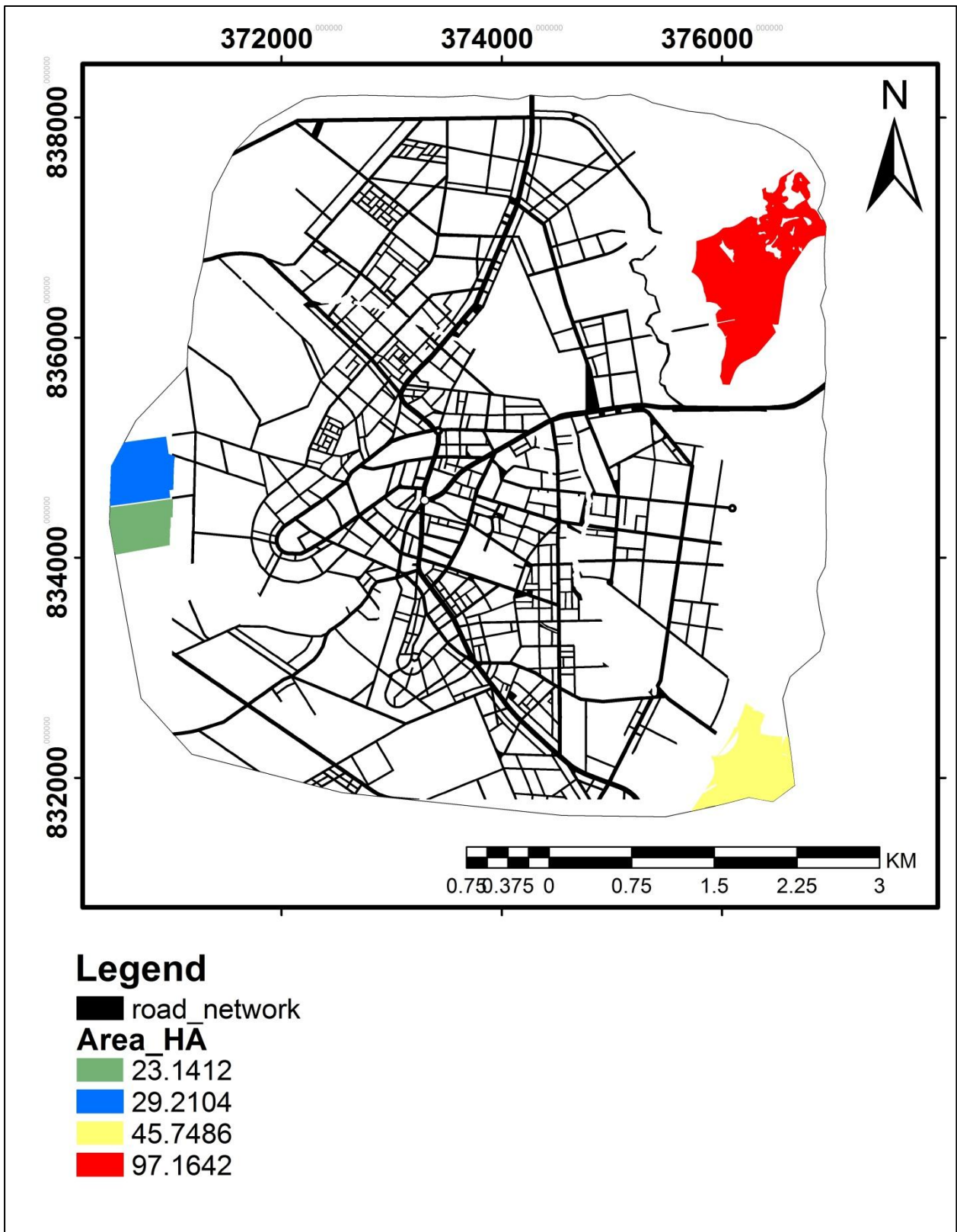


Figure 4.17: Overall Landfill Suitability Map

CHAPTER FIVE

Conclusion and recommendation

5.1 Conclusion

Solid waste disposal system in a town is an open dumping system. As a result there are environmental and social problems resulted from the dumping site. Some of the sources of solid wastes are from household, market, service areas and commercial area that dumped in an open dumping site, which may contain leachable toxic compounds that are harmful to the environment and human health, at the site without any treatment and separation. Moreover, the dumping site is very close to the main road to Gimbch (Soro), Ajo River and currently building construction has been taken for offices immediate to the site hence resulted in societal problems like nuisance, health hazard and environmental problems. Furthermore, landfill suitability map shows that, the dumping site is located at environmentally and socially unsuitable area that does not satisfy the international and national environmental standards, therefore, it is environmentally unfriendly and socially unacceptable.

The present study considered seven factors namely: land use, slope, soil permeability, proximity from roads, protected area, streams/rivers and urban center for proper landfill site selection. Integrating AHP with GIS for spatial decision making process is a worthwhile technique to handle large and conflicting criteria in landfill site selection processes. Accordingly, landfill suitability map for each of the factors were prepared in GIS environment. The factor maps were combined according to their importance to have overall suitability map. The result of the final suitability map showed 1215.8ha fall under very highly suitable, 95.7ha fall under highly suitable, 52.7ha moderately suitable land and most part of the total area is unsuitable (restricted). Discontinuous and small area sites were masked according to their importance. These sites were compared to each other in relation to their size, distance from nearby settlement and distance from the center of the town. AHP pair-wise comparison method was applied again to select the most suitable landfill site among the candidate sites. Accordingly, weight was derived separately for each criteria and candidate landfill sites in relation to the criteria. The final rank was computed from mathematical matrix and those are scored the highest weight in the comparison selected as suitable sites. The findings have shown the ability of GIS and remote

sensing as a power full tool for analyzing the criteria that used as determinant factor to select the suitable site.

The results have shown that four sites fulfilled the criteria and selected as the most suitable sites, which are located in northeast, southeast and western part of the town.

5.2 Recommendations

- ❖ The selected landfill site should serve at least for 10 years to reduce the cost of landfill site selection, construction and closure. Therefore, the rates and volumes of solid waste produced from the town should be known in order to determine the dimension of the landfill site during construction.
- ❖ The selected landfill site was only for non-hazardous solid waste. Therefore, hazardous wastes should not be dumped in this site. Hence, separate landfill should be selected for such hazardous solid waste as sitting parameters and construction of landfill for hazardous solid waste is quite different from that of non-hazardous waste.
- ❖ Even though the major factors for landfill site selection were considered in this study, hydro-geological investigation for the selected landfill sites should be needed because there is no high resolution geological study in the area.
- ❖ Further studies are necessary about the design and costs of construction of land fill, even though the excavation cell/ trench landfill sitting method is recommendable.
- ❖ Landfill solid waste management is an avoidable but not the only method, therefore, the municipality should be recommended to apply the source reduction method and recycling method before come across to landfill site disposing method.
- ❖ The municipality should be recommended to locate waste collection bins in major waste generating areas which may reduce the habit of waste dumping anywhere.

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Apendex_4

AREA ESTIMATION: - Area for landfill site estimated based on the following factors (Joseph A. Salvato, 1984).

Population----- 133,764

Q=peck/d

in which,

Q= space or volume needed in acre-ft per year;

p= population served;

e= ratio earth to compacted fill; use 1.25 if one part earth is used to four parts fill. Use 1.20 if one part is used to five parts of fill; use 1.0 if no earth is used;

c= pounds collected per day; 0.4L/h/day=0.4kg/h/day=0.882pu/day

k=0.266=365 days/yr*27 ft³/yd³
43.560 ft³/acre-ft

d= density of compacted fill: a density of 800 to 1000 lb/ yd³ is readily achieved with proper operation; 600 or less is poor; 1200 or more is very good.

$Q=133,764*1*0.882pu*0.266/1000pu/yd^3$
=31.38acre
=12.7ha

Apendex_2

No.	Year	Annual RF (mm)
1	1986	1417.9
2	1987	1280.5
3	1988	1216.2
4	1989	1199.7
5	1990	1058.9
6	1991	1028.3
7	1992	1387.6
8	1993	1413.5
9	1994	920.4
10	1995	1160.7
11	1996	1168.2
12	1997	1442.5
13	1998	1556.4
14	1999	1011.3
15	2000	991.9
16	2001	1145.5
17	2002	1346.4
18	2003	1152.9
19	2004	1185.1
20	2005	1179
21	2006	1201.7
22	2007	1098.8
23	2008	1202.8
24	2009	1150.4
25	2010	1121.5
26	2011	986.9
27	2012	981.6
28	2013	1031.7
29	2014	1334.5
30	2015	744.8
31	2016	1133.1

Apedex-3 sample points of protected areas

No	X	y	LU/LC
1	373272	833841	Bank
2			
3	373477	833479	municipality
4			
5	373191	833549	Betel church
6	373372	834391	mosque
7	372490	831904	BW-school
8	373168	832774	Catholic-church
9	373739	832414	D/MKC
10			
11	373023	833966	Ykatit25/67school
12	372208	831349	Balewolde church
13	373441	836102	G/M/Mekaneyesus
14			
15	373534	837130	Teachers college
16	373696	836539	Polly-technic
17	373412	837124	Hakmuraschool
18			
	373877	836059	Wachemo h/school
19	374971	835303	D/M/synodos
20			
	375350	834129	M/K/Church
21	374164	833902	Mosque
22	372878	839978	Enat k/H/church
23	373933	833106	T/H/church
24	373961	834937	Mariam-church
25	372081	834330	p/M/Mekabir
26			
27	373784	834577	stadium
29	373769	835172	sport hotel
30	373796	833774	wuha-wana
32	372815	834737	N/E/Hospital

Appendix_1

YEAR	Min.average ann.Temp(°C)	Max.averagg ann. Temp(°C)	average. ann. Temp(°C)
1987	11.10695777	22.38588478	16.74642128
1988	10.82360802	21.68775202	16.25568002
1989	10.20643561	20.97521639	15.590826
1990	10.51076037	21.36621014	15.93848525
1991	10.91124286	21.99643469	16.45383877
1992	11.33252635	21.08966014	16.21109325
1995	10.77260056	21.65241935	16.21250996
1996	10.65388086	21.68886369	16.17137227
1997	11.1499392	22.29181411	16.72087665
1998	11.2984799	21.96939071	16.63393531
1999	10.41962814	22.16341479	16.29152146
2000	10.12252385	22.2487248	16.18562433
2001	11.06679901	21.77329875	16.42004888
2002	10.68195148	22.23445195	16.45820172
2003	11.11280651	22.27210442	16.69245547
2004	10.65340731	21.96756171	16.31048451
2005	11.0584287	22.32009727	16.68926299
2006	11.26302099	22.25941255	16.76121677
2007	11.14732271	22.41743749	16.7823801
2008	10.41912588	22.41353607	16.41633097
2009	10.75230904	23.03049414	16.89140159
2010	10.96224206	22.94306326	16.95265266
2011	10.9437802	22.71215326	16.82796673
2012	10.60597114	23.04068156	16.82332635
2013	10.22491831	22.37295796	16.29893813
2014	11.0151263	22.21455166	16.61483898
2015	11.53888773	23.86015554	17.69952163
2016	11.99693252	22.89854234	17.44773743