

ADDIS ABABA UNIVERSITY SCHOOL OF GRADUTE STUDIES COLLEGE OF SOCIAL SCIENCES DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

SUITABLE SOLID WASTE DISPOSAL SITE SELECTION USING GIS AND REMOTSENSING APPROACH: A CASE OF WELKITE TOWN, ETHIOPIA

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SUITABLE SOLID WASTE DISPOSAL SITE SELECTION USING GIS AND REMOTSENSING APPROACH: A CASE OF WELKITE TOWN, ETHIOPIA

A PROJECT SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ART IN GEOGRAPHY AND ENVIRONMENTAL STUDIES SPECIALIZATION IN GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

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Declaration

I hereby declare that a project entitled "Suitable Solid Waste Disposal Site Selection Using GIS and Remote Sensing Approach: A Case of Welkite Town, Ethiopia" has been carried out by me under the supervision of Dr. Muluneh Woldetsadik (PhD), Department of Geography and Environmental Studies, Addis Ababa University during the year 2013/14 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: May 25, 2014

Kumel Beshir

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Acronyms

AHP	Analytical Hierarchy Processes
CR	Consistency Ratio
3D	Three Dimensions
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EMA	Ethiopia Mapping Authority
EPA	Environmental Protection Authority
G.C	Gregorian Calendar
GIS	Geographic Information System
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
ITCZ	Inter Tropical Convergence Zone
MCDM	Multi-Criteria Decision-Making
MS	Microsoft
MWE	Ministry of Water and Energy
PC	Personal Computer
SRTM	Shuttle Radar Topography Mission
SPOT	Systems Probatoire d'Observation de la terre
UNEP	United Nation Environmental Program

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 Welkite town. To achieve the objectives, the present study was conducted by integrating Geographic Information System and remote sensing for selecting suitable landfill sites. All the factor maps 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, 49.64km^2(62.17%) of the study area is unsuitable, 22.16km^2(27.75%) of the total study area is moderately suitable and 8.04km^2(10.1%) is highly suitable for landfill. The finding of the study shows that 9 candidate landfill sites in relation to those evaluating criteria. Landfill site 2 which is located in Addis sub- town, is chosen as the most suitable site. Landfill sites 6 and 9 located in Gubre sub-town are the second and third most suitable sites respectively. Therefore, landfill sites 2, 6 and 9 are ranked from 1 to 3 based on their area and distance from the center and nearby settlements due to their minimum environmental and social negative effects compared to the other sites. In general, landfill site selection has been required appropriate consideration from stakeholders and other concerned bodies.

Key Word: *Landfill, Suitability Analysis, Solid Waste Management, GIS, Remote Sensing.*

Chapter One

1. Introduction

1.1. Background

Solid wastes could be defined as non-liquid and non-gaseous products of human activities, regarded as being useless (Babayemi and Dauda, 2009). Its origin is mainly from households, municipal and construction (Munier, 2005). The generation and management of solid wastes are the problems facing both developing and developed countries. Generation of solid waste has become an increasing environmental and public health problem everywhere in the world, particularly in developing countries. Fast expansion of urban, agricultural and industrial activities spurred by rapid population growth has produced vast amounts of solid and liquid wastes that pollute the environment and destroy resources (UNEP, 2005). In many countries with increase in population and the rising demand for food and other essentials, there has been a rise in the amount of solid waste being generated making its management and disposal problematic (SS.Asadi et al, 2005). Solid waste management has long been a worldwide environmental problem. This is because of the rapid growth of population and urbanization that decreases the non renewable resources and disposal of waste and toxic waste arbitrarily, as a result of this major environmental issues posing stress to the arrival of human being (Allen et al, 1997). The most common problems associated with inappropriate management of solid waste include transmission diseases, fire hazards, foul odor, atmospheric and water pollution, aesthetic pain and economic victims (Jilani et al, 2002).

Urban solid waste management is considered as one of the most urgent and serious environmental problems facing municipality authorities in developing countries particularly in Africa. General awareness of our environmental problems has led to the development of pollution control technologies, more rigorous legislation, strategies on waste handling and disposal to minimize the environmental impact associated with solid waste. Waste disposal is an important part of waste management system, which requires much attention to avoid environmental pollution (Md.Mujibor et al, 2008). Based on this it is convincing that waste management will be effective if a suitable site is identified and properly utilized.

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).

A suitable disposal site must have environmental safety criteria and attributes that will enable the waste to be isolated so that there is no unacceptable risk to people or the environment while it is operating. Criteria for site selection will include natural physical characteristics as well as socio-economic, ecological and land-use factors. Preferable selection of suitable site for waste disposal has been normally carried by traditional approaches i.e. throwing it at all types of free land in or around the city (Md.Mujibor, et. al., 2008).

The geographical information system (GIS) can provide an opportunity to integrate field parameters with population and other relevant data or other associated features, which can help in the process of site selection. Site selection procedures can benefit from the appropriate use of GIS. The employment of GIS in the selection process will reduce the time and enhance the accuracy of the project.

1.2. Statement of the problem

As a consequence of population growth and development activities, high amounts of household and municipal solid wastes are generated. The population of a town is growing due to both natural increase and through immigration of people from rural areas to towns. High rate of wastes are facing problem of their disposal and have very high potential effect to pollute environment such as surface water, ground water, soil and air. Public health is also highly affected by the uncontrolled solid waste generation and disposal. In Ethiopia most of the diseases are related to poor environmental sanitation and water contamination. It is obvious that lack of suitable waste disposal site, public latrine and general sanitary mechanisms in the vicinity can affect the community's economic and social activities directly or indirectly (Tsegaye, 2006).

The increased wastes from the growing population and development activities have to be reduced via waste reduction, recycling and reuse techniques. Despite these solid waste management systems, collecting and depositing in safe sites by landfill technique is the primary means of waste disposal (Gizachew, 2011). This is due to the difficulty or the impossibility of managing all solid wastes through waste reduction, recycling and reuse. The solid waste disposal system

should be in an environmentally sound and socially acceptable way so as to protect the environment and safeguard public health.

The major sources of solid wastes in the town are commercial institutions such as bars, hotels, restaurants. Due to no landfill sites, people are forced to dispose the wastes from home or other areas like commercial institutions such as bars, hotels, restaurants, etc irregularly. These causes' sanitary conditions of the area deteriorate and certainly will have high potential environmental and human health risk. This irregular removal of wastes serves as a cause for different diseases causing and transmitting agents as well. So the people are at risk in their day to day activities because of this problem.

Therefore, solid waste disposal system should be an environmentally sound and socially acceptable way so as to protect the environment and safeguard public health. However, the traditional and manual method used to select suitable landfill site is inaccurate, tedious, time consuming and costly.

Although, in Ethiopia on most parts of the area had been already conducted researches concerning on landfill sites selection. Earlier, the municipality of a town was tried to select solid waste disposal site. However, they did not fully utilize GIS and remote sensing technology and were unable to consider many of these factors.

The current waste disposal system of the town is open dump system and the site is filled out, causing social and environmental problems. That is why, the research need to conduct in order to select solid waste landfill site for the town by considering ecological, environmental, economical and social factors. The study focused on integrating GIS and Remote Sensing techniques to provide appropriate information about geographic data to assist in selecting suitable solid waste disposal site using different factors. Therefore, the present study employs GIS and remote sensing techniques for appropriate landfill site selection for Welkite town and that this project comes up with the solutions for previously stated problems.

1.3. Objective of the project

1.3.1. General objective

The main objective of this project is to select suitable solid waste disposal sites that are environmentally sound, economically feasible and socially acceptable for solid waste landfill in Welkite town by applying geographic information system and remote sensing technology.

1.3.2. Specific objectives

- To asses solid waste disposal system of the study area;
- To examine environmental, social and economic factors that are necessary for selecting landfill and prepare their suitability maps in GIS environment;
- To produce thematic map showing potential landfill sites; and
- To evaluate the final selected Landfill Sites to prioritize and rank the identified suitable landfill sites according to their suitability.

1.4. Project questions

- What does the present waste disposal system of the study area look like?
- What are the factors that are necessary in waste disposal suitable site selection?
- How the suitable waste disposal site identified and its map prepared?
- How does the final selected landfill site evaluated?

1.5. Significance of the study

This project helps to protect environmental safety of Welkite town by selecting `suitable site for waste disposal using different sitting criteria. The final result of the project will help different stakeholders in the area in their day to day activities. Because unsuitable waste disposal site may affect the economic, social and other activities of the people. Moreover, exploitation of the analytical techniques employed in the project provides insight about the significance of GIS and Remote Sensing technology in suitable site selection in the study area and at a national level in general.

1.6. Scope of the study

The study is limited to suitable solid waste disposal site selection in Welkite town .It focuses on some technical aspects of solid waste disposal site selection. The issues under consideration in this study are only solid wastes. Sanitary wastes area, engineering and design part of the construction are not included.

1.7. Limitations of the Study

In addition to financial limitation, the study is constrained by the following limitations:

- There is no prior study in the study area to be used as a springboard,
- Lack of organized secondary data due to the absence of documentation and organized database system in the study area,
- The data collected at national levels are in collected as small sample in a very wide range of area, so that the data lack well representation of the area.
- The resolution of the recent satellite imagery data were the major problem to deal the current land use condition of the town. The most recent high resolution imagery data found was spot-5 satellite image of 2006. So that, the writer was used master plan of the town to obtain the current land use condition.

Therefore, the study relies on a combination of different primary data collection mechanisms with special emphasis and secondary data prepared well in GIS environment to carry out the study well. So that, utmost effort was made to minimize the negative impact of such constraints on the result of the study.

1.8. 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 area. Chapter Two, is related to literature reviewed. The focus area of the literature reviews are explaining terms, concepts related to the subject matter. This section is emphasized different scholars ideas around the global regarding causes and consequences of landfill. Chapter Three, deals with descriptions of the study area and methodology. Chapter Four, deals with finding of the study. Chapter Five presents conclusion and recommendations of the research work.

Chapter Two

2. Review of related literature

2.1. Landfill

Landfill is a common solution for the final disposal of waste in lower- income countries (Laura, 2003), and a large majority of communities practice continuous land filling or open dumping as their core method of waste disposal (Rush, 1999 as cited in Laura, 2003). Recently, due to the growing necessity of urban environmental problems, solid waste management in lower income countries has been paid due attention (Laura, 2003), and there is now an interest towards landfills design to increase environmental safety.

However, many areas do not have a process and criteria or guidelines for landfill sitting and design, and in some great areas, there have been inclinations to adopt guidelines or regulation of higher- income countries without modifying or adapting them to local conditions (Laura, 2003).

These create a problem because the developments of landfill require complex engineering design and construction techniques. In addition, complicated landfills normally have measures to control or use landfill gas, broad environmental monitoring points, leachate collection and treatment systems, and have need of a greatly qualified work force. As such, the implementation of complicated engineered landfills can only occur where the local economy can afforded the high level of expenses required for construction and operation of the landfill and where the technical resources to achieve high standards of construction and operation are made available (Laura, 2003). It is therefore important to ensure that when landfills are sited, the construction and operational capabilities of the local communities are considered in selecting the criteria that the environmental protection objective can be met.

By considering this and other factors I reviewed different researches; like how landfill is implemented by using GIS, criteria used by different researchers in different countries, process of landfill site selection and steps of landfill site selection as follows.

2.2. The role of GIS and Remote Sensing for Landfill Site Selection

2.2.1. 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). Remote sensing serves as a tool for environmental resources assessment and monitoring. Nishanth et al. (2010) also states remote sensing as one of the excellent tools for inventory and analysis of environment and its resources, owing to its unique ability of providing the synoptic view of a large area of the earth's surface and its capacity of repetitive coverage. With the availability of remotely sensed data from different sensors of various platforms with a wide range of spatio-temporal, radiometric and spectral resolutions has made remote sensing as one of the best source of data for large scale applications and study (Assefa et al., 2007). The use of remote sensing is becoming increasingly frequent in environmental studies. In the recent years, no serious research of the environment performed without advanced image processing and analysis. One of the most important applications of remote sensing can be found in the case of solid waste landfill site selection where remote sensing data (satellite images) are used for extracting most of the site selection criteria used for siting landfill (Oštir et al.,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.

2.2.2. 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 frame work 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 frame work for data capture, storage, synthesis, measurement and analysis. For assessing a site as a possible location for solid waste land filling, 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 land filling process.

One of the benefits of GIS is its capability for landfill site selection. Landfill sitting is complex, tedious and costly as it requires multiple criterions from environment, social and economic point of view. Moreover, landfill siting is a complicated process requiring a detailed assessment over a vast area to identify suitable location for constructing a landfill subject to many different criteria

(Chang et al., 2007). 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). GIS is a tool that not only reduces time and cost of the site selection but also provides digital data bank for future monitoring program of the site. The procedure followed under the GIS framework rejects 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, the GIS offers the spatial analytical capabilities to quickly eliminate parcel of land unsuitable for landfill site (Chang et al., 2007) and hence reduce cost and time of siting processes.

2.3. Criteria used for waste disposal site selection

The criteria used in landfill site selection include environmental, economic and socio-political, some of which may contradict to each other. With increase environmental awareness, new rules and criteria developments are emerged over time. The waste disposal site selection process has become much more complicated, as new procedures and tools have been created. By considering this and other factors I would like to review landfill site selection criteria used by different researchers in different countries.

2.3.1. Criteria used in Khulna City, Bangladesh

Formulation of criteria for site selection is a dual purpose activity as it helps to set the objective of the project in the other side specify the methodology used. Though there are numerous criteria used for evaluation, these are classified as environmental, economic, social and technical operations (Md.Mujibor et al, 2008). The corresponding indicators are the following:-

i. Environmental criteria: it consisting of surface water, ground water quality, land cover and ecological character, disposal site management and public health, safety and pain (Md.Mujibor et al, 2008).
ii. Economic criteria: it refers to land use and social value consisting of the distance from human settlements, industry and proximity to protect places, and impacts on housing and other development activities (Md.Mujibor et al, 2008).
iii. Technical and operational criteria: technical and operational criteria consisting of the altitude, the design of the site, i.e. hydrological evaluation, and grading of the surface of

slopes, access to roads, and the distance from the main source of waste consumption (Md.Mujibor et al, 2008).

2.3.2. Landfills selection criteria used in the case of Uganda

Several countries like Australia, Malaysia, Niger, North Dakota, Philippines, Uganda, and United States among others have put in place rules and regulations to follow when selecting suitable sites for sanitary landfills. These guidelines are used the primary mechanism used to protect the host community and the environment at large.

The following are the factors that several researchers have used to determine the appropriateness of a site to be used as a sanitary landfill (North Dakota Department of Health, 2002; and Yaw et al, 2006).

i) **Site capacity**: a site should be capable of providing at least ten years of use in order to minimize costs for site establishment and operation.

ii) **Land cover**: buffer zones should be provided between the landfill and sensitive areas or other land uses. For example at least 100 meters from public roads, at least 200 meters from industrial developments, at least 500 meters from urban residential or economic area, at least 1000 meter from rural residential areas.

iii) **Airports:** the distance between an airport and a landfill should be a minimum of three kilometers, there is a clear demonstration of bird control measures at the landfill.

iv) **Surface water:** the distance between the landfill and the nearest surface water should be a minimum of 100 meters, or 200 meter to minimize the risk of polluting water with leachate. However, North Dakota Department of Health (2002) uses a minimum distance of 60 meter to the nearest surface water, and

v) **Ground water:** an extremely deep water table region is suitable so that underground water is not contaminated by the leachate of the waste. According to North Dakota Department of Health (2002) and Yaw et al, 2006), the bottom of disposal drain should be at least four feet above the water table.

vi) **Local topography:** land forms located in flat or undulating land, in an empty extracts are suitable for waste disposal. Major landfills must not be sited in hill areas, those with ground slopes nominally greater than ten percent. However, North Dakota Department of Health (2002) recommends that 15 % slope or less.

vii) **Soils:** soil should be of sufficiently of low permeability to significantly slow the passage of leachate from the site. Thus, sites in clay-rich environments are preferable.

viii) **Climate:** areas with heavy rainfalls need extra care to avoid side effects of drainage and erosion; sites with prevailing winds require extra efforts to control litter and dust.

ix) **Unstable Areas:** landfill must not be located within 100 meter of an unstable area.

x) **Infrastructure:** although landfill should have suitable transport accesses, with power and water available, they should not be located within 100 meter of any major highways, city streets or other transportation routes. Yaw et al, (2006) recommended that 300 meter.

xi) **Local Flora and Fauna:** sites that contain protected or endangered fauna and flora, or sensitive ecosystems are unsuitable for landfill facilities.

xii) **Distance from environmentally protected areas:** a landfill must not be located in close proximity to sensitive areas such as fish sanctuaries, mangrove areas and areas for special protection would be excluded. Therefore a 3,000 meter buffer is necessary to surround an environmentally sensitive area.

xiii) **Distance from urban areas:** landfill should not be placed too close to high-density urban areas in order to mitigate conflicts. Development of landfills should be prohibited within 3000 meter from village or rural settlements Yaw et al. 2006, and a distance of 4000 meter from a town.

xiv) **Population:** Yaw et al, (2006), recommend that areas with a population density less than 200 persons were regarded as suitable for landfills.

2.3.3. Criteria used in West Bandug Regency

i. **Geology**: bedrock in areas of potential landfill is very significant in minimizing the spread of leachate naturally, both at the time of moving into ground water or when moving laterally along the ground water. Therefore, required landfill area selection demands that do not have bedrock with the formation of sandstone, limestone or hollow rock. The other geological areas which are important to be evaluated are the potential for earthquakes, the active volcanic zones and land slide areas. The area around the volcano and areas for potential earthquake is geological-prone areas that are not encouraged to become candidate landfill sites. High soil movement is not considered suitable candidates landfills (Akbari, 2008).

ii. **Hydrogeology**: Hydro-geological information is needed to determine the presence of ground water, soil impermeability detection, the location of rivers or reservoirs or surface water and

drinking water sources used by the residents around. Soil with rapid permeability assessed to have a low value to a potential landfill site because it provides small protection against ground water and require special additional technology. Soil type also affects the permeability of water into the ground. Landfill site cannot be selected on the type of sandy soil because it has a high porosity so that the graduation rate in the ground water will be relatively high so that it can interfere with ground water quality. The ability of permeability of soil to absorb water is fast, good, medium and slow. Rapid permeable soil (coarse sand), is classified the rate and permeability which is 3.6-36 cm per hour; permeability of the medium, i.e. 2.0-3.6 cm per hour; whereas the slow permeability below 2.0 cm per hour (Akbari, 2008).

iii. **Topography**: Landfill area should not be located on a hill with an unstable slope. An area is preferable if located on the sloping area with high topography. The best slope for solid landfill should be modest slopes, which enable easier storm water control, leachate control and site stability measures, as well as facilitating the operation of the site. Different researchers set different slope criteria for landfill site selection. For example, Hasan et al. (2009) set areas with slope <15-20% as the best site for landfill, while Change et al. (2007) describe slope <12% as the best site and slope >12% unsuitable for landfill. Very steep areas considered to have a smaller value because it was feared could cause a fatal avalanche especially when there is rain or high water seepage (Akbari, 2008).

iv. **Land use**: land filling which receive organic waste can attract birds so that it should not be placed within 300 meters of the airport runway used by the turbo-jet flight or within 1500 meters distance from the airport runway used by piston-type flights. In addition the location could not be in areas designated for fisheries protected areas, wildlife and plant conservation. Other land use types that are usually considered less suitable are the local conservation and forestry areas. This is to prevent potential contamination and negative impact on the community around the landfill (Akbari, 2008).

2.3.4. Criteria used in solid waste management in Kottayam Municipality

The criteria are grouped into two main categories including physical and socio-economical information. The criteria were selected according to study areas local characteristics. The principal sub criteria that used for spatial analysis are lithology, geomorphology, slope, inhabitants, and distance from major roads, distance from major streams and distance from drainage (Ozeair Abessi et al, 2009). This will apply these criteria with their specific values.

2.4. Multi-Criteria Decision Analysis (MCDA) for Landfill Site Selection

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice (Chakhar and Mousseau, 2008). MCDA consists of a series of techniques such as weighted summation or concordance analysis that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by, for example, experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/sitting a particular facility/service (Malczewski, 2004) like landfills. Analytic Hierarchy Process (AHP) is one of the most commonly used MCDA tools. This tool is applied in site selection processes as it assists the decision making process by allowing decision-makers to organize the criteria and alternative solutions of a decision problem in a hierarchical decision model (Eldrandaly et al., 2005). Furthermore, Multi-criteria approaches have the potential to reduce the costs and time involved in sitting facilities by narrowing down the potential choices based on predefined criteria and weights while also permitting sensitivity analysis of the results from these procedures (Higgs, 2006). Hence, multi-criteria techniques could be particularly useful in situations where there are a large number of alternative sites for a development, where there are large number of potential criteria to be taken into consideration or where subjective judgments by different stakeholders of the different alternatives is needed to try to reach an objective consensus in the final decision- making process or to make these processes more open and accountable (Petts et al., 2003 cited in Higgs, 2006).

A solid waste management program often involves conflicting economical, environmental, and socio-ecological impacts. For example, locating a new site for landfill development at minimal cost is feasible, but the tradeoff could be the likelihood of groundwater pollution. The landfill selection problems have often been tackled using MCDA through defining the criteria for landfill sitting. According to Moeinaddini et al., (2010) a sitting municipal solid waste landfill is a spatial multi-criteria decision analysis (SMCDA) for which both GIS and MCDA methods should be used. Moreover, landfill site selection by GIS is a multi-criteria evaluation (MCE) and generally has four steps criterion establishment, standardization of factors, establishment of factors weight and weighted linear combination. With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of results to yield a suitability map (Hasan et al., 2009). Therefore, the role of MCDA in landfill site selection can be completed by integrating it with GIS. Eldrandaly et al. (2005) emphasis, integrating GIS and MCDA can solve the

challenges of landfill site selection which involves highly complex spatial decision-making processes.

2.5. Landfill site selection process

Landfill site selection is a significant step in implementing a waste management program. Proper sitting 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 (Laura, 2003). To insure that an appropriate site is chosen, a systematic process should be developed and followed (Laura, 2003). Unsuccessful landfill sitting is typically the result of strong public opposition, and much research has been conducted to explore reasons for sitting failures and to recommend changes in sitting 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 economical criteria. Lawrence (1996) in Tsegaye, 2006) identified three major sitting 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:

i. 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).

ii. 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 sitting processes (Tsegaye, 2006).

iii. Community control Approach

This method uses a high degree of process and outcome control by attracted and potentially affected parties. Proponents of the landfill and community groups work together to make decisions, there are various ways in which the community can have control over the process: procedural control on the structure and implementation of the sitting process; location control, or the freedom to choose whether or not accept a site; and facility control over the need for, size and operation of a facility (Tsegaye, 2006).

Each, of these approaches can be applied in a variety of ways, and they can be combined in numerous steps to suit the needs of the project. Because the success of the landfill sitting can be strongly influenced by the choice and application of the sitting methods as well as the steps followed (Tsegaye, 2006).

2.6. Steps in the landfill sitting process

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

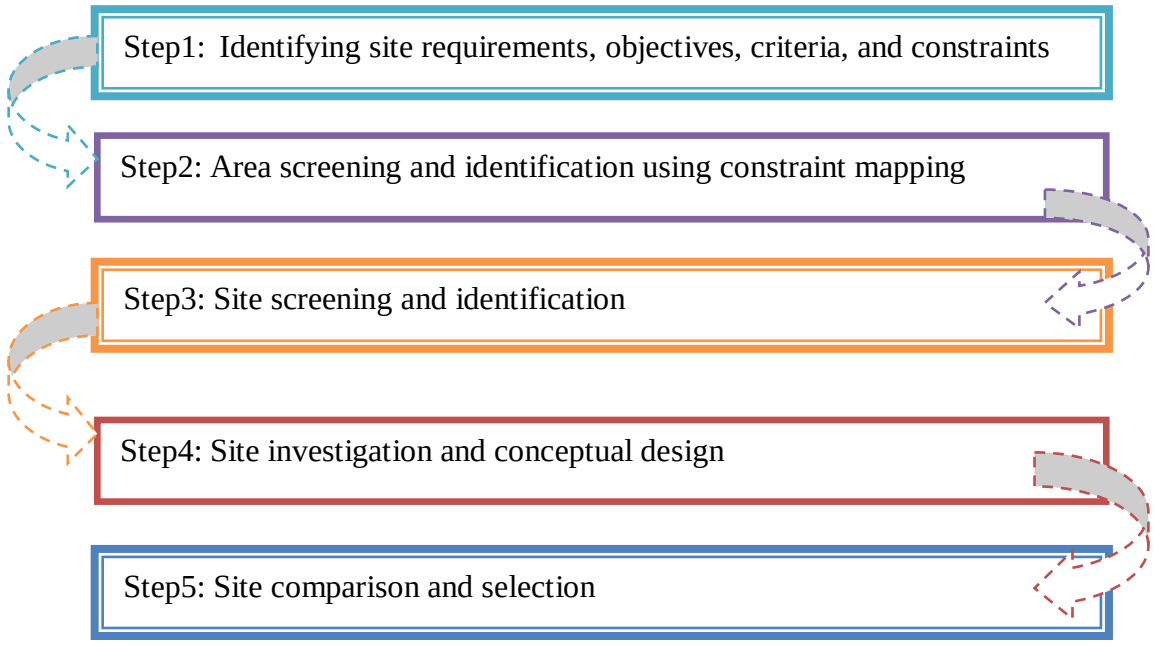


Figure 1: Steps in the landfill sitting process (Tsegaye, 2006)

i. Identify Site Requirements, Objectives, Criteria, and Constraints

The first step in the process is to identify the landfill requirements and determine the objectives, constraints and criteria to be used in the process. For example, one objective may be to minimize the risk of groundwater contamination. One of the criteria may be to minimize the depth to the

water table, with constraint that the water table must be 1.5 cm below the base of the land fill. Once the criteria and the constraints are established the data requirements can be determined. In addition to these criteria there are other criteria that can be used in this study.

ii. **Area Screening and Identification using Constrain Mapping** An important element of a successful landfill sitting process is evaluating the basic suitability of all available land for land filling to aid in the selection of a limited number of potential sites for more detailed evaluations. This should be taking into consideration the resources and constraints of the government agencies and consultants involved in the process (McAllister, 1986 in Laura, 2003). As such it should be based on published data, such as topographic maps, aerial photographs and official developments and structural plans. Constraint mapping is a commonly used technique that involves creating a series of maps to show the areas identified as unsuitable for land filling based on each of the constraints. When the maps are overlaid, the potential candidate sites can be easily identified (McAllister, 1986 in Laura McNally, 2003). Recently the GIS used to facilitation of land filling site selection process by converting geo-referenced data into computerized maps and map analysis tools can be used to manipulate maps in efficient way (Kao et al, 1997 in Laura, 2003). This is especially useful when dealing with large amounts of data which is typically in landfill sitting. The main purpose of this step is to minimize unwanted areas for site selection.

iii. **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 land filling. The objective is to reduce the number of candidate sites to three; however, it may be practical to consider more than three sites. The key issue to keep in mind is that in the next step, each site will require detailed data collection, which is time consuming and costly, thus, given time or budget constraints comparing many sites may not be feasible. In this case the data used to compare and evaluate the site are based on published data, documents from the town administration and data from walk over on field work which are common to all candidate sites.

iv. **Site evaluation and conceptual design** In this step, detailed data are collected for each candidate site. Site investigation should be designed to confirm published data and collected 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.

v. **Site comparisons and selection,** This step involves a detailed evaluation and comparison of the candidate sites. This requires comparing the data collected from site investigations and published sources, and conceptual designs to determine which site best meets the criteria. Often, this is achieved by weighting and rating criteria (McAllister, 1996 in Laura McNally, 2003). With this method the weight of each criterion is determined according to its relative importance and each site is related 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 1 to 10, or a qualitative ranking such as high, medium or low can be used. For example, a site with no ground water resources underlying the landfill may receive a rating of 8, or high acceptability, and a site with groundwater resources less than 5 m below the landfill may receive a rating of 3 or low acceptability. Sites are also being compared based on the conceptual design, and more than one design alternative may be considered for a site. A matrix can be used to compare all the sites based on the criteria by filling in the ratings.

Chapter Three

3. Description of the Study Area and the Research Methods

3.1. Description of the Study Area

3.1.1. Geographic Location

Welkite is an administration and trading center of Guraghe zone which is part of SNNPR. It is one of the twenty two reform towns opted as a hub of development in the region. It is found southwest of Addis Ababa along the main Addis Ababa - Jimma road at a distance of 158 km at the geographic coordination of 905500-916500 North latitude and 360500-371500 East longitude.

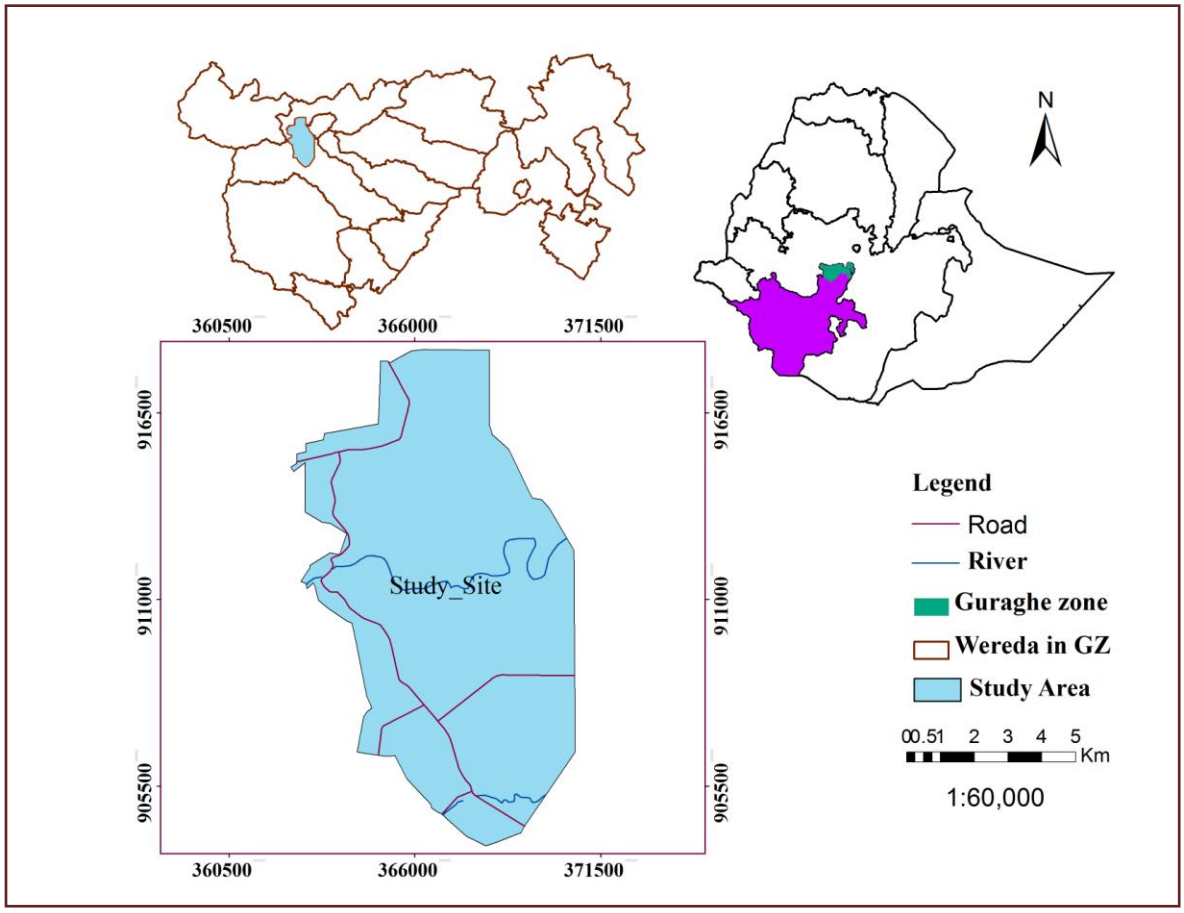


Figure 1: Location map of the study area (Author, 2014)

3.1.2. Climate

The whole area, lying in a tropical climate, classified as humid region (Ethiopian Meteorological Authority, 1981 cited in Dawd, 2013). The climate of Welkite town is characterized by four distinct seasonal weather patterns. The main wet season, locally known as kiremt, extends from

June to August, a minor rainy season locally known as mehir, extends from September to October, a little rainy season locally known as belg , extends from March to May and more likely no rain season locally known as bega, extends from December to February . In general based on local climatic classification, Welkite town is grouped under woeina-dega climatic zones. As meteorological data has shown that the annual mean average temperature of the town for consecutive for five years is around 12^0c and the maximum temperature reaches up to 26^0c in May as seen in the following graph.

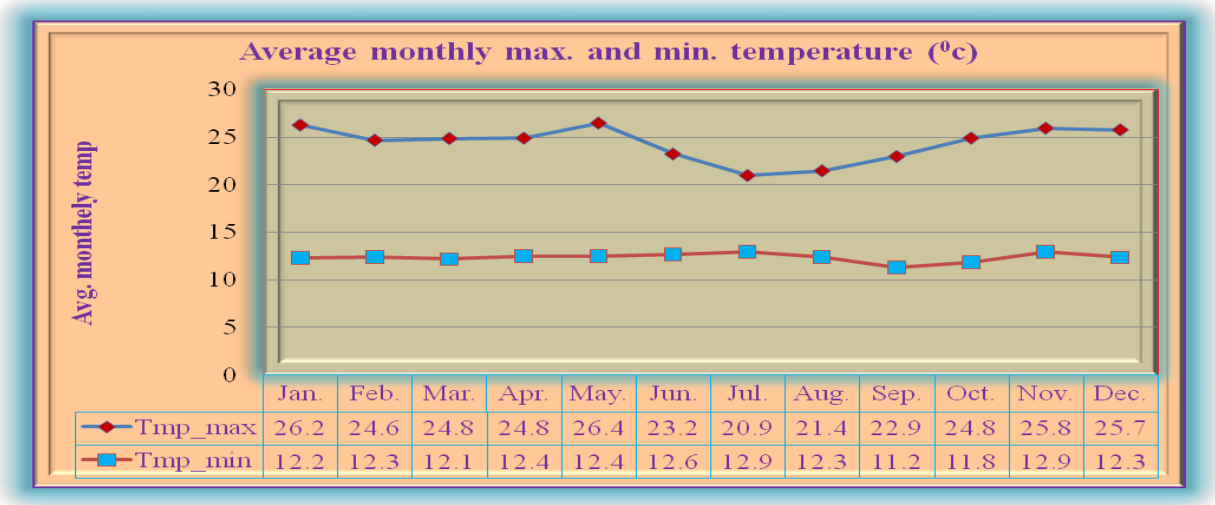
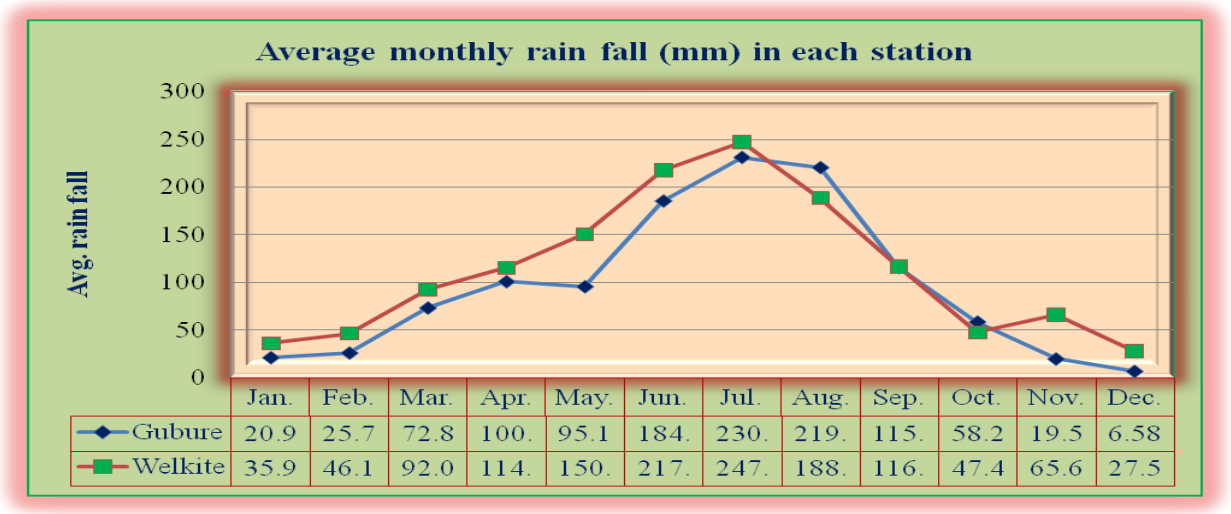


Figure 2: Average monthly maximum and minimum temperature of the study area (Ethiopian Meteorological Authority, 2006)

1.1.3. 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 total annual rainfall record of the area was 1391 mm while the lowest was 950 mm. May and July are the warmest and the coldest months respectively.



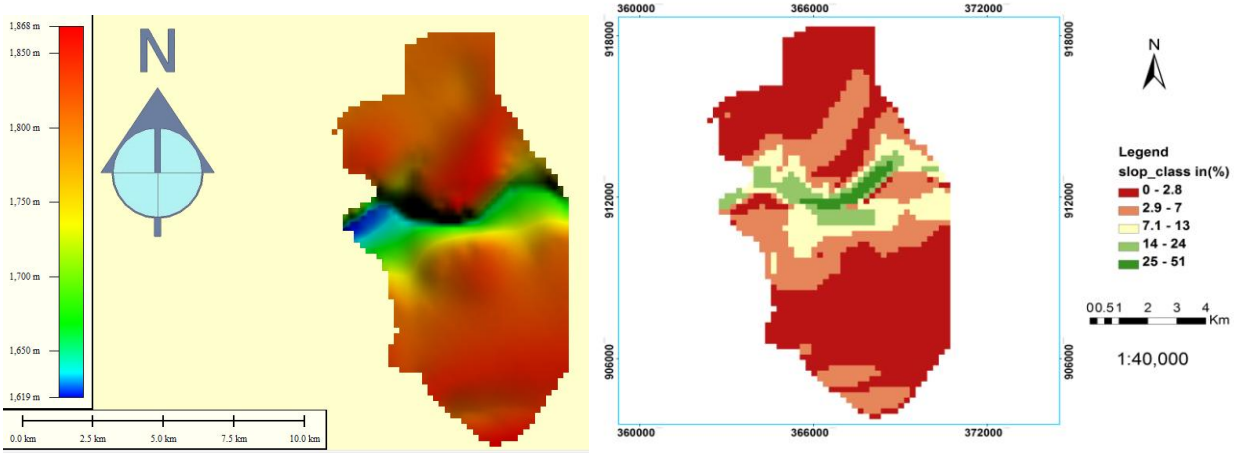
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Gubure	20.9	25.7	72.8	100.	95.1	184.	230.	219.	115.	58.2	19.5	6.58
Welkite	35.9	46.1	92.0	114.	150.	217.	247.	188.	116.	47.4	65.6	27.5

Figure 3: Average monthly rain fall distribution for the study area (Ethiopian Meteorological Authority, 2006)

The amount of rainfall recorded in the town varies from one month to other. Generally, June, July, August and September have been the wettest season (kermet) while December, January and February were the driest season (bega).

3.1.4. Relief

Welkite has been built up on rugged terrain that its elevation ranges from 1619 to 1868 m a.s.l dominated by undulating flat topography and low lying areas. Gentle slope surface with a range of 0-2.8% accounts for about 55.51% area coverage and slope in between 2.9% - 24% accounts for about 42.78% while a slope greater than 24% covers about 1.7% of total land coverage of the study area.



(a) **(b)**

Figure 4: Terrain patterns of Welkite town in 3D (a) and distribution of surface slope (b)

3.1.5. Topography of the town

Topography of the town is characterized by flat table land, slightly inclined in all directions. There are four rivers surrounding the town flowing in different directions, these are Wabe, Gibe, Walga and Rebu. The town has also elongated shape that extends from northeast to southeast direction and it covers a total area of 10.3km^2 and the area increased to 79.84km^2 as it is integrated with Gubre town (Welkite town municipality, 2012). The principal natural constraints for the physical expansion of the town are hills, plains, gorges and steep slopes and its manmade constraints are illegal settlements (Welkite town municipality, 2012).

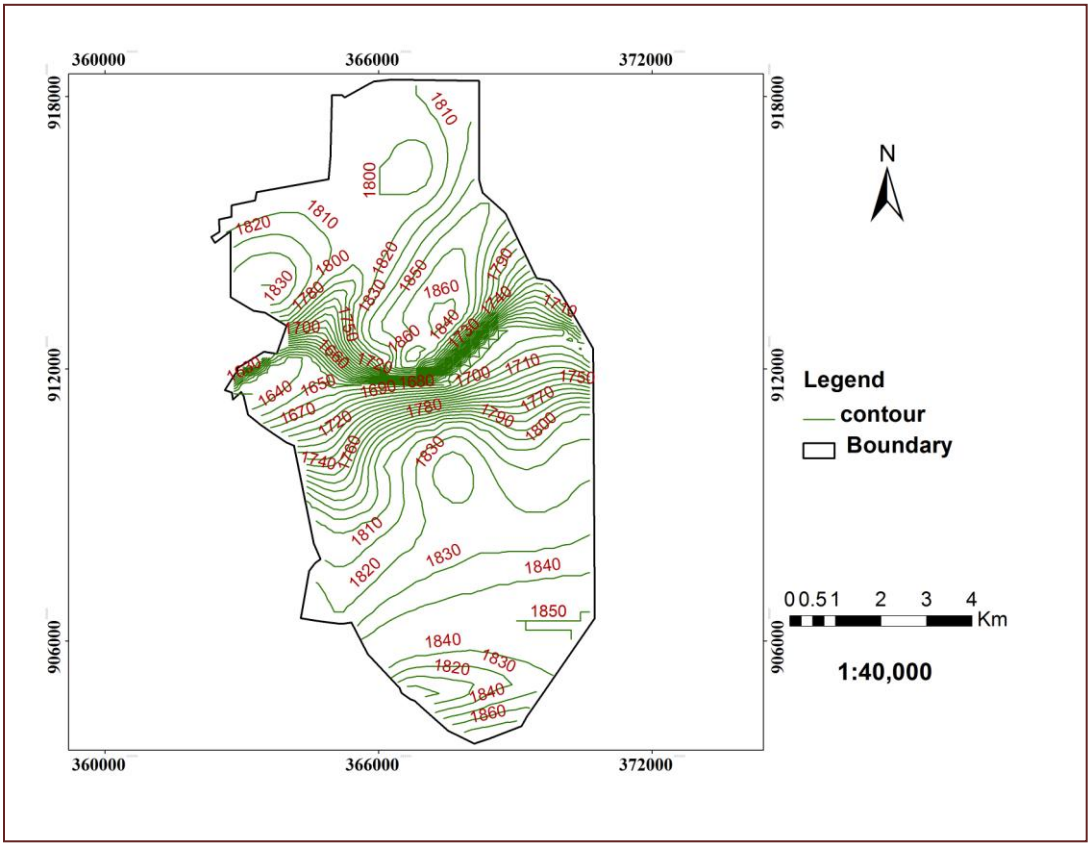


Figure 5: Contour map of the study area (Author, 2014)

3.1.6 Population

As it is key issue in carrying out any planning activity, having knowledge of population size of any urban center is vital. According to Central Statistic Agency of Ethiopia (CSA,2007), total population of the town was 28,856 of which 15063 (52.2%) were male and the rest 13793 (47.8%) were female. Currently in 2013 the total population size of the town is expected to be 33,877 of which male accounts 17,684 and female accounts for the rest 16,193 if the rate is considered to be constant. The population growth rate at medium variant was 2.9% (CSA,2007).

3.1.7 Economic activity and housing

The main economic activities of the town are trade, public administration, transport, construction and other services. Among these activities trade, hotel and restaurants are the main ones. The physical characteristic of the housing units in the town has revealed that the majority of them are dilapidated 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, Jimma and Woliso towns creates good opportunity of the future development of the town. Welkite has access road that links the town with Addis Ababa, Jimma, Woliso, Hossana and Butajira town. Welkite town is now administratively divided into three sub towns: Addis (Menaharia, Edeget_chora and Selamber keble) , Bekur and Gubre sub towns. The town linearly stretches over 45 km^2 from north to south, mainly along the Welkite to Hossana/ Butajira highway and 15.7 km^2 from east to west.

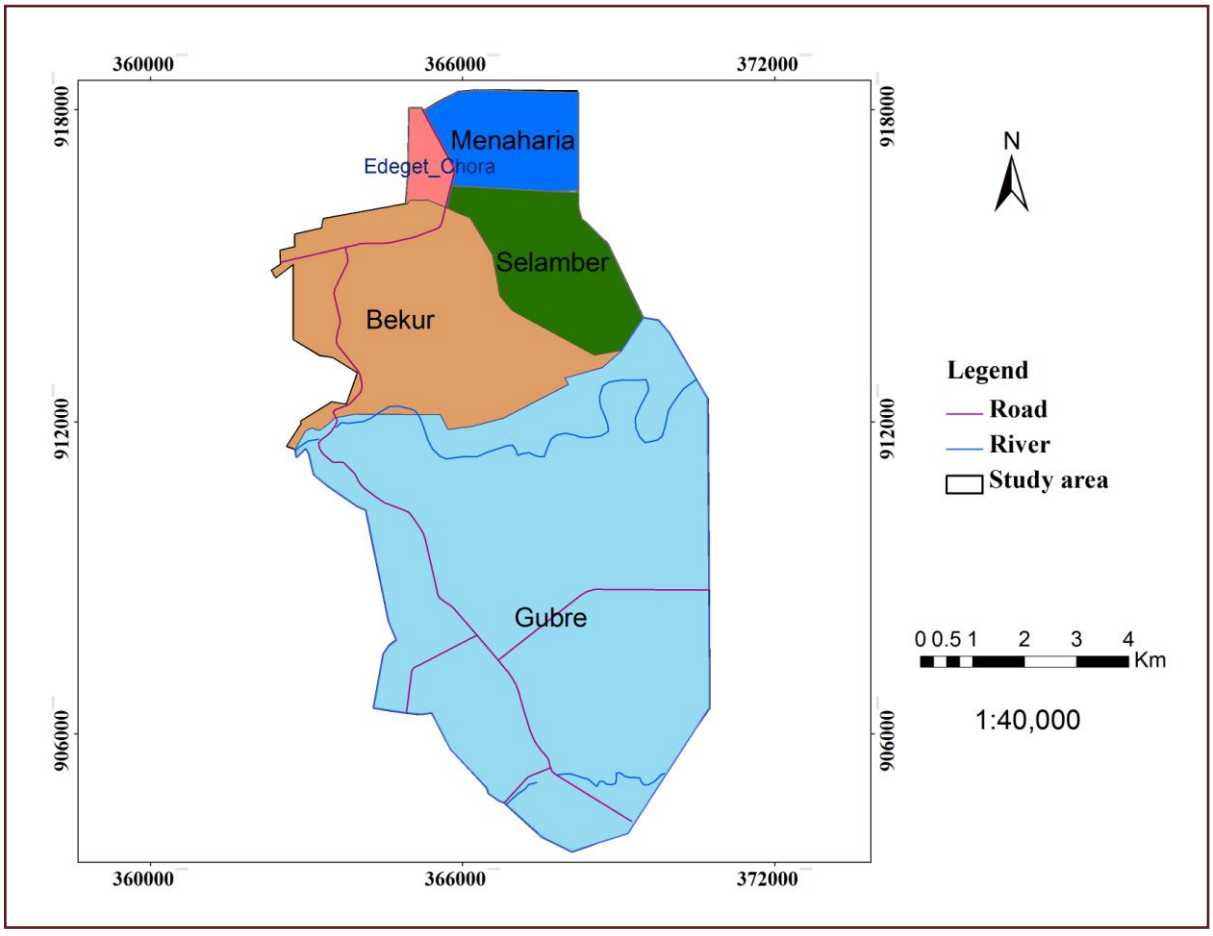


Figure 6: Administrative unit of Welkite town (Author, 2014)

3.2. GIS based waste disposal site selection

Suitable site selection analysis would be conducted by using GIS technology. Because it is an important tool for site selection as it has the advantage of managing large spatial data that originates from primary or secondary sources (Aysheshum**,** 2002), potentially also saves time and money.

Many approaches are employed looking for the best site for waste disposal. Most of these approaches heavily depend on mathematics and optimization techniques. Since, site selection is a potential solution it incorporates all relevant aspects of the problem in the overall frameworks. An alternative framework that is capable for resolving site selection is GIS (Aysheshum**,** 2002).

By considering this advantage of GIS for waste disposal site selection process, I would applied the GIS technology. Because the fundamental analytical method of GIS based site selection system includes: proximity or buffering analysis, overlay analysis, 3D analysis and spatial analysis which are important to select the criteria used in the study.

3.3. Sources of data

Collecting accurate and reliable data is the most determinant factor for any research as it determines the quality of the research. Accordingly, the necessary data were collected from the respective secondary and primary data sources. Borehole data like ground water well points and lithology were collected from Ministry of Water and Energy (MWE) and converted as an input data in GIS environment.

Geological map of Welkite town from Geologic Survey of Ethiopia for mapping geologies found in the study area, soil map of the study area from Ministry of Water and Energy (MWE) for mapping soil texture in the study area. Structural plan of Welkite town was obtained from the Graghe Zone Urban Development Department (GZUD). Topographic map (1:50,000) were used to extract surface water like streams/rivers. The SRTM (30m x 30m resolution) was used to extract Digital Elevation Model (DEM). The DEM was used to derive slope and contour pattern of the study area. Road networks were digitized from the structural plan and ready for use in the GIS environment. All the data were collected, manipulated, and analyzed in the environment. 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 final waste disposal site. Digital camera and GPS used to capture primary data.

3.4. Data analysis and presentation

There are different types of GIS spatial operation tools that are used to achieve the objectives of this study. The methods used include buffering, overlay, spatial analysis, 3D analysis, and suitability modeling. How each of these have been operated was outlined as follows.

3.4.1. Digitizing

This function of GIS converts the base map of the area into digital map to use in GIS environment. This is done by using on- screen digitizing by encoding the spatial coordinates of the features on the map. It was used to digitize boundaries, roads and streams that exist in the study area from the structural plan.

3.4.2. Buffering

Buffering is a spatial analysis also called proximity analysis. It is used to generate areas of a given distance around the specified criteria used for waste disposal site selection. Such as polygons around roads and line or polygon around streams based on the specified distance to each criterion. The features that buffered include: roads, streams, ground and surface waters, settlement and other socio economic facility with different values.

3.4.3. Overlay

An overlay operation was performed to identify areas that fulfill all the site selection criteria and to show areas that do not meet these criteria. GIS can overlay different types of information that helps to understand the association between network analysis and specific geographic features (Tsegaye, 2006). In this study the overlays different input features to the base map (structural plan of the study area), such as DEM, geology, soil and hydrogeology from different sources. The final map is intersected from the factor map and constrain map by using overlay operation.

3.4.4. Spatial analysis

ArcGIS 3D analysis is a powerful tool used to slope generation and conversion from their sources (Tsegaye, 2006). The writer have been used this operation to generate slope, contour and aspect of the study area from the DEM that limits the site selection process.

Generally, solid waste disposal site selection is the complex, tedious and costly process that needs to consider many conflicting criteria. In this research soil, geology, and groundwater well and proximity from rivers/streams were used as factors. Moreover, proximity from road, land use/land cover and slope of Welkite town was also considered as landfill sitting constrains. All

the factors and constrains were internally classified in to two classes as suitable and unsuitable. Finally these factors are integrated into one by applying suitability modeling technique and the constrains also integrate by this method and the final landfill site is produced by integrating this two factor map and constrain map in to one by using suitability modeling.

3.4.5. Multi-criteria decision-making (MCDM)

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice (Chakhar and Mousseau, 2008). MCDA consists of a series of techniques such as weighted summation or concordance analysis that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by, for example, experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/sitting a particular facility/service (Malczewski, 2004) like landfills. Analytic Hierarchy Process (AHP) is one of the most commonly used MCDM tools. Pair wise comparisons are also used to determine the relative importance of each alternative in terms of each criterion.

3.5. Materials used (hardware and software)

The materials used in this study for data analysis include computer hardware and software. The hardware used in this study includes PC, color printer, scanner, Sony trace digital camera and GPS receiver. The software for preparing and analysis of the data include MS word 2007 for editing purpose, MS excel 2007 to store attribute information collected during field survey, Arc GIS 10.1 for digitizing, buffering, overlaying, intersect, data analysis including spatial analysis and suitability modeling, Global Mapper 14.1 was used to show the terrain pattern of the study area in 3D, ERDAS imagine 2010 was used for georeferencing and to weigh each class of criteria were derived in IDRISI3.2 software using AHP methods.

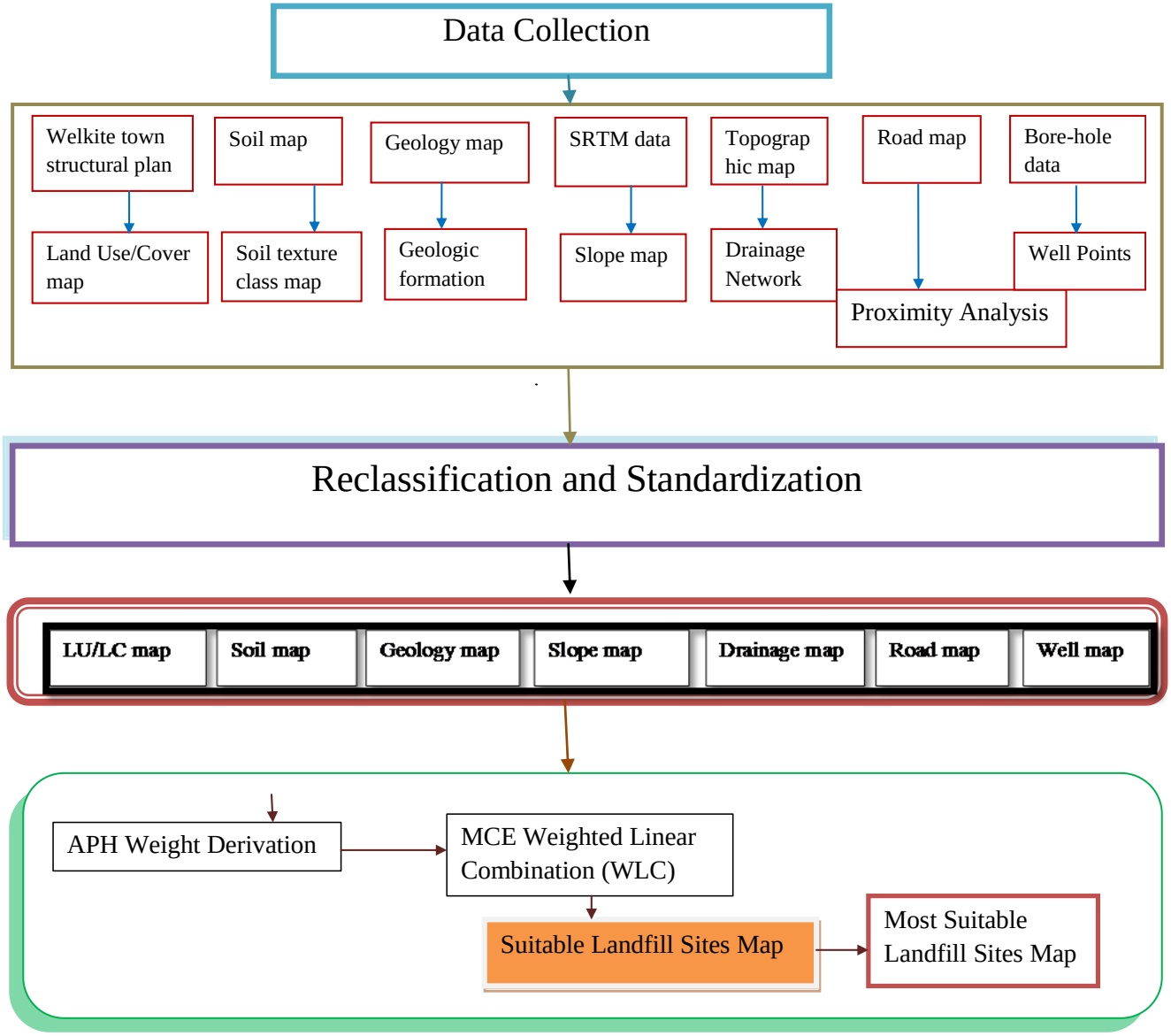


Figure 7: General Methodology flow chart (Author, 2014)

Chapter Four

4. Results and Discussion

4.1. Waste Disposal Trend of Welkite Town

The first objective of a study is to examine the present waste disposal system of the municipality. This objective is achieved by reading different documents and reports about waste disposal from Welkite town municipality and field observation. According to the survey the present waste disposal system of Welkite is not as such satisfactory because of different factors. Municipal waste shall be collected in a manner which is economical but at a frequency that meets public expectations and minimizes public nuisances from odour and the breeding of pests such as flies and mosquitoes, and where used, overflowing community containers. Collection shall be undertaken during daylight hours. Collection at night shall be avoided, due to noise nuisance to the residents and safety risks. In areas of high density housing, with narrow streets, often with poor road conditions, a primary waste collection system is sometimes applied using handcarts or donkey-carts. Accordingly, Welkite town municipality collects waste as: Door-to-door collection with handcarts or donkey-carts to transfer station allowing access by vehicles. Rresidents and shopkeepers put their waste out for collection. Collection vehicles empty containers located within the selected block of waste producers to promote public co-operation and reduce uncontained dumping of waste and secondary collection. A community-based group may collect waste from houses and it is left at a transfer point for removal by municipal vehicles or a private contractor. Waste collected from community container site and taken to transfer station or open dump site.

Researches with respect to sanitation, beautification and green area development, attend the town sanitation, collect the solid wastes with suitable condition are among many responsibilities of the municipality (Ministry of Urban Development and Construction, 2012). To carry out such responsibilities Welkite town municipality works hard by developing different plans year to year. Even though, it failed to carry out its waste management in disposal sites that are environmentally sound, economically feasible and socially acceptable for solid waste landfill. The main waste sources in the town are wastes arising from residents, commercial, municipal services (kera, road, market wastes etc.), construction centers and from enterprises. There is no toxic waste in the town till now. About 90% of the solid wastes in the town are disposed illegally

at any place and about 10% of the solid waste burned at suitable place (Welkite town municipality, 2012). The main solid waste management and disposal problems rises due to the absence of waste collection and not enough transportation machines, carts or other ways and the absence of suitable waste disposal site (Ministry of Urban Development and Construction, 2012).

Generally, the cleaning of the town is not satisfactory because the solid wastes are disposed along the road, sewage canals, eroded places and open spaces.

Wastes were disposed illegally in many areas of the town. These include among other areas found at Gassore, behind Electric Corporation, *Gebrel* church, *Diyaspora sefer*, 20 *Quteba* site, close to *Kera* and around *Selamber* primary school and behind Health Center.

A. Open dumpsite disposal of liquid and solid waste at the same site



Figure 8: Open dump site at Gassore (Field Survey, 2014)

Appropriate segregation (separation) and identification of the hazardous health care waste shall be achieved at the point of generation. Segregation of hazardous from non-hazardous health care waste should be assured as close as possible to the point of waste generation. Separated materials shall be kept separate within storage areas and during transport. As well as separation of solid to liquid wastes should be required to manage easily in all levels of waste management. What is shown in the above photos is illegal disposal of solid and liquid waste together in open dump site un separately in a way that is not environmentally sound, economically feasible and socially acceptable for solid waste landfill in a manner of not easy to manage/control the effects on health.

B. Illegal disposal of waste along road, fence, near to house and in drainage



(a) **(b)** **(c)** **(d)**

Figure 9: Illegal disposal of waste along a) fence, b) road, c) near to house and d) drainage (Field Survey, 2014)

Solid waste management process must be participatory. Such participation would directly result in reduction of solid waste generation, cleaner streets, appropriate preparation and storage of waste for collection and cheaper operation. The head of each household shall ensure that recyclable solid wastes are segregated from those that are destined for final disposal and are taken to the collection site designated for such waste. It is prohibited to dispose of litter on streets, waterways, parks, bus stop, sport fields, water bodies in urban areas or in other public spaces while litter bins are available.

To promote community participation in order to prevent the adverse effect and to enhance the benefits resulting from solid waste. The solid waste management action plans designed by and implemented at, the lowest administration unit of urban administration can ensure community participation. What are shown with the photo plates (Fig.9) the municipality were not efficient enough in solid waste management by participating the community, by making appropriate plan and providing enough logistics such as temporary containers as cardboard boxes and plastic carrier bags, galvanized-iron bins with lids containers, car and truck tires to make a clean town.

Even if the municipality works hard by developing different plans year to year, it failed to carry out its waste management in disposal sites that are environmentally sound, economically feasible and socially acceptable for solid waste landfill. Competent authorities shall set out an action plan detailing how they will ensure compliance with the standards, including closure or upgrading of existing disposal sites, and/or construction of new sanitary/controlled landfills. As stated among many responsibilities of the municipality of a town to work a research with respect to sanitation,

beautification and green area development, attend the town sanitation, beauty and green area development and collecting the solid wastes with suitable condition. Where as many roads, settlement areas and drainages of a town are not clean and not attractive due to the absence of landfill site in a town.

C. Amount of solid waste disposed legally in open dump site

The residents and shopkeepers know when collection is made so that they can put their waste out for collection or to collection vehicles empty containers located within the selected block of waste producers to promote public co-operation and reduce uncontained dumping of waste and secondary collection, waste collected door-to-door collection with handcarts or donkey-carts to community container site and transferred to dumping station or open dump site access by vehicles. As a result, the amount of waste collected and disposed in open dump site by a municipality in each month is shown below (Table 1).

Table1. Amount of solid waste disposal of the town in each specific month

		2012 (2004)	2013 (2005)
	Month	Amount of disposed waste (m^3)	Amount of disposed waste (m^3)
	September	1605	1505
	October	1618	1634
	November	1304	1360
	December	1412	1102
	January	1321	989
	February	1336	975
	March	980	1350
	April	1104	1128
	May	927	1028
	Jun	1140	1271
	July	1300	1156
	August	1573	1276
Total		15620	14774

Source: The municipality annual report, 2013

By considering improper disposal of solid waste the writer wants to select suitable waste disposal site by considering different criteria of the municipality. The criteria used for site selection project are the ones used by the municipality of Welkite town are include the followings.

i. The geological criteria: site must be free from gypsum, charcoal, and open space minerals within 1.5 meter depth of the area. In addition, the area is free from mineral exploitation activities. No fault lines or significantly fractured geological structure within 500 meters of the perimeter of the proposed landfill cell development that would allow unpredictable movement of gas or leachate. In addition, the site must be in the suitable soil with 104 cm depth and cannot be easily penetrate by water.

ii. No environmentally significant wetlands of important biodiversity or reproductive value are present within the potential area of the landfill cell development about 500-meter buffer zone. The site must be far from endemic species and other biodiversity. No major lines of electrical transmission or other infrastructure (i.e. gas sewer, water lines) cross the landfill cell development area, unless the landfill operation would clearly cause no concern or rerouting is economically feasible. It should be buffer for a minimum of 500-meter distance. The site must be one kilometer far from settlement areas. No sitting within a floodplain subject to ten-year floods and, if within areas subject to a 100 years flood, must be amenable to an economic design, which would eliminate the potential for washout, to minimize such problem 300-meter buffer along streams must be delimited. The site must be far from religious institutions, educational institutions and other social services by a minimum of one-kilometer distance. The site must be in ten kilometer distance from the center of the town and it should be free from any traffic conjunction. The site must be located in the opposite side of the main wind direction. Moreover, the site should be located in areas of low economic or ecological values. These criteria are generally included into topographical and land use criteria.

iii. Site must have suitable and adequate place, not closed with road and water bodies and it cannot be flood-affected area, is used for waste disposal. The site must check the ten year ground water information whether it is free from contamination or not. No private or public drinking, irrigation, or livestock water supply wells within 500 meters down gradient of the landfill boundaries, unless alternative water supply sources are readily and economically available and the owners give consent to the potential risk of well abandonment. In addition, the site must be far from the ground water that used for the people for drinking. These criteria are totally considered as hydrological and/hydro geological criteria.

The overall national and international criteria used in this project are discussed as follows by grouping into geological criteria, hydrological/hydro geological criteria and topographical or land use criteria.

4.2. Suitable site screening and identification of each criterion

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 underlain by karastified limestone

b) Area prone to subsidence caused by previous mining activities
c) Areas under lain 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 give detail emphasis how a given geology affects the landfill construction activity and how it can be suitable. Lets us see the geological condition of the study area and examine how it can be suitable for this project site.

Geological Conditions of the Study Area

Welkite town is located on the Ethiopian plateau just west of the rift valley. It consists of extensive flat surfaces desiccated by deep and shallow river gorges. The elevation varies from 1619 to 1868 meters a.s.l. The geology of Welkite 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 are: Nazareth pyroclastic rocks and Tarmaber-Megezez Formation (Tamiru et.al, 2005).

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. Along the main Ethiopian rift and adjacent plateau margins, the group crops out along the north –east watershed of the Omo-Gibe Basin over a large tract of land stretching from south of Woliso to Welkite, Gubre area and Selam ber.

It is widespread over all of the study area covering most extensive regional exposure of the south east, 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) this unit consists of three members.

Welded pyroclastic flows

Tsegaye et al., (2005) mapped this unit as the lower member consists of welded peralkaline pantelleritic ignimbrites with minor intercalated basaltic lava flows. It is light to dark-grey in fresh sample and reddish yellow to pink up on weathering. Efrem, (2010) described this unit as fine grained densely welded rock containing vitrophyric fiamme and lithic fragments with associated rhyolitic lava flows interleaved with ash and tuff.

Welded to partially welded pyroclastic flows

It is fine grained, densely welded ignimbrite to poorly welded pyroclastics with developed fiamme and lithic fragments. In most exposures it is associated with rhyolitic lava flows and intercalated with ash and unwelded tuff. The weathering activity changes the light to dark-grey color to reddish yellow to pink (Geological Survey of Ethiopia, 2011).

Rhyolitic and Trachytic lava domes

It is exposed in the form of unevenly distributed small dome and gently circular to elliptical hills. It has a characteristic color light grey to pink in fresh ample. Efrem, (2010) identified an intercalation of ash and tuff locally.

Tarmaber-Megezez formation

This lithological unit crops out in the central, west to east and southern part of the study area. It forms most flat and extensive geomorphology. Usually it is vesiculated fine to medium grained basalt, very often massive. In some places it is collumunarly jointed. In most places, where it is out cropped, the weathering activity gives this rock reddish brown color but the fresh specimen has dark-grey color. It is fine-grained volcanic rock composed of plagioclase, pyroxene, and opaque minerals (Geological Survey of Ethiopia, 2011). The constituents of these rocks type are predominantly sand, clay and gravel. Gravel formations are shown in to lower parts of the cross section, the upper part is clay, and sandy predominate. The thickness of the sediments in the region varies from 0-25 meters and their thickness is high in the western part of the town (Geological Survey of Ethiopia, 2011).

The geology map of the town was obtained from Geologic Survey of Ethiopia (GSE) in soft copy. The map was geo-referenced and then digitalized in GIS environment to utilize the raw data as information. Accordingly, 2 different geologic units of the study area were digitized and their thematic map was prepared. The geology type of the town as stated above Nazareth pyroclastic rocks and Tarmaber-Megezez Formation with the area coverage of 38.91 (48.73%) and 40.93 (51.27%) respectively.

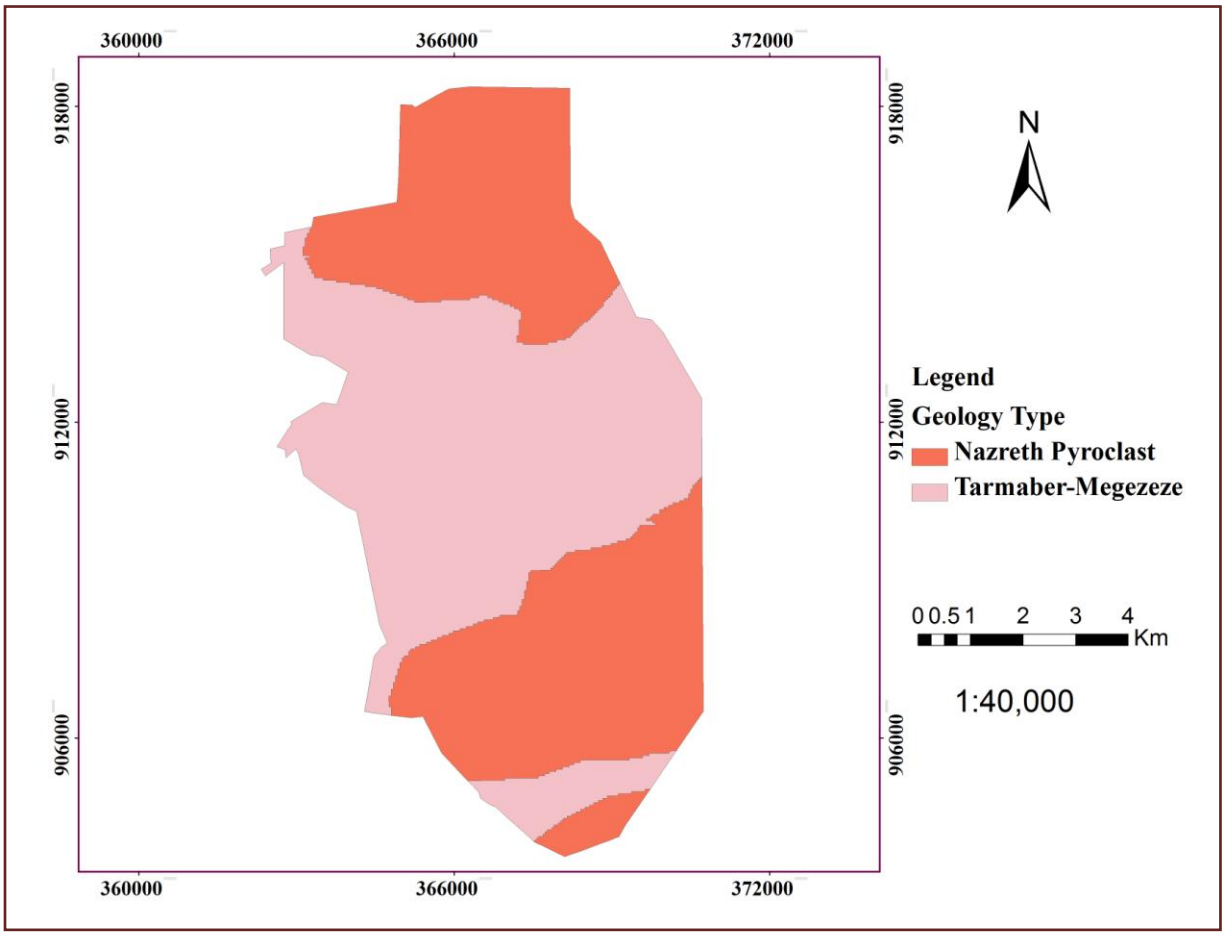


Figure 10: Geology map of the study area (Author, 2014)

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 instable 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 spatial analysis operation of GIS with extraction specifically selection is used. 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).

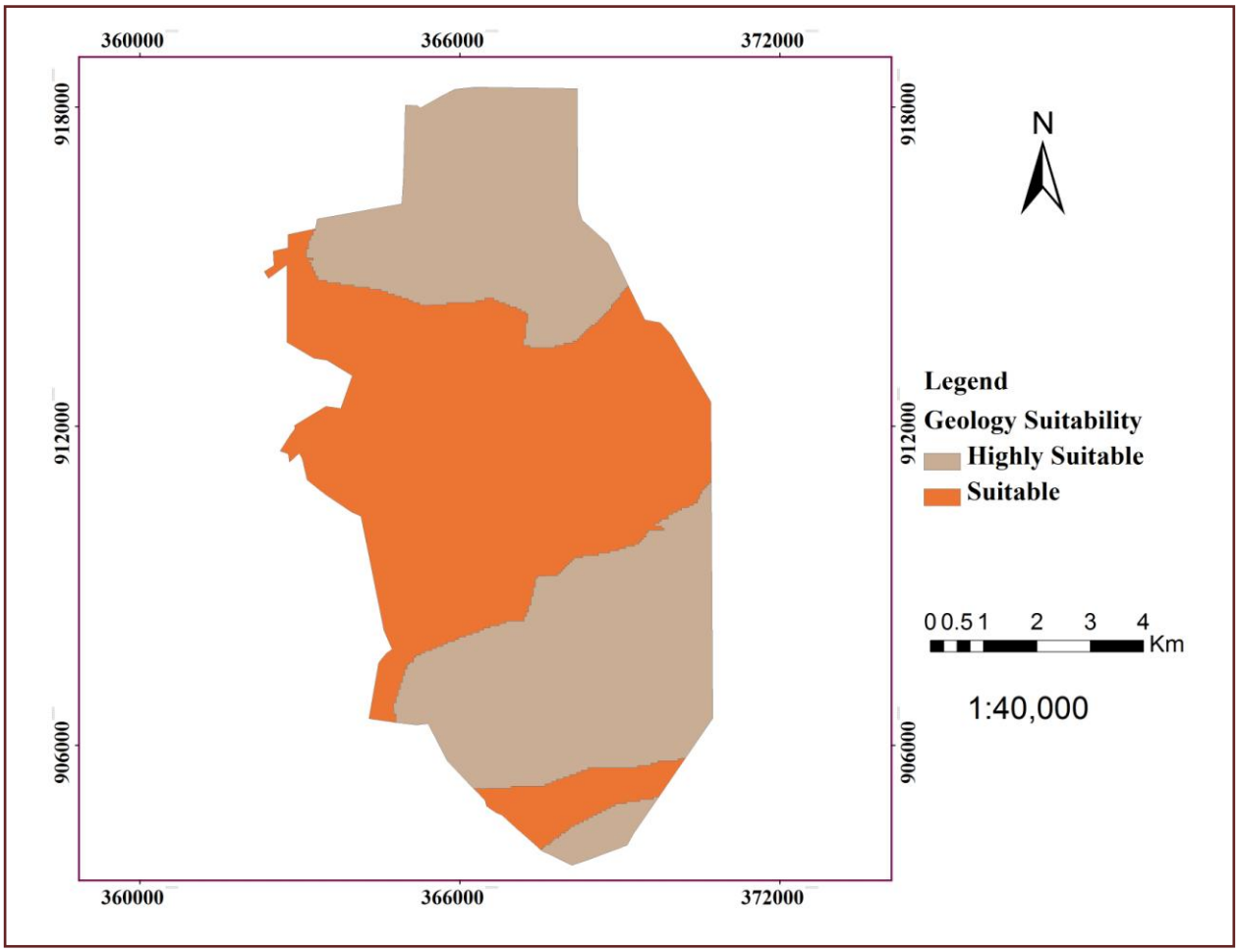


Figure 11: Geology suitability map of the study area (Author, 2014)

4.2.2. Soil criterion characteristics

The five soil forming factors namely climate (temperature and rainfall), topography, parent material, biological activities (flora and fauna) and time determine the types of soil that are formed at a particular area. 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 of Welkite is classified in to three major types namely Eutric fluvisols (10.47 km^2), Leptosols (9.89 km^2) and Pellic Vertisols (59.49 km^2). The dominant soil of the region is Pellic Vertisol (59.49 km^2) which is found in the southern and northern part of the town.

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 as follow.

1. Eutric Fluvisols

The reference soil group of the fluvisols accommodates genetically young, a zonal soils in alluvial deposits. The name fluvisols is a misleading in the sense that these soils are not confined to river sediments (fluvius means ' river') but occur also in lacustrine and marine deposits. It is a soil having a thickness of 25cm or more and fluvic soil material starting with in 50cm from the soil surface. It contains sand and clay with high porosity in nature. The permeability of eutric fluvisols is moderate as its texture is generally characterized as moderately fine size textured and with relatively less clay content than Vertisol (GSE, 2011).

2. Pellic Vertisols

They are important agricultural soils. They have high clay content and consequently a high moisture storage capacity. The PH is slightly acidic to neutral. These soils have high yield potential, but require proper fertility management. Vertisols are naturally fertile soils, but poor drainage and difficult workability because of limited nutrient availability. The most important characteristic of Vertisol is their high water holding capacity, a consequence of the deep profile and high content of clay. Because of its low porosity in nature it is very important to landfill construction with a thickness of more than 109 cm and it is characterized by fine textured soil with >60% clay in composition. As a result, the porosity of such soil is very fine making the movement of material difficult within the soil (GSE, 2011).

3. Leptosoil

Leptosoil in the FAO world reference base for soil resources is a very shallow soil over hard rock or highly calcareous materials or a deeper soil that is extremely gravelly or stony. It is very shallow, less than 10 cm deep (GSE, 2011). This type of soil is found in the centeral part of the study area. From its characteristics, this type of soil is not suitable for landfill construction due to its shallow depth underlined by hard rock and with less developed soil.

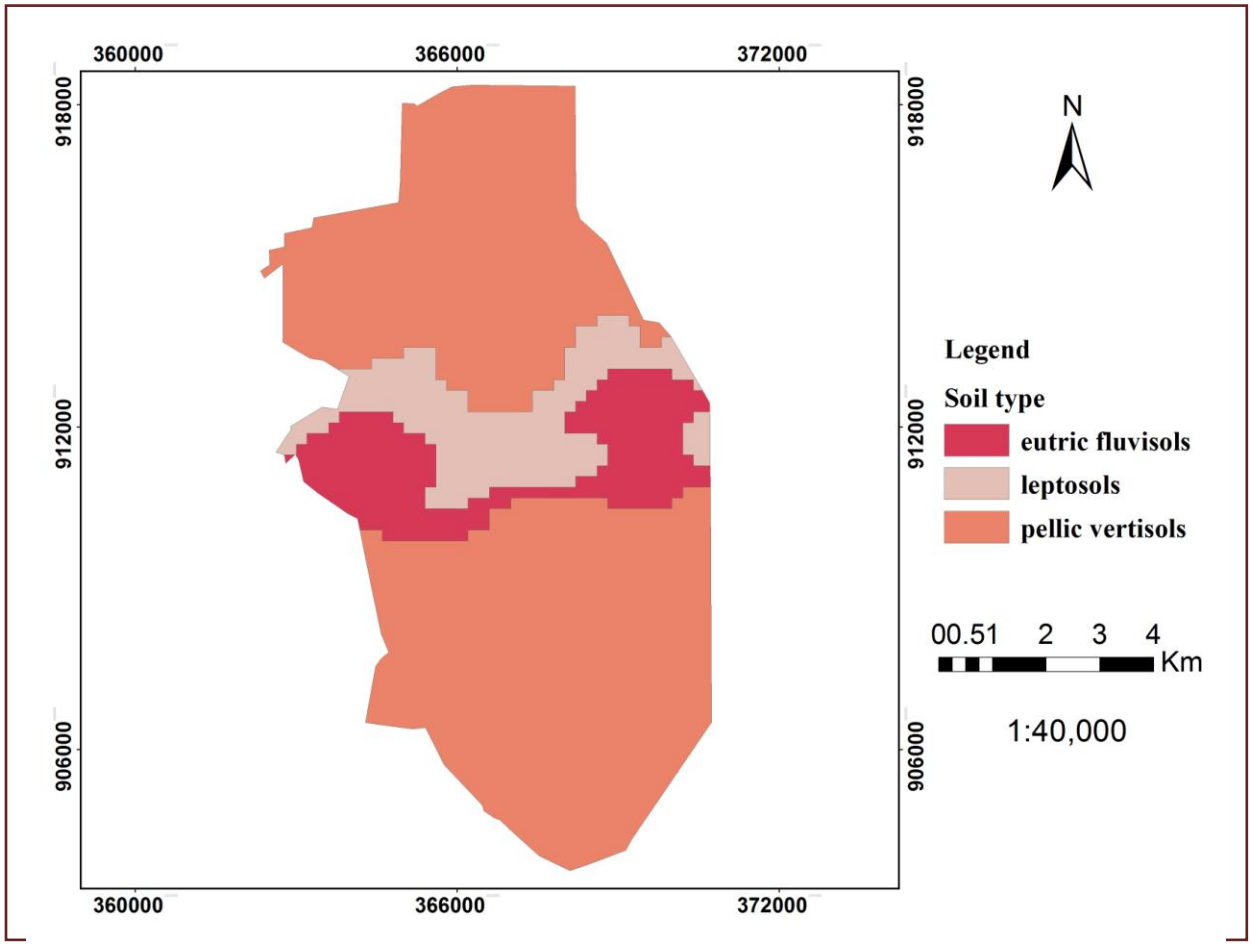


Figure 12: Soil map of the study area (Author, 2014)

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. In this study, Pellic Vertisols identified as highly suitable soil for landfill due to its clay dominated (60%) and very deep soil (Gizachew, 2011). Leptosols were identified as unsuitable soil types for landfill due to its coarser texture and shallow soil depth (Gizachew, 2011). The other soil type of the study area fall in between these extremities due to it's moderate depth and fine texture (GSE, 2011).

As shown in Fig12, most part of the study area is safe for landfill sitting due to low permeability. But for high permeability area, lining the base of landfill will be required to protect ground water from leachate contamination.

From the above soil map of the study area the next map is produced based on the criteria given by the municipality that states, 'the site must be on a suitable soil with 104 cm depth and cannot be easily penetrate by water.' Accordingly, Fig13. show the selected suitable soil map by applying selection operation of extraction from the spatial analysis function of GIS.

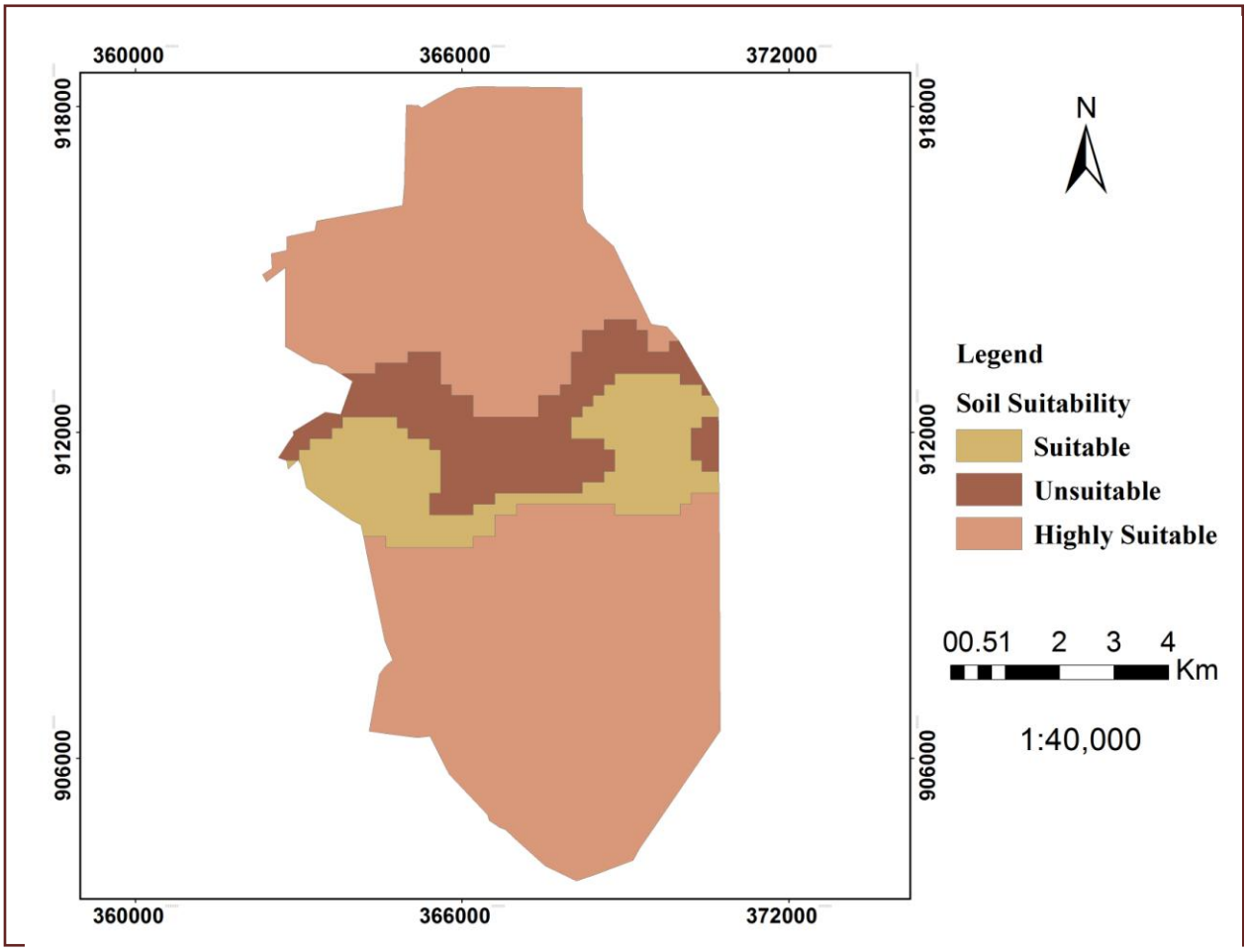


Figure 13: Suitable soil map of study area (Author, 2014)

Table2. Soil suitability of the study area

R.No	Soil Type	Suitability	Area cover (Km^2)	Area cover in (%)	Rank
1	Pellic Vertisols	Highely Suitable	59.5	74.52	5
2	Eutric Fluvisols	Suitable	10.46	13.10	3
3	Leptosols	Unsuitable	9.88	12.37	1
Total			79.84	100.0	

Accordingly, about 74.52% of the total area is highly suitable, 13.1% suitable and 12.37% unsuitable for landfill site.

4.2.3. Hydrology/Hydrogeology

4.2.3.1. Groundwater Well Proximity

The groundwater circulation and the downward flow of pollutants through rocks and soils are depending on the hydro geological condition of the materials more specifically hydraulic properties such as porosity, permeability, transivity etc (Tsegaye, 2006). The flow and chemical constituent of ground water are controlled by the type of lithology, distribution, thickness and structure of hydro geological units through which it moves (UNESCO, 1992 in Tsegay, 2006). Moreover the stresses due to tectonics and weathering govern the hydro geochemical characteristics of earth materials (Tamiru et al, 2005 in Tsegaye, 2006).

Proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection so that wells may be protected from the runoff and leaching of the landfill. Hence, solid waste disposal should be placed away from water wells. Otherwise, it can have irretrievable human and environmental effects.

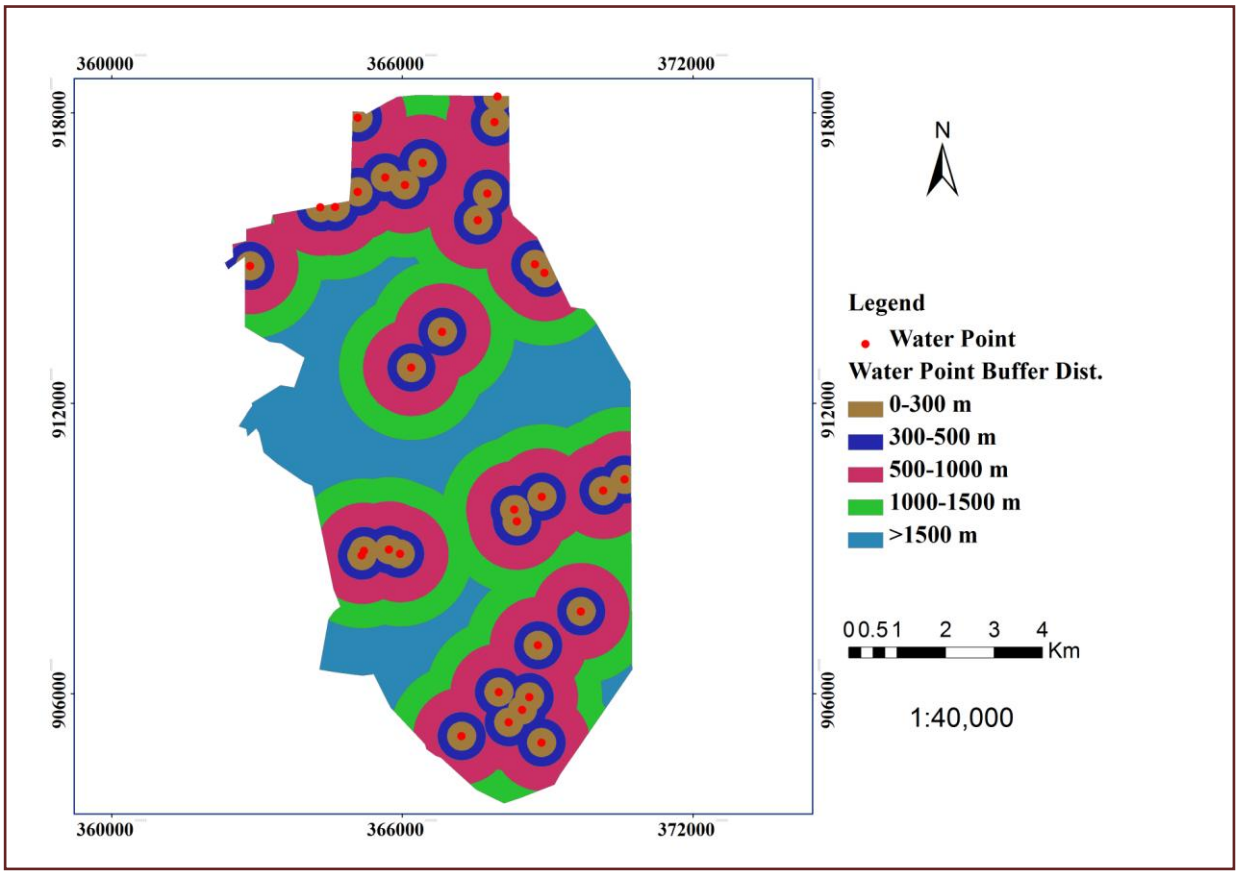


Figure 14: Groundwater well point map (Author, 2014)

As a result, proximity from groundwater well was considered as an important criterion for this research. Accordingly, 41 groundwater well points are currently functional, it was obtained from Ministry of Water, and Energy (MWE) and Multiple Ring Buffer tools were used to prepare buffer zones around each well. Chang et al. (2007) described as landfill should not be sited within 50m buffer distance from water wells.

However, Hasan et al. (2009) used 500- 1000m and Jamjan (2009) used 700m as a minimum distance from which landfill can be safely sited in (Gizachew, 2011). For this work, Multiple Ring buffering was performed around the wells in order to identify the best site for landfill.

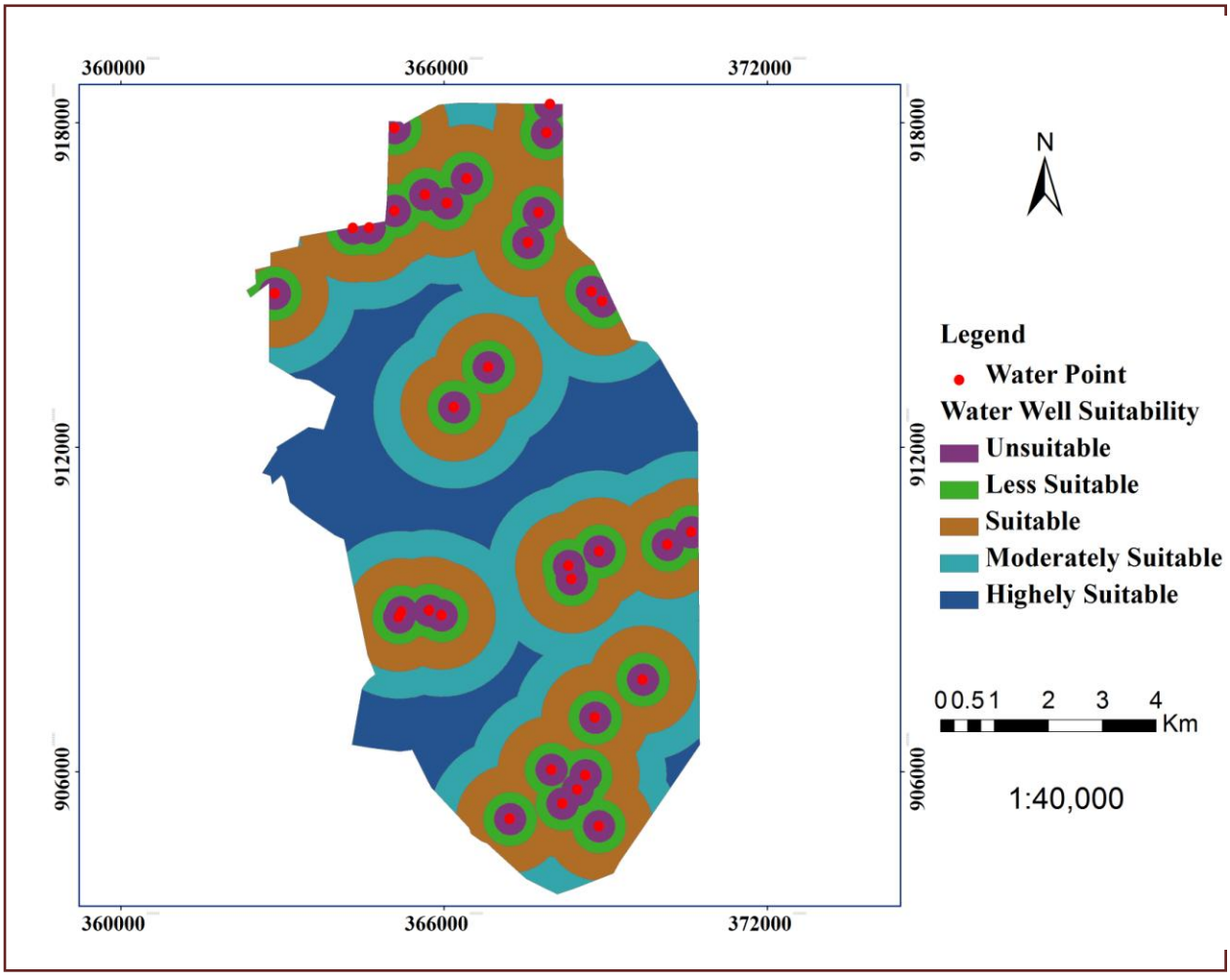


Figure 15: Groundwater well buffer map (Author, 2014)

Buffer distance of 0-300m, 300-500m, 500-1000, 1000-1500m and >1500m were prepared around each and every well points. As a result, the map is prepared and shows the suitable and unsuitable area based on this criterion.

Landfill very far from water well will have minimum effect and landfill very close to water well will have high effect. Generally, the more closely the landfill, the more probable for ground water to be contaminated. Areas with >1500m buffer distance were highly suitable and areas with 0-300m is the least.

Table3. Groundwater proximity suitability

R.No	Distance in (m)	Suitability	Area cover (Km^2)	Area cover in (%)	Rank
1	0 - 300	Unsuitable	7.63	9.56	1
2	300 - 500	Less Suitable	9.54	11.95	2
3	500 - 1000	Suitable	25.78	32.29	3
4	1000 - 1500	Moderately Suitable	19.68	24.65	4
5	>1500	Highely Suitable	17.21	21.56	5
Total			79.84	100.0	

Table 3 shows that 21.56% of the total study area is highly suitable for landfill from ground water proximity point of view and 9.56% is not suitable as they are in the vicinity of water wells. In addition, 24.65%, 32.29% and 11.95% of the study area are moderately, marginally suitable and less suitable respectively. Hence, the above groundwater suitability proximity map was prepared.

4.2.3.2. Surface water

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 m^2) 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 streams that flows towards south west of the town. These streams are used for drinking for humans and animals in the peripheral part of the town. Perennial and intermittent rivers and streams of the study area were generated from topographic map in GIS environment.

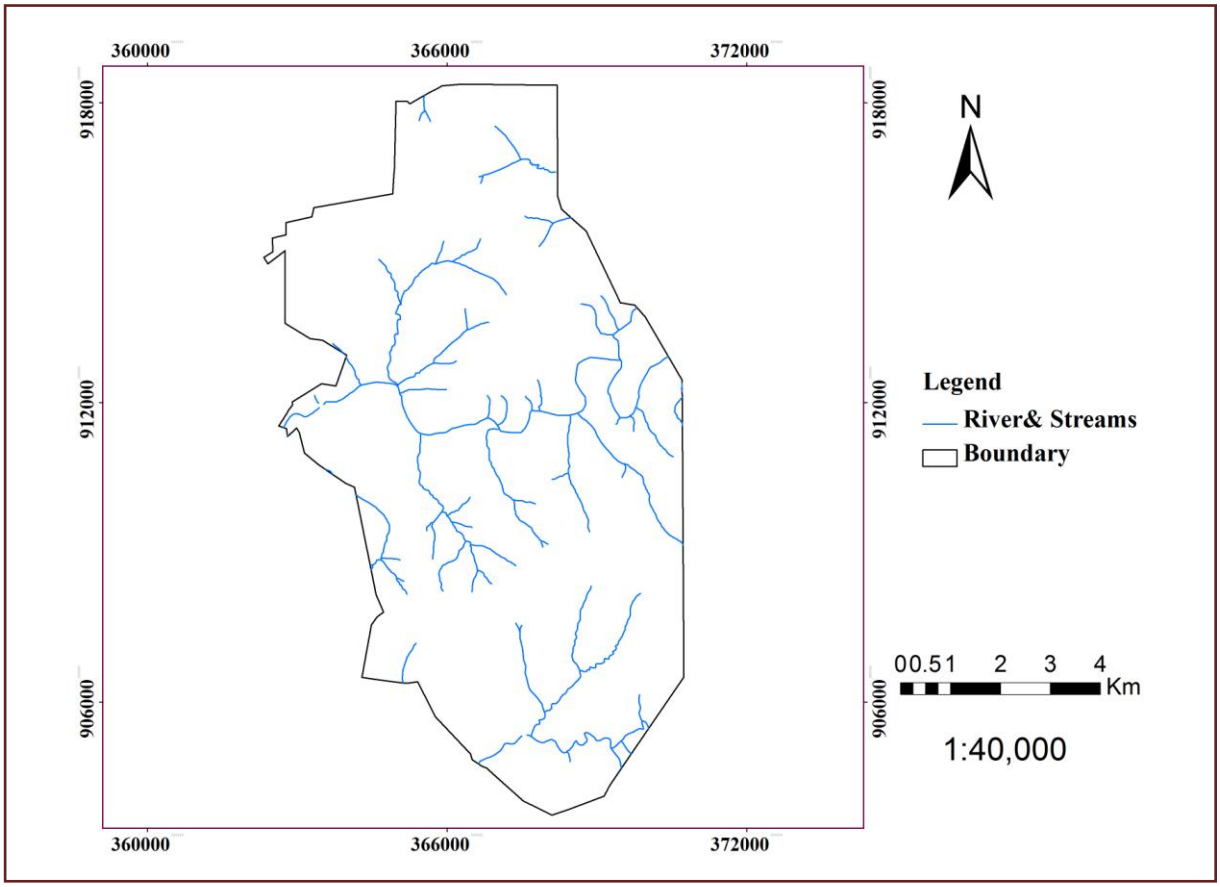


Figure 16: Drainage map of the study area (Author, 2014)

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. For example, Hasan et al. (2009) used 100 m buffer distance, UNEP (2005) & EPA (1995) used 300-500m as a minimum buffer distance while 300m minimum distance is set by Map Asia (2004), Ersoy and Bulut (2009) and Jamjan (2009). Furthermore, Akbari et al. (2008)

use 200m buffer distance. The further the distance from rivers and streams the more preferable area for landfill sited in (Gizachew, 2011).

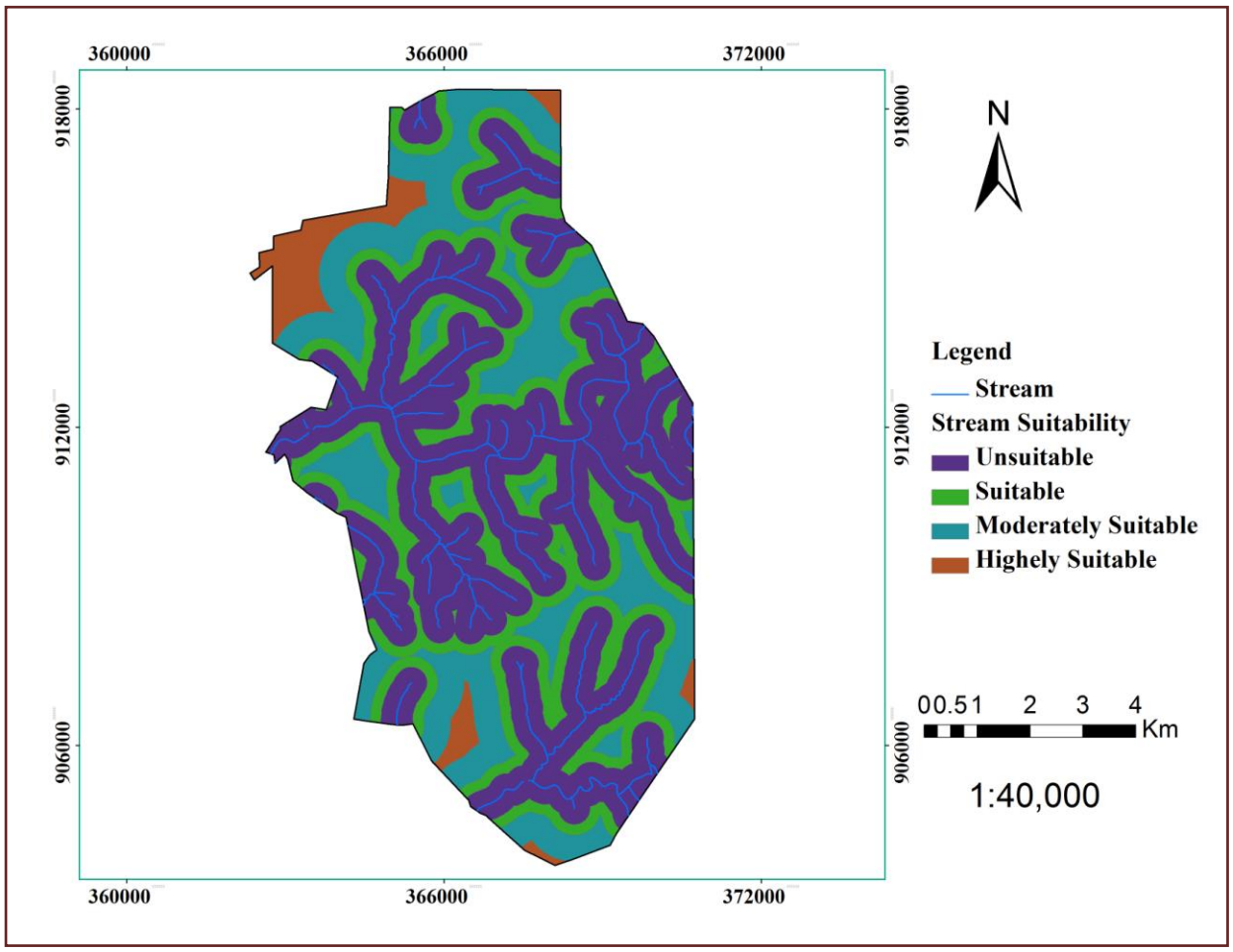


Figure 17: Drainage and streams buffer map (Author, 2014)

Accordingly, Multiple Ring Buffer from Analysis Tools was used to prepare multiple polygons around each streams and rivers within the following distances: 0-300,300-500, 500-1000, >1000m. To minimize the effect of landfill leachate on surface water pollution, 0-300 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.

Table4. Rivers and streams proximity suitability

R.No	Distance in (m)	Suitability	Area cover (Km^2)	Area cover in (%)	Rank
1	0 – 300	Unsuitable	40.41	50.61	1
2	300 - 500	Suitable	18.52	23.20	3
3	500 - 1000	Moderately Suitable	17.13	21.46	4
4	>1000	Highly Suitable	3.78	4.73	5
Total			79.84	100.0	

This buffering activity is performed by GIS technology from the above map of the study area and the next stream buffer map is produced. 50.61% of the study area was excluded from the sitting processes due to the vicinity to the streams and rivers and hence unsuitable for landfill. An extent of 4.73% of the area was highly suitable for landfill sitting because of the minimum effect on surface water. Moreover, 21.46% and 23.20% of the total areas were moderately and marginally suitable respectively.

4.2.4. Topographical criteria

The topography of an area is an important factor for site selection, structure integrity, and the flow of floods surrounding a landfill site because it has important implication for landfill capacity, drainage, ultimate land operations (Wilson, 1977, in Basak, 2004) is directly related to topography of a site. Flat and gently rolling hills that are not subjected to flooding are the best sites for landfill. However, this type of topography is also suitable for other land uses like agriculture, residential or commercial development that lead to higher land prices (Basak, 2004).

Depressions associated with unstable area should be avoided because they may cause to contamination of groundwater sources of drinking water. Other topographical depressions resulting from human activities, such as stone quarries, depths, and narrow piece cannot be suitable for landfills. If the floor of these depressions are typically consists of low permeable formations such as clay, siltstone, or shale are more suitable for landfills whereas sand gravel pits should be avoided according to permeability, except when the bottom formations are impermeable (Schwartz, 1997 in Basak, 2004).

4.2.4.1. Slope

The potential for slope breakdown is related to the degree or evaluation of the topography. Slope failure below or adjacent to landfills, will result in waste containment disappointment and release of debris into the surrounding area. Land with slopes greater than 15% should be considered unsuitable for waste disposal sites (Bagchi, 1994 in Basak, 2004).

Slope is an important factor in suitability site selection process because it governs the amount of surface runoff produced the precipitation rate and displacement velocity of water to the potential site in addition to the construction cost. It means that when the slope is gentle it decrease the construction cost as compared to the sharp slope area (Tsegaye, 2006).

As such a like importance and relationship between the topography of a given area to the landfill site selection process it is essential to discuss the topography of the study area. Welkite town is characterized by rugged topography with an average altitude of 1744 meter above sea level. The slope of the area is gentle morphology and flat lands topography in the northern, eastern and southeastern part of the town. The central part of the town lies on very sharp with few flat land. The slope map is generated from the digital elevation model with a resolution of 90 meter. Slope of the study area was calculated from DEM and used in GIS environment as a thematic map. Slopes were calculated and reclassified in GIS environment to identify the suitable and the unsuitable slope for landfill site. To make it appropriate for analysis the slope map is digitized and converted into vector format as follows. Accordingly, the region was classified in to five slope classes: 0-2.8%, 2.9-7%, 7.1-13%, 14-24% and >24%. Total area coverage and slope classes of the study area are shown in Table5.

Table5. Slope Classes and area coverage of the study area

R.No	Slope Class (%)	Area cover (Km^2)	Area cover in (%)
1	0-2.8	44.32	55.51
2	2.9-7	21.12	26.45
3	7.1 - 13	8.76	10.97
4	14 - 24	4.28	5.36
5	>24	1.36	1.70
Total		79.84	100.0

The topography of the region is dominated with slope of 0-2.8% which accounts 55.5% of the total area. However, only 1.7% of the area is with slope >24%, which is mainly found in the central part.

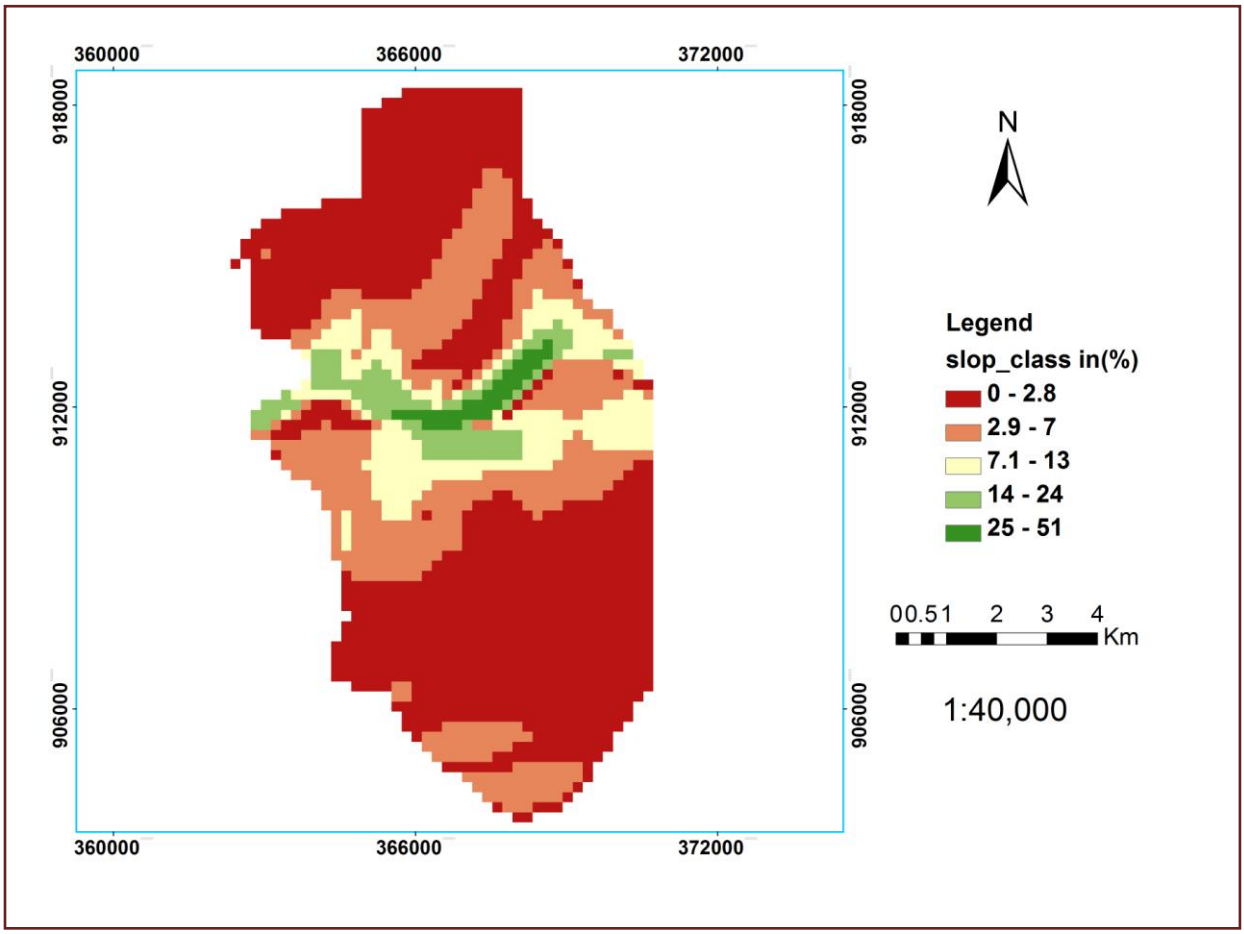


Figure 18: Slope map of the study area (Author, 2014)

As described in the previous section, slope is one of the key criteria to be considered in landfill site selection. This is because site topography can reduce or increase adverse effects of landfill on the environment (Centre for Advanced Engineering, 2000). Flat land and depression topography not recommended for landfill due to water logging problem and downstream surface and ground water pollution. Moreover, steep slope is either not best option for solid disposal because of the difficulty posed in construction or leveling, which incur additional cost. Moreover, high topography areas reduces the stability of the side slopes (increase risk of landslides) and increase leachate movement. Therefore, the best slope for solid landfill should be modest slopes, which enable easier storm water control, leachate control and site stability measures, as well as facilitating the operation of the site. Different researchers set different slope criteria for landfill site selection. For example, Hasan et al. (2009) set areas with slope <15-20% as the best site for landfill, while Change et al. (2007) describe slope <12% as the best site and slope >12% unsuitable for landfill. Moreover, Ersoy and Bulul (2009) state that areas with slope <20% is optimum site for landfills.

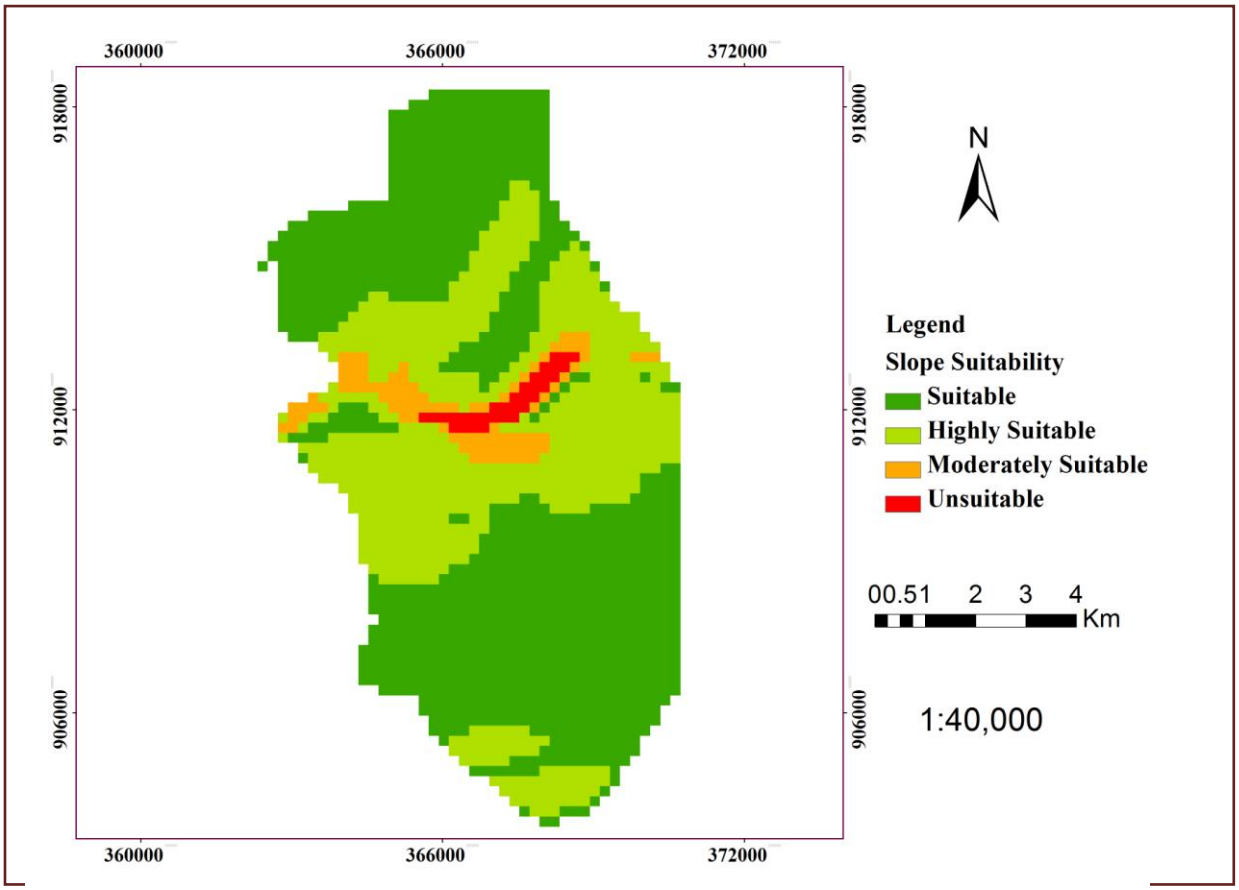


Figure 19: Slope suitability map (Author, 2014)

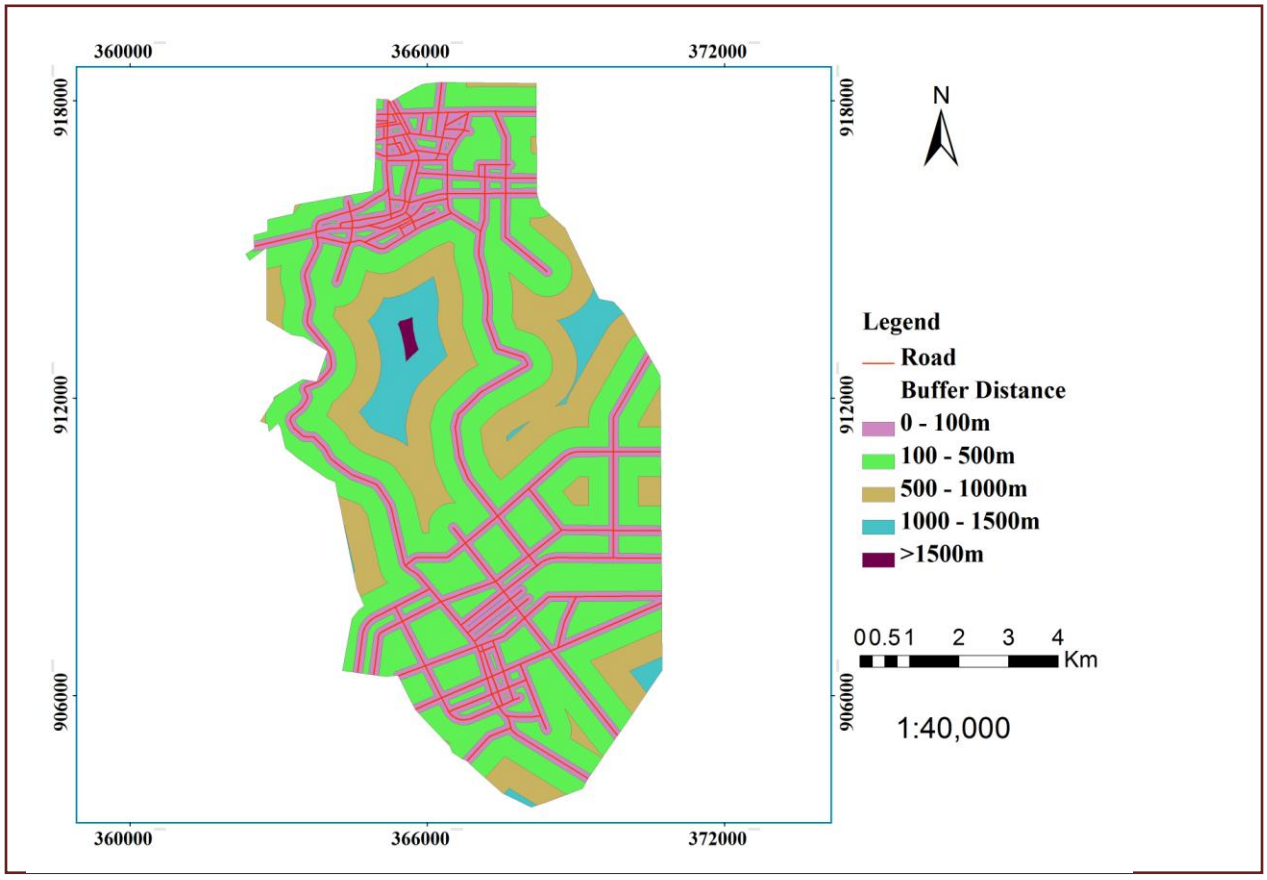
In this study, areas with slope >24% were excluded as it is unsuitable for landfill 3-15% slope was ranked in the first place and highly suitable, because of its optimum suitability for easy control of runoff and operation. Areas with 15-24% slope were the second option for landfill this is because as steepness increases, operation will be difficult and construction cost will increase and 0-3% slope class was ranked as the third option for landfill site due to water logging problem. The summary of slope class and their suitability are shown in Table 6.

Table6. Slope suitability classes and area coverage

R.No	Slope Class (%)	Suitability	Area cover (Km^2)	Area cover in (%)	Rank
1	0-3	Suitable	45.76	57.31	3
2	3 -15	Highly Suitable	29	36.32	5
3	15 – 24	Moderately Suitable	3.76	4.71	4
4	>24	Unsuitable	1.32	1.65	1
Total			79.84	100.0	

4.2.4.2. Proximity from Road

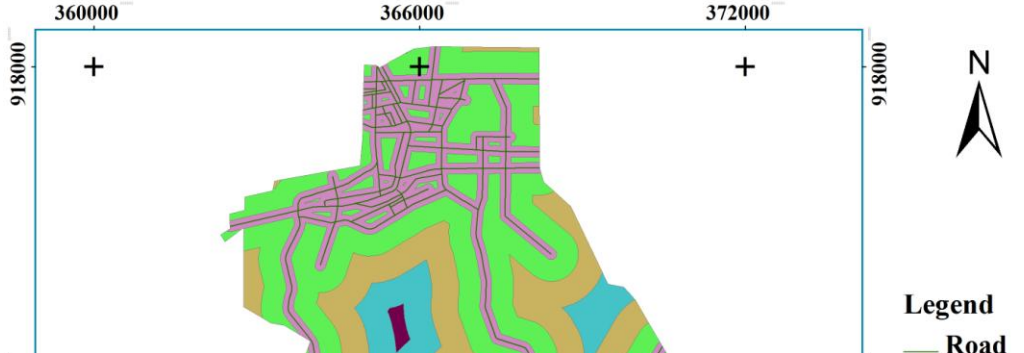
A road is one of the criteria that should be considered from economic and social point of views during solid waste landfill site selection processes. This is because sitting landfill very close to roads may have public health problem as landfill can have hazardous effect to health. Moreover, landfill 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 sited in (Fesseha, 2012). Chang et al. (2007) set 75m buffer while Hasan et al. (2009) uses 50-100m buffer from road as a minimum distance within which landfill should not be located. However, 100m buffer distance is mentioned as the safest distance (Map Asia, 2004; Zain, 2009; Yahaya, 2010; Ersoy and Bulut, 2009; EPA, 1995 in Fesseha, 2011). For this study, Multiple Ring Buffer tools were used to create buffer classes around the roads with 0-100m, 100-500m, 500-1000m, 1000-1500m and >1500m distance ranges as we see in the figure below (Fig.20).



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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. Accordingly, 0-100m and >1500m buffer distances were unsuitable and less suitable respectively. But, the areas, from 100m to 1500m, were given suitability according to their preference. The highly suitable site is 500-1000m radius from the roads; moderately suitable site is 100-500m. Generally, for areas between 500-1500m suitability decreases with increasing distance. This is due to increased transportation cost and inaccessibility of the area. Table 6 summarizes weight assigned and suitability level with their area coverage.

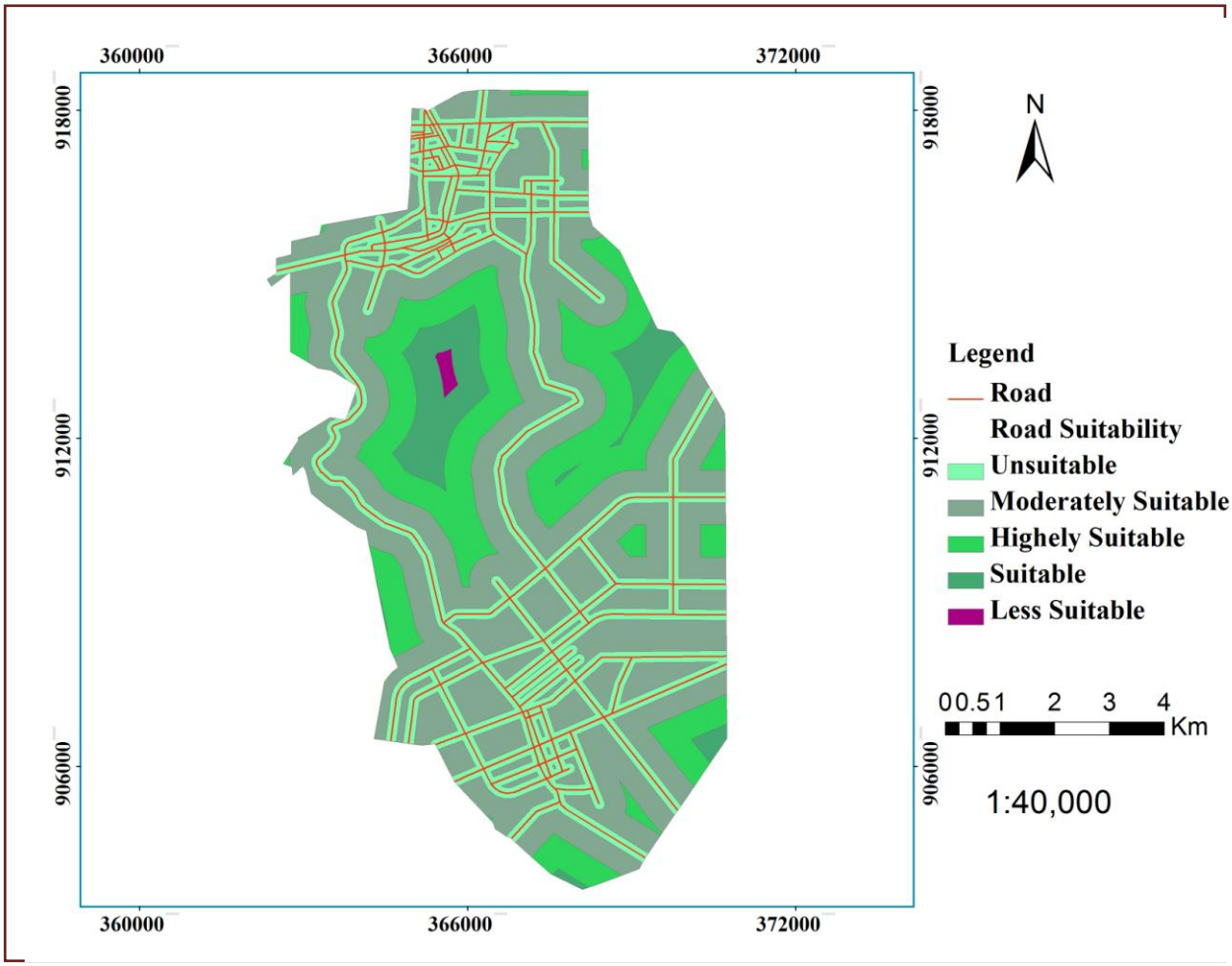


Figure 21: Road network suitability buffer map (Author, 2014)

Table7. Road network suitability of the study area

R.No	Distance in (m)	Suitability	Area cover (Km^2)	Area cover in (%)	Rank
1	0 – 100	Unsuitable	21.86	27.38	1
2	100 – 500	Moderately Suitable	37.82	47.37	4
3	500 – 1000	Highly Suitable	15.7	19.66	5
4	1000 – 1500	Suitable	4.27	5.35	3
5	>1500	Less Suitable	0.19	0.24	2
Total			79.84	100.0	

Table 6 shows 19.66% of the total areas is highly suitable while, 27.38% is unsuitable for landfill. However, 47.37%, 5.35% and 0.24% are moderately suitable, suitable and less suitable for landfill sitting.

4.2.4.3. Proximity from Built-up area

Proximity of a landfill to a built-up is an important environmental criterion in the landfill site selection. Built-up area includes settlements, commercial areas, governmental and private institutions, schools, health centers, religious institutions, educational institutions and other social services area. Hence, solid waste disposal should be placed away from built-up areas. Otherwise, it can have irretrievable human and environmental effects. As a result, proximity from built-up was considered as an important criterion for this research.

When we see the built-up condition of the study area about 24.9 km^2 of the total area is covered by built up area, it includes settlements, commercial areas, governmental and private institutions, schools, health centers, religious institutions, educational institutions and other social services area. The land use land cover map is obtained from the structural plan of Welkite town and Multiple Ring Buffer tools were used to prepare buffer zones around the built-up area. Built-up cover of the study area is shown as in Fig.22.

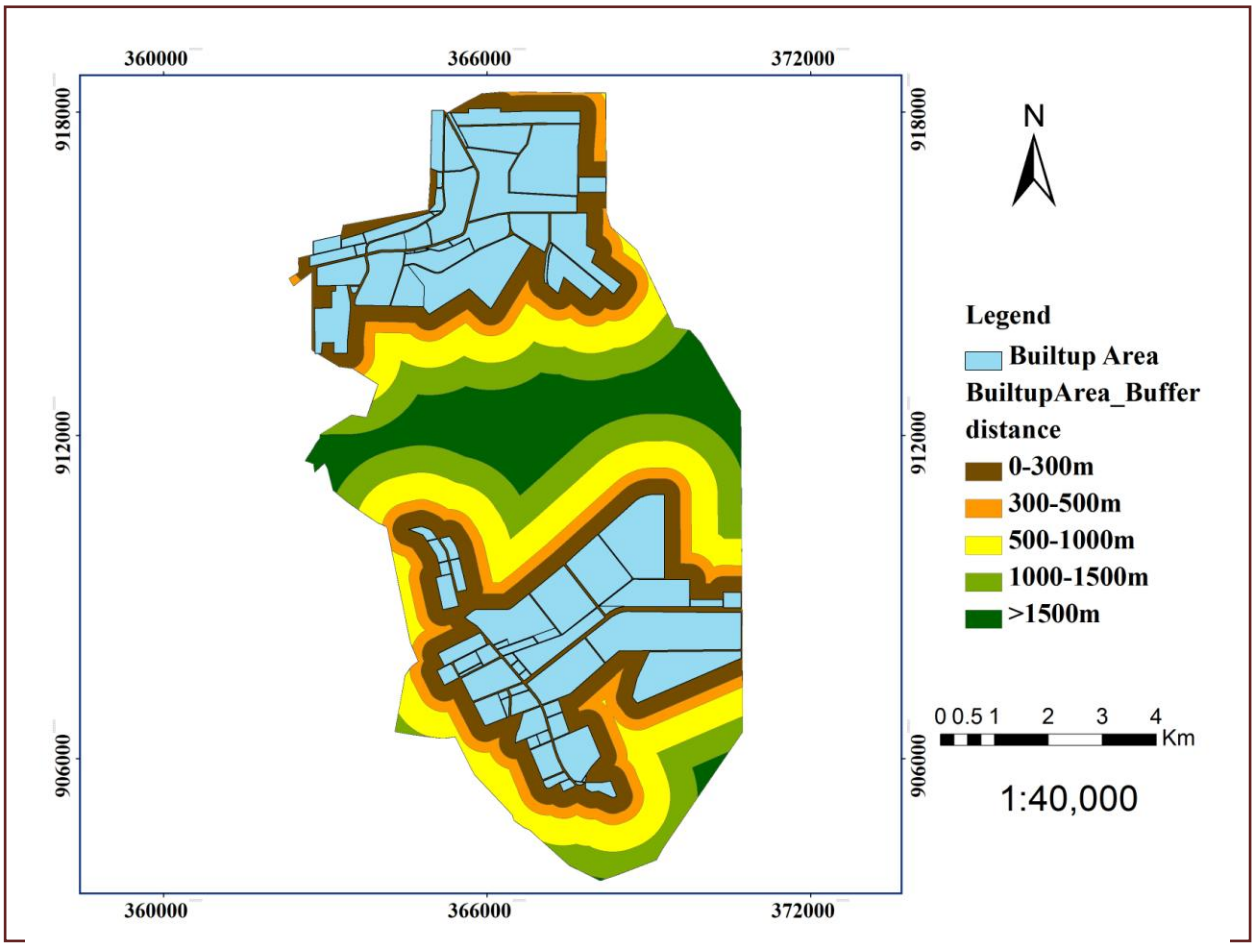


Figure 22: Built-up Proximity buffer map (Author, 2014)

With regard to land use land cover of the study area, there are different criteria as no major lines of electrical transmission or other infrastructure (i.e. gas, sewer, water lines) cross the landfill cell development area, unless the landfill operation would clearly cause no concern or rerouting is economically feasible. To minimize the risk a buffer of 500 meter should be done. Nevertheless, due to lack of data about these infrastructures they are considered as a built-up socio economic services. The landfill site must be one kilometer far from settlements, religious areas, educational areas and other social activities. In addition, the site should be constructed in areas that do not have an important economic or ecological value. Different researchers set different built-up criteria for landfill site selection. For example, Hasan et al. (2009) set built-up areas with distance between 500-2000m as the best site for landfill, while Change et al. (2007), Map Asia (2004), Yahaya (2010), Ersoy and Bulut (2009), EPA (1995) & UNEP (2005),

describe built-up distance 3000m as the best site and built-up distance <3000m unsuitable for landfill.

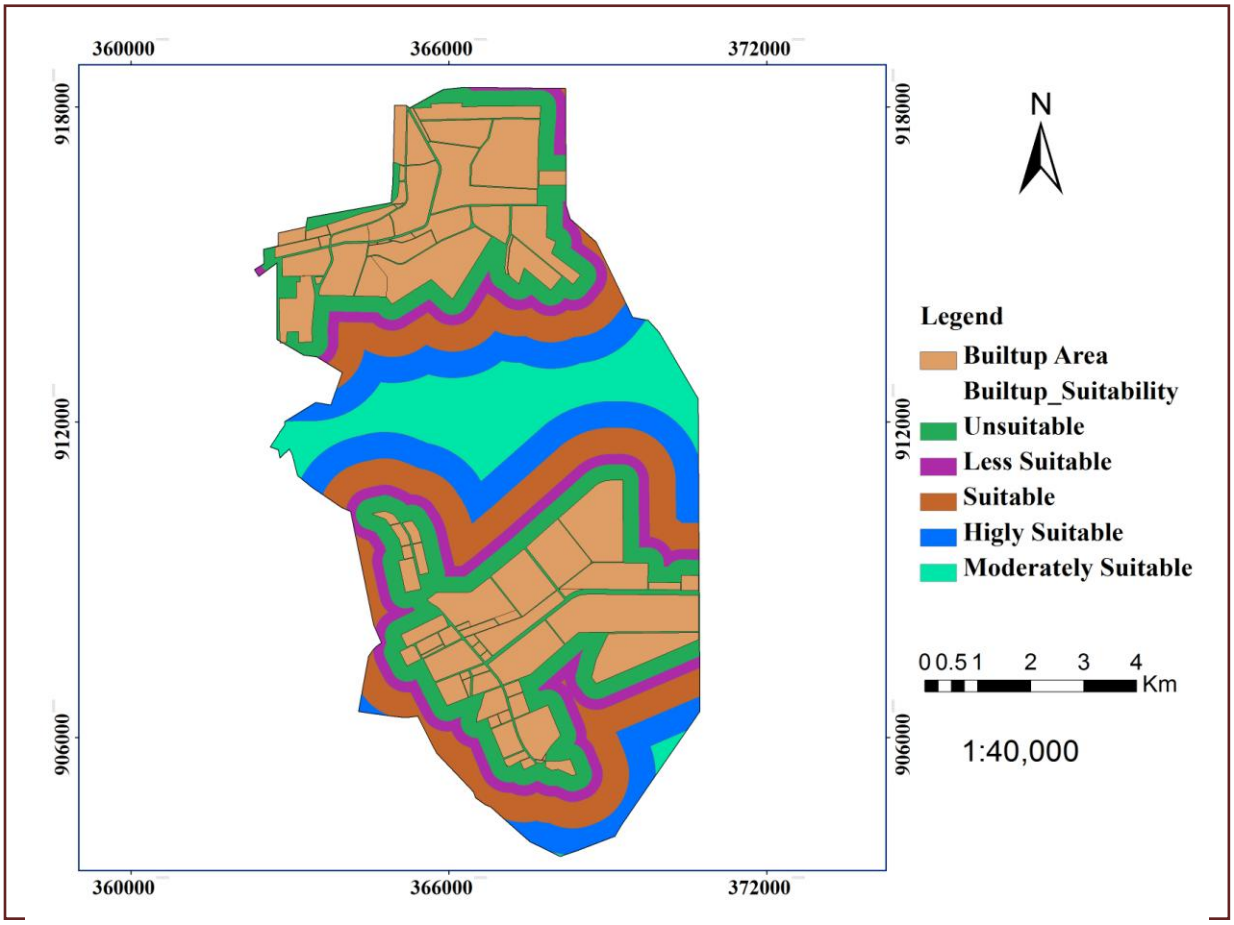


Figure 23: Built-up suitability buffer map (Author, 2014)

Accordingly, researchers set different built-up distance suitability, in this project used different built-up suitability distance as, >500m proximity from built-up area. However, built-up suitability distance <500m considered as less suitable to unsuitable for landfill site.

Table8. Built-up suitability of the study area

R.No	Distance in (m)	Suitability	Area cover (Km^2)	Area cover in (%)	Rank
1	0 - 300	Unsuitable	40.05	50.16	1
2	300 - 500	Less Suitable	7.02	8.79	2
3	500 - 1000	Suitable	13.15	16.47	3
4	1000 - 1500	Highly Suitable	10.53	13.19	5
5	>1500	Moderately Suitable	9.09	11.39	4
Total			79.84	100.0	

Table 6 shows 13.19% of the total areas is highly suitable while, 50.16% is unsuitable for landfill. However, 11.39%, 16.47% and 8.79% are moderately suitable, suitable and less suitable for landfill sitting respectively.

4.3. Potential Landfill Sites Thematic Map

4.3.1. Assigning Criteria Weights

One of the components of GIS-Based Multi Criteria Evaluation (MCE) methodology is assigning criteria weights for each factor maps. The purpose of weighting in landfill site selection process is to express the importance or preference of each factor relative to other factor effect on landfill sitting. 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 1. Accordingly, in IDRISI, the weight module utilizes the pair-wise comparison technique to help develop a set of factor weights that will sum to 1.0 (Table.9). In AHP, weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved at a time, in determining suitability for the stated objective. Accordingly, all possible combinations of two factors were compared based on expert judgment to prepare a pair-wise comparison matrix from which the module calculates a set of weights and consistency ratio. This ratio is very important as it shows any inconsistencies that may have arisen during the pair-wise comparison process. Fig.24. reveals the AHP weight derivation interface to derive the weights, with its consistency ratio, for solid waste landfill site selection.

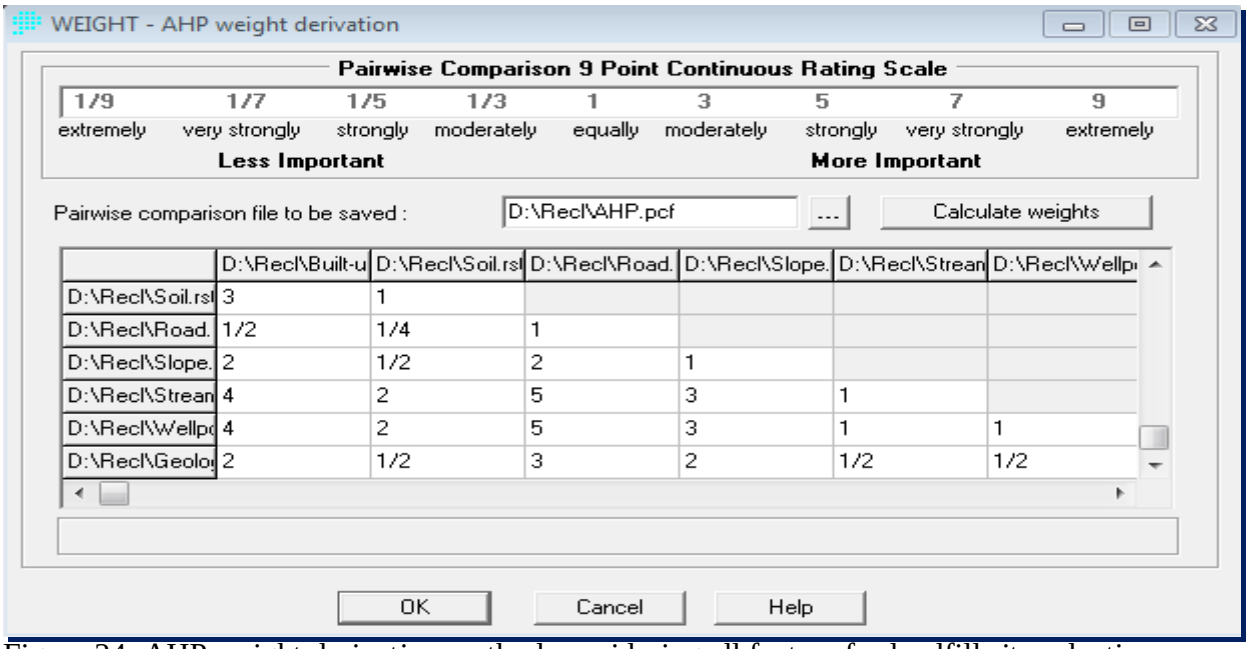


Figure 24: AHP weight derivation method considering all factors for landfill site selection (Author, 2014)

Based on this AHP weight derivation module, the following eigenvectors of weights for all factors considered for landfill site selection are generated (Table 9).

Table9. Factors and their eigenvectors weights for landfill sitting

	Built-up	Soil	Road	Slop	Stream/R	Well point	Geology	Weights	Weights(%)
Built-up	1							0.0617	6.2
Soil	3	1						0.1699	17.0
Road	1/2	1/4	1					0.0428	4.3
Slop	2	1/2	2	1				0.0865	8.7
Stream/R	4	2	5	3	1			0.2568	25.7
Well point	4	2	5	3	1	1		0.2568	25.7
Geology	2	1/2	3	2	1/2	1/2	1	0.1255	12.6
Total								1.00	100.0

Consistency Ratio = 0.01<0.1 = ➪acceptable

Using Pair-wise Comparison Matrix, factor weights are calculated by comparing two factors at a time using a scale with values from 1/4 to 5. A rating of 1/4 indicates that relative to the column factor, the row factor is less important. On the other hand, a rating of 5 indicates that in relation to the column factor, the row factor is more important. In cases where the column and row factors are equally important, they have a rating value of 1. When we see the intensity of importance 3 for example indicate that one variable is slightly important over the other variable

being compared, on the other hand 5 indicate that one variable is strongly important over the other variable being compared. Accordingly, the higher the weight, the more influence a particular input will have in the suitability model.

4.3.2. Landfill Suitability Analysis Results

The importance's of environmental factors like geology and soil permeability, hydrological factors such as proximity from groundwater well and streams/rivers and topographic factors such as slope and land uses, for determining landfill sites are not the same. The analysis of the weight assignment shows that ground and surface water related factors like soil permeability, proximity from wells and streams/rivers are more influential than the other factors (Table 9), as they are very important to protect water pollution from landfill leachate. Weighted Linear Combination result showed four classes of suitability levels. These are unsuitable, suitable, moderately suitable and highly suitable. As the overall suitability result shows there is no area that fulfills the very highly suitable criteria. This indicates that there is no parcel of land that is very highly suitable in all the seven criteria considered. The area coverage of each suitability class was calculated in GIS environment after converting raster map to vector. The result showed 49.64km^2 (62.17%) of the study area is unsuitable as the areas are environmentally unfriendly, socially unacceptable and economically unfeasible for landfill. The unsuitable area includes built up and vegetation cover, steep slope (>24%), areas close to road, groundwater well and rivers/streams. The main purpose is to protect human health and environment from potential effects of landfill and as well to minimize the cost of construction and waste transportation. However, 8.04km^2 (10.1%) of the area satisfies the environmental, social and economical criteria set in the previous section and hence identified as highly suitable. These areas are preferable land for landfill cover because of their minimum effect on environment and public health and cost effective than other parts of the area. 22.16km^2 (27.75%) of the study area is moderately suitable for landfill. The moderately suitable areas can be used for landfill site with some careful management system such as lining the base of landfill so as to minimize their negative effects on the environment and public health.

Most of the suitable landfill sites were identified in the southern and south eastern part of the study area of the town (Fig.25.). The central part of the town, which is at high elevation, is excluded from sitting landfill as it is the recharge area for the low-lying area.

Moreover, the central and northern part of the town is believed to be the potential source of ground water for the town and the surrounding, hence not allowed for landfill site. Therefore, the northern and central parts of the town are excluded for landfill site so as to protect water pollution.

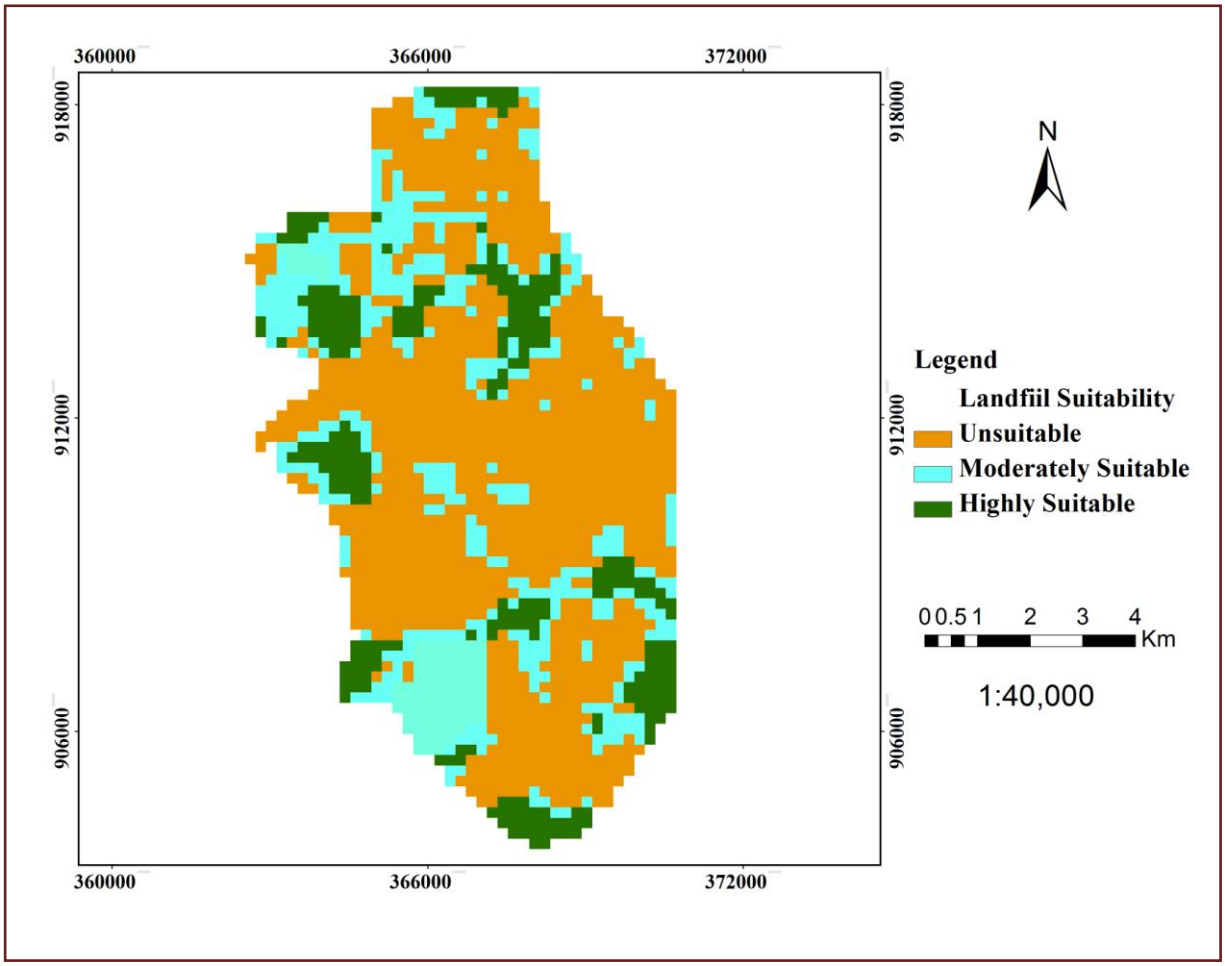


Figure 25: Landfill Sites Suitability map (Author, 2014)

4.4. Evaluating Candidate Landfill Sites

Socio-economic criteria like size of the site, distance from nearby settlements and distance from the center of the town are the determinant criteria used to evaluate potential landfill site so as to choose the best suitable. 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. 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 less than 0.3km^2 and those sites occurred in built-up area due to high weight of other factors are economically and environmentally not feasible and hence excluded from further analysis. The rest sites with area greater than 0.3km^2 are preferable and selected to further evaluation with the previously set criteria. Accordingly, the result of the analysis shows 9 landfill sites are selected for further evaluation.

The analysis of candidate landfill sites with the previously used criteria like geology, slope, land use/land cover, soil permeability, proximity from road, stream and well are shown in Table 10.

Table10. Analysis of candidate landfill sites with the previously used landfill sitting criteria

Criteria	Landfill Sites									Suitability
	LF-1	LF-2	LF-3	LF-4	LF-5	LF-6	LF-7	LF-8	LF-9	
Built-up	0.3-1.0	>1.5	1.0-1.5	0.3-1.0	0.3-0.5	>1.5	0.5-1.5	>1.5	>1.5	Ms-H
Soil	PV	PV	PV	PV	PV	EF	PV	PV	PV	M-H
Slope	3-15	3-15	3-15	3-15	3-15	3-15	3-15	3-15	3-15	M-H
Road	0.1-0.5	0.5-1.0	>1.5	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5	0.5-1.5	0.5-1.5	M-H
Water point	1.0-1.5	0.5-1.5	1.0-1.5	>1.5	0.5-1.0	>1.5	>1.5	1.0-1.5	1.0-1.5	M-H
Stream/Riv	0.5-1.0	1.0-1.5	0.3-1.0	0.5-1.0	>1.0	0.5-1.0	0.5-1.0	0.5-1.0	0.5-1.0	M-H
Geology	NP	NP	TM	TM	NP	TM	NP	NP	NP	Ms-H

Note: PV= Pellic vertisol, EF= Eutric fluvisol, TM= Tarmaber Megezez, NP= Nazreth Pyroclast LF1=Landfill 1, LF2=Landfill 2, LF3=Landfill 3, LF4=Landfill 4, LF5=Landfill 5, F6=Landfill 7, LF 8=Landfill 8, LF9=Landfill 9, Ms= Marginal suitable, M= Moderate and H= High suitable.

The main reason to do so is to check whether the suitable landfill sites were in suitable area with respect to each criterion used. The results of the analysis showed that the suitability level for most of the landfill sites range from highly to moderately suitable for most landfill sites except that there is some part of landfill sites that fall in low and marginal suitability level. However, even most parts of these landfill sites are highly to moderately suitable from those criteria point of views.

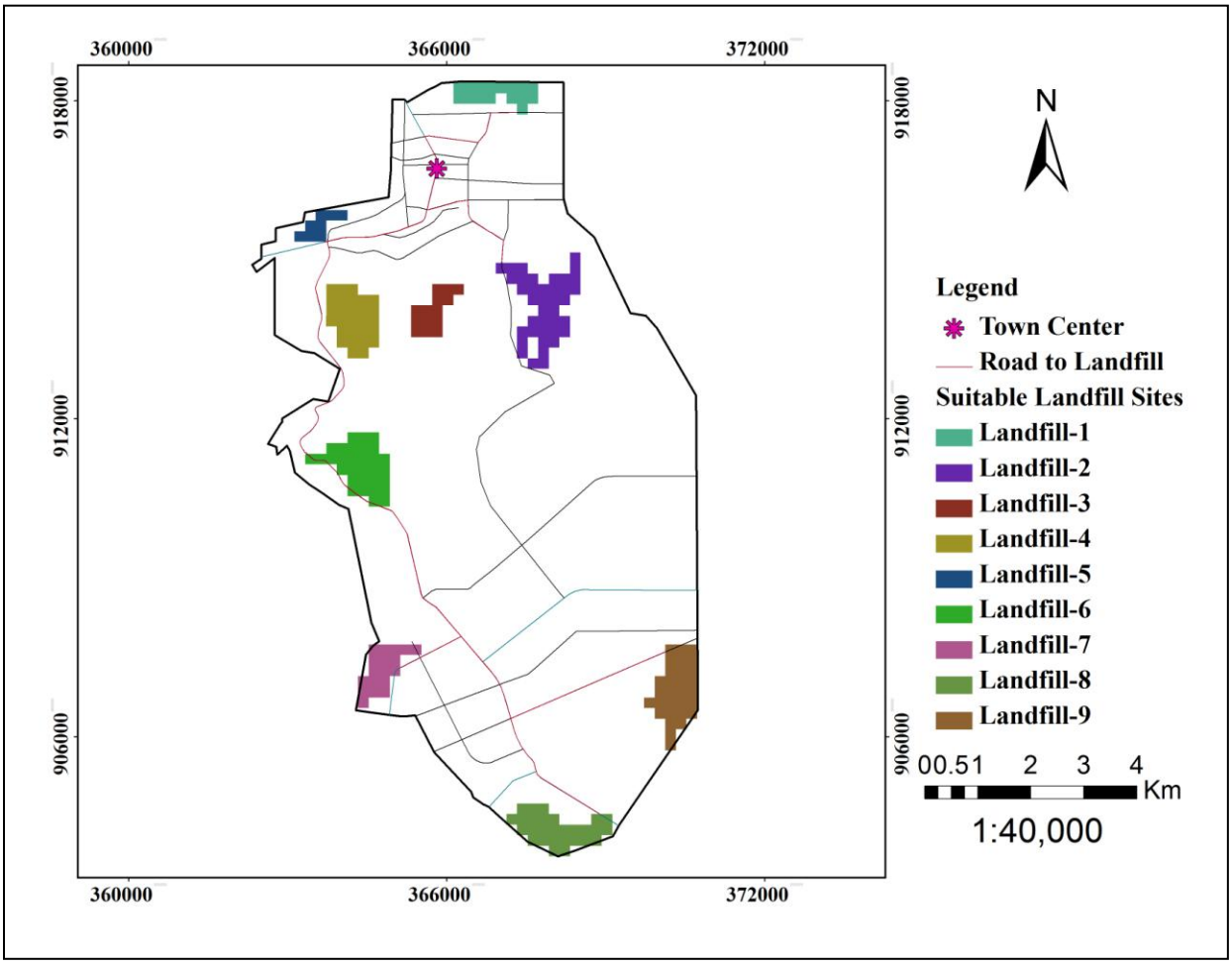


Figure 26: Suitable Landfill Sites Map (Author, 2014)

For evaluating landfill site, distance from the center of the town is also another very important criterion from economic point of view. Landfill far from the center of the region is not preferable due to high transportation cost that will be incurred during its life time. Therefore, site close to the center of the town is more preferable than far sites. The analysis of all the candidate landfill sites with shortest path following the roads showed that, landfill site 1 is close 2.8km to the center than other sites while landfill 7, 8 and 9 are far compared to the rest of the sites. They are 13.69km, 16.98km and 17.43km away from the center of the town. Hence, from transportation point of view, landfill site 1 is the most suitable landfill of all candidate sites. However, landfill should not be located near settlement area as it poses negative impact on human health.

Evaluation of candidate landfill sites with the distance from the nearby settlement area can minimize such effects. Accordingly, the analysis of the sites with distance from the nearby settlements in GIS environment shows that landfill site 6 is the safest site as it is far 4.26km from nearby settlement area. However, landfill site 1 is located near settlement <1km and thus unsuitable to be used for solid waste disposal in this point of view. In addition, evaluation of candidate sites in relation to their size shows that landfill site 2 and 4 with area coverage of 1.56km^2, are equally the most suitable sites as it will serve for longer years while landfill site 5 is less suitable due to its smaller area 0.32km^2.

Table11. Candidate landfill sites with respect to those evaluating criteria value

List of landfill sites	Area(km^2)	Distance from Center(km)	Distance from nearby settlement (km)
Landfill-1	0.64 km^2	2.8 km	0.6 km
Landfill-2	1.56 km2	3.13 km	2.1 km
Landfill-3	0.56 km2	5.13 km	1.43 km
Landfill-4	1.12 km2	4.15 km	1.28 km
Landfill-5	0.32 km2	2.94 km	0.39 km
Landfill-6	1.24 km2	7.6 km	4.26 km
Landfill-7	0.72 km2	13.69 km	1.28 km
Landfill-8	1.12 km2	16.98 km	1.78 km
Landfill-9	1.2 km2	17.43 km	2.37 km

As described above, the criteria are conflicting to each other for example distance from town center and distance from nearby settlement area. MCE solves such decision problems so as to choose the most suitable landfill site/s by considering all the three criteria at a time for the entire candidate landfill site.

AHP weight derivation method for other evaluation criteria such as area of landfills, distance from nearby settlement area and distance from center is shown in Table 12. The result of weight assignment shows the importance of those criteria, size is more important for evaluating landfill sites.

Table12. Pair wise comparison matrix

	Size of landfill	Distance from center	Distance from nearby settlement	Weight	Weight (%)
Size of a landfill	1			0.5400	54.0
Distance from center	1/3	1		0.1633	16.0
Distance from nearby settlement	1/2	2	1	0.2967	30.0
Total				1.00	100.0

CI = 0.07, RCI =1.45 CR =0.05<<0.1 where CI, Consistency Index, RCI, Random Consistency Index and CR for Consistency Ratio

The analysis of all the candidate landfill sites with respect to those evaluating criteria is shown in Table 13.

Table13. Comparison of the calculated weight for each candidate landfill sites with each of the criteria

Size	LF_1	LF_2	LF_3	LF_4	LF_5	LF_6	LF_7	LF_8	LF_9	Weight	Weight (%)
LF_1	1									0.07107	7.1
LF_2	3	1								0.22661	22.7
LF_3	½	1/4	1							0.04511	4.5
LF_4	2	1/2	3	1						0.12669	12.7
LF_5	1/3	1/5	1/2	1/5	1					0.02978	3.0
LF_6	3	1/2	4	1	5	1				0.15969	16.0
LF_7	1	1/3	2	1/2	3	1/2	1			0.0738	7.4
LF_8	2	1/2	2	1	3	1/2	2	1		0.11461	11.5
LF_9	2	1/2	4	2	5	1	2	1	1	0.15264	15.3

Distance from Center

DfC	LF_1	LF_2	LF_3	LF_4	LF_5	LF_6	LF_7	LF_8	LF_9	Weight	Weight (%)
LF_1	1									0.23063	23.1
LF_2	1/5	1								0.15463	15.5
LF_3	1/3	1	1							0.12152	12.2
LF_4	1/2	1	1	1						0.13993	14.0
LF_5	1	1	2	1	1					0.19099	19.1
LF_6	1/3	1/3	1/2	1/2	1/3	1				0.06423	6.4
LF_7	1/5	1/5	1/4	1/4	1/6	1/2	1			0.03353	3.4
LF_8	1/6	1/5	1/4	1/5	1/6	1/2	1	1		0.03188	3.2
LF_9	1/6	1/5	1/4	1/4	1/6	1/2	1	1	1	0.03265	3.3

Distance from nearby settlement (DfS)

DfS	LF_1	LF_2	LF_3	LF_4	LF_5	LF_6	LF_7	LF_8	LF_9	Weight	Weight (%)
LF_1	1									0.03887	3.9
LF_2	4	1								0.14378	14.4
LF_3	2	1/2	1							0.07724	7.7
LF_4	2	1/2	1	1						0.06882	6.9
LF_5	1/2	1/6	1/4	1/3	1					0.02243	2.2
LF_6	7	2	3	4	9	1				0.27884	27.9
LF_7	2	1/2	1	1	4	1/4	1			0.07147	7.1
LF_8	3	1	2	2	5	1/3	2	1		0.12216	12.2
LF_9	4	1	2	3	8	1/2	3	2	1	0.17639	17.6

Consistency Ratio = 0.02, 0.02, 0.02<<0.1 respectively

Table 13 shows that landfill site 2 with weight of 0.2266 is the most suitable site while landfill 5 with weight of 0.0298 is the least suitable site from area point of view. From distance from the center criteria, landfill site 1 with weight of 0.23063 is most suitable while landfill 8 with weight of 0.03188 is the least suitable site. Moreover, from distance from nearby settlement criteria of evaluation, landfill 6 with weight of 0.27884 is the most suitable site while landfill 1 is the least suitable site with weight of 0.03887. To solve the conflicting decision problems of choosing the most suitable landfill site, all the evaluating criteria were considered at a time in MCE methods. Hence, weight for all candidate landfills were derived from multiplying criteria weight and landfill site's weight that are derived in relation to that criteria and then summing the corresponding products (Table 14).

Table14. Weight and rank of the candidate landfill sites

Landfills	Area capacity 0.54	Distance from center 0.1633	Distance from nearby settlement 0.2967	Weight of candidate landfill sites	Weight of candidate landfill sites (%)	Rank
Landfill_1	0.54**x**0.07107	0.1633**x**0.23063	0.2967**x**0.03887	0.08757	8.757	6
Landfill_2	0.54**x**0.22661	0.1633**x**0.15463	0.2967**x**0.14378	0.19028	19.028	1
Landfill_3	0.54**x**0.04511	0.1633**x**0.12152	0.2967**x**0.07724	0.06712	6.712	7
Landfill_4	0.54**x**0.12669	0.1633**x**0.13993	0.2967**x**0.06882	0.11168	11.168	4
Landfill_5	0.54**x**0.02978	0.1633**x**0.19099	0.2967**x**0.02243	0.05392	5.392	9
Landfill_6	0.54**x**0.15969	0.1633**x**0.06423	0.2967**x**0.27884	0.17945	17.945	2
Landfill_7	0.54**x**0.0738	0.1633**x**0.03353	0.2967**x**0.07147	0.06653	6.653	8
Landfill_8	0.54**x**0.11461	0.1633**x**0.03188	0.2967**x**0.12216	0.10334	10.334	5
Landfill_9	0.54**x**0.15264	0.1633**x**0.03265	0.2967**x**0.17639	0.14009	14.009	3

Table 14 shows that landfill site 2 with weight 0.19028 (19.028 %) is the highest compared to other sites. This shows that the site satisfies the criteria set in the previous section relative to the rest landfill sites. Landfill 5 with weight 0.05392 (5.39 %) is the least mainly due to its smaller area. Moreover, landfill 6 and 9 are with the second and third highest weight of 0.17945 (17.945 %) and 0.14009 (14.009 %), respectively.

Table 12 indicates that landfill site 2 is the most suitable site for landfill, because of its larger area and optimum distance from the center and nearby settlement than the rest of landfill sites. Moreover, site 6 and 9 are the second and third suitable site, respectively. Landfill sites 2, 6 and 9 are also moderately to highly suitable for all parameters analyzed. The Figure shows that landfill 2, 6 and 9 are accessible and they are at 100m-500m away from the road which make them more acceptable from economical and social health points of view. That means the site is at a location that requires minimum transportation cost and health effect. Generally, landfill 2, 6 and 9 are the first three most suitable sites to be used for landfill site and landfill 5, 7 and 3 are the last but not the least suitable sites to be used for landfill site.

Chapter Five

5. Conclusion and Recommendations

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, agriculture and commercial area and 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 Gassore, Wabe river and surrounded by residential houses 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. Hence, it is environmentally unfriendly and socially unacceptable.

The present study considered seven factors namely: geology, slope, soil permeability, proximity from roads, built-up area, ground water well, streams/rivers 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, groundwater related factors were more important to have overall suitability map. The result of the final suitability map showed that 10.1% of the study area is highly suitable for landfill, 27.75% moderately suitable and 62.17% of the total area is unsuitable (restricted). Discontinuous and small area sites were masked according to their importance. Accordingly, 9 candidate landfill sites were selected. 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 landfill 2 scored the highest weight 19.028 % while landfill site 5 scored the least score 5.392 %. Hence, landfill site 2, which is found in Addis sub-town, north east of the town is the most suitable site among the 9 suggested sites due to its minimum environmental and social negative effects than other sites. Landfill site 6 found in western part of

study area in Gubre sub-town and landfill 9 in Gubre sub-town are the second and third most suitable site, respectively, due to their smaller area, closeness to settlement and farness from the center than landfill 2.

5.2 Recommendations

- To protect downstream surface water pollution, runoff must not flow into and out of the sanitary landfill. Hence, the municipality should be constructed drainage system around the landfill.
- 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 deposited in this site. Hazardous wastes from industries, health institutions and from house-holds should be separated from non-hazardous solid waste before disposal. 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.
- The present study considers major environmental, social and economical factors for landfill site selection. However, other factors such as cost of construction, community preferences, landscape and aspect also influence landfill site selection and therefore, should be included as evaluating criteria. Therefore, the selected landfill sites site 2, 6 and 9 should be evaluated with these factors especially with cost of construction.
- Detailed hydro-geological investigation for the selected landfill sites should be studied in order to further compare the landfill sites and predict the effects that will result from the landfill. Moreover, hydraulic conductivity of the sites should be studied so as to know whether the suitable site requires leachate and gas collector.
- Design and permitting of bioreactor landfills, design and permitting of landfill gas collection systems and beneficial reuse systems (waste-to-energy projects) are issues that need further research.

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