JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCE AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

EVALUATING THE EXISTING LANDFILL SITE USING GIS AND RS: THE CASE OF HOSANNA TOWN, SNNPR, ETHIOPIA.

By: DANIEL DESALEGN

A THESIS SUBMITTED TO SCHOOL OF GRADUATE JIMMA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIRIMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING.

October, 2018

Jimma, Ethiopia

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Declaration

I whom declare that, the thesis entitled "Evaluating the existing landfill site using GIS and RS: the case of Hosanna town, SNNPR, Ethiopia." comprised my own work. All the materials and methods used for this work are as likely acknowledged.

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Acronyms and Abbreviations

LU/LCC	Land Use or Land Cover
AHP	Analytical Hierarchy Process
ASBPDA	Addis Ababa City Sanitation, Beautification and Park Development Agency
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
NUPI	National Urban Planning Institute
GIS	Geographic Information System
RS	Remote Sensing
GPS	Global Positioning System
MCDM	Multi criteria decision making
MUDC	Ministry of Urban Development and Construction
SMCDM	Spatial Multi-Criteria Decision Making
MSW	Municipal Solid Waste
MUDC	Ministry of Urban Development and Construction
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
UNEP	United Nation Environmental Protection
OHCHR	Office of the High Commissioner for Human Rights
USGS	United States Geological Survey
GSE	Geological Survey of Ethiopia
a.m.s.l	Above Mean Sea Level
WHO	World Health Organization
SNNPR	South Nation Nationalities and Peoples Regional State
HZWD	Hadiya Zone Water Department
HTFED	Hossena Town Finance and Economic Development Office

Abstract

Solid waste management is a problem encountered by every country in the world but the situation is particularly severe in developing countries where poor waste disposal can be unsafe for environment and public health. The process of finding ideal solid waste landfilling site is very difficult and hard task as it involves manipulating and considering a number of spatial data from different sources. The negative effect of landfill on the environment and society is mainly caused due to improper location of landfill site. Due to this, proper landfill siting for solid waste management has become the most serious environmental and socioeconomic issue challenging most of the towns and cities especially in developing countries like Ethiopia. Selection of landfill site at appropriate location requires consideration of several biophysical and socioeconomic factors. The recent Potential improvement in GIS and RS integrated with AHP can help such decision problems to be solved systematically. The present study was interested to apply GIS and RS techniques integrated with AHP for proper landfill site selection in the case study. Landfill site selection is complex task. But, GIS can ease because of its potential to store large volume of data and manipulation ability. AHP is a method for analyzing decisions when multiple and contradicting objectives are considered. The factors used for this study includes (land use/cover, protected area, slope, road, drainage, borehole, soil, and geology). From these factors, more relative importance weight was given to LU/LC. Using these factors, after being reclassified their suitability thematic maps were prepared. Different weights for each criterion was assigned by AHP procedures then all the datasets were combined together in weighted overlay tools. For further analysis, highly suitable areas were used. The findings have shown only about 192 hectares of area was potentially very high suitable for landfill siting. From highly suitable locations, only four candidate sites with size capacity > 20 hectares were considered for further landfill siting analysis. Then, four candidate sites were identified and were prioritized using 3 most important criteria. The Analysis of evaluation on the study area have shown that among the four candidates, LF1 with areal coverage of 68.25 hectares was prioritized as the 1st rank top suitable landfilling site. Generally, the South East part of Hosanna town is the most suitable area for solid waste landfilling.

Keywords: GIS, AHP, Solid Waste, Landfill Siting

CHAPTER ONE

Introduction

1.Background

Every municipality and urban cities in the world are facing the problem of solid waste management due to fast growth of urban population, economic growth and rising living standards (Behzad, 2011; Kahan & Smadder, 2014). As a result of this, there is tremendous increase of solid waste generation in the world. Although solid waste management is a problem faced by both developing and developed countries, the situation is particularly severe in developing countries where inadequate waste disposal can be very dangerous for environment and human health (Jilani, 2002).

The importance of solid waste management becomes a concern because of the problems caused by solid waste to the health of society and environment is sever. Due to lack in management and inappropriate disposal of solid waste urban areas are facing several problems like diseases, environmental pollution and economic loses. The only solution is to management solid waste in a sound way and its management can be done more precisely by selection of suitable site for solid waste landfilling. If suitable site is not selected in the process of solid waste management, the cost to come on environment and socioeconomy is several in long run (Duve et al, 2015). Similarly, (Tirusew & Amare, 2013) argued selecting appropriate landfill site far away from environmentally sensitive areas is the major issue for management of solid waste. So disposing solid waste in a way that doesn't cause adverse impact on environment as well as socioeconomy becomes the first priority problem for any municipality or urban cities in the world (Al-Hanbali, 2012; Paul, 2012; Nishanth et al, 2010).

Landfill is an integral component of the waste management chain and requires greater attention to reduce its environmental impact and needs key engineering principles to be applied to minimize negative environmental and social impact(Gbanie et al., 2013). The management of solid waste in Africa is often weak due to lack of appropriate planning, poor technology, and the absence of economic and fiscal incentives to promote environmentally sound development. As a result of this, nearly all nations are applying open dumping for waste disposal without taking management care in order to minimize negative impact on ecology (Tirusew & Amare, 2013; Kabite, 2011). This method of waste disposal is also more common in our country Ethiopia and is becoming a major public health and environmental concern (Abebaw, 2008). In middle-income as well as poorer parts of lower-income countries such as Ethiopia, an estimated of 30 to 50% solid waste produced in urban areas is left uncollected (MUDC, 2012; Gedafaw, 2015).

Like other towns of Ethiopia, Hosanna town has experienced rapid population growth due to migration from rural areas and rapid urban area expansion and this has caused an increased volumes of solid waste generation and resulted in solid waste management problems. Most of solid wastes that are generated in the town are left uncollected and are disposed irregularly at every open spaces (Lemma & Tekilu, 2014). Likewise, (Berisa, & Birhanu, 2015) have reported a survey conducted for fifteen randomly selected large and medium towns of Ethiopia about their status of solid waste management showed that 86.6 % of them were using open dumping to dispose solid waste in a landfill site and most of the other urban areas in Ethiopia are believed to use open dump for disposal and this also has adverse impact on natural environments as well as society.

Problem of too much of solid waste generation along with disposal problem is a challenging issue to the municipality and local authorities of Hosanna town. Since, landfill siting linked to solid waste management services are becoming difficult to locate in urban areas because of the shortage of large tracts of land and community opposition (Rafiee et al, 2011; Oppio & Corsi, 2017). Similarly, all these situation of Hosanna town has called a concern for proper landfill site selection which is in compatible with environment, community health and plan of the town. One of the most important steps in the disposal of solid waste is the delineation of the disposal site. But the process of finding ideal solid waste landfilling site is hard task because it needs manipulating and considering a number of spatial data from different sources which are very sensitive to environment and human life (Baban and Flannagan, 1998; Sumathi et al, 2008; Mahamid, & Thawaba, 2010; Bah, Tsiko, & Kingdom, 2011; Duve et al, 2015). Due to this, selecting landfill site complicates the decision making process(Gbanie et al., 2013).

In environmental planning, waste managing had become a serious danger torturing the cities mainly due to lack of knowledge to newly developed GIS technologies which is an appropriate tool to select landfill site and collection routes optimization for efficient and capable environmental performance (Jerie & Zulu, 2017). Integrating GIS and MCDA serve as powerful tool to solve the landfill siting problems because GIS is used as a tool to find solid waste landfilling sites which are environmentally safe and acceptable to people. Mainly GIS is used to view, understand, question, interpret and visualize huge amount of spatial and non-spatial data in many ways that tells relationships, patterns and trends in the form of maps, reports and charts, which are vital for critical decision making whereas MCDA supplies the consistent ranking of the potential landfill areas based on a different criterion (Duve et al, 2015).

Bearing in mind the above problems, this research aims to apply GIS and RS technique that can be fully utilized for locating potential suitable solid waste landfilling site to maintain environmental pollution, public health risk and other socioeconomic problems while selecting solid waste landfilling site for hosanna town.

2. Statement of the problem

As populations continue to increase, society produces more and more waste. Yet it is becoming increasingly difficult to build new landfills, and the existing landfills are causing significant environmental damage. Finding solutions is not simple; the problem is enormous in size, vital in terms of its impact on the environment, and complex in scope (Tammemagi, 1999). So this situation has brought necessity to look environmentally and socioeconomically sound urban waste disposal and management system. Intelligent and integrated landfill sitting is a hard, multifaceted, tiresome, and prolonged process requiring evaluation of many different criteria (Ouma et al, 2011).

Suitable landfill selection process requires broad criteria and assessment steps to optimize best available locations, reducing later difficulties such as bad smell, scenic beauty and severe long term impacts of environmental contamination (Gorsevski et al. 2012). This convinces that waste management will be in effect if a suitable site is selected and appropriately developed. In Ethiopia solid waste management collection services are often inefficient and don’t cover all areas. In general, the unauthorized and most of the authorized dump sites are poorly managed causing significant environmental impacts (Regassa et al., 2011).

Similarly, as it was observed and reported by (Mekonin, 2012) due to rapid population growth and developmental activity Hosanna town has practically faced problems of high amount of household and municipal solid wastes which are not properly handled. This can be manifested being solid wastes are thrown irregularly at every open spaces as an option and untidiness in dumping site. Similarly, (Gedefaw, 2015) stated different institutions and households dispose solid wastes without considering the consequences on environment and society. In Hosanna town, despite knowing the adverse impact to the environment and public health from landfilling site and unsafe solid waste disposal practices low attention has been given to do research to control the situation.

Even though there are a number of studies in different cities and towns of Ethiopia about landfill site selection using GIS and RS techniques, in the case of Hosanna town there is no study about disposal site selection using GIS and RS methodology. But there are studies about solid waste management using other methodologies like survey based study in case of Hosanna town. For instance, the work of (Mokennen, 2012; Lemma & Tekilu, 2014) were a survey based research. Despite presence of efficient Technologies like GIS and RS techniques for solid waste landfilling site, no study has been applied in the study area. Moreover, since dump site location is one of the determining factor for sound waste managing as such it needs integrating environmental, social and economic factors. So the current study was interested with the view if proper location of solid waste landfilling site is researched by combining environmental and socioeconomic criteria using GIS and RS technologies, it is believed that the situation of solid waste disposal practices and its management might become better. Having identified these gaps, the researcher was motivated to apply GIS and RS methodologies to select landfill site at environmentally, socially, economically suitable location to fill the above gaps.

As it was observed Hosanna town is currently using temporary open solid waste dumping site since few years before and this site has been under use without taking the necessary care in selecting the site for collection, management, future development and disposal site suitability. The site also found very close to new residential areas and drainage networks without any flood control facility being constructed. Generally, the site is not at acceptable standard as seen from environmental, social and economic suitability. Similarly, (Aden, 2016) argues solid waste disposal is an important part of waste management system, which requires much attention to avoid environmental pollution and health problems. Even though it is difficult to select appropriate landfill site and managing solid waste dumping in developing countries like Ethiopia with limited finance and rapid population growth rate, the use of GIS and RS provide appropriate method to select landfill site more accurate, cost and time efficient (Minalu, 2016). Additionally, application of GIS and RS provided an appropriate platform in which different factors that had a direct influence on the site decision making process to be combined in a single environment (Kimwatu & Ndiritu, 2016). Therefore, it is needed time for application of GIS and RS methodologies for selecting and mapping potentially suitable solid waste landfilling site for Hosanna town in order to enhance solid waste disposal practices with minimal adverse impact on environment as well as on socioeconomic aspect.

3. General objective

The main aim of this study is to select environmentally, socially and economically suitable area for locating solid waste landfilling site in hosanna town using GIS and RS techniques.

3.1. Specific objectives

Specifically, this research aims:

- To identify suitability factors necessary for selecting optimum suitable landfill site in Hosanna town
- To prepare thematic map that shows potential suitable landfill site in the study area.
- To prioritize and rank the identified suitable candidate landfill sites based on their suitability level.

4. Research questions

1. What are the necessary suitability factors that are needed for selecting optimal suitable landfill site for Hosanna town?
2. How are the potential landfill sites be identified and their map be produced?
3. How does the identified suitable candidate landfill sites be prioritized and ranked to decide the best suitable landfill site?

5. Significance of the study

Potential solid waste dumping site selection using GIS and remote sensing technique is one of the precise decision making tools to select and map suitable dumping sites in a manner that bearing in mind social and environmental factors. Therefore, the findings of this study was found significant for municipality of hosanna town as a base in solid waste management decision making process. The suggestion and recommendation provided by this study could also be used an input for decision makers to improve the existing solid waste management system of the town. Moreover, the information provided by this study may be used as a springboard for further studies related to disposal site selection for sound solid waste management.

6. Scope and limitation of the study

The scope of this study will be limited in terms of space, time and subject. Spatially this study was confounded within the boundary of the hosanna town and temporally study was conducted in a single time series. In theme wise, the study has limited its study on suitable landfill site selection using GIS and RS techniques as a decision making. Some of the limitations in my study were unable to access high resolution DEM data of grid cell size <30m in which it can represent well the landscapes; time shortage to review literatures in detail, absence of GIS based published work about the study area and also financial shortage.

7. Ethical Consideration

According to (Gatrell et al., 2012), the research code of ethics for GIS professional declares that Spatial scientists must make every effort to closely follow any guidelines established for human subjects research and, beyond these, to make every effort to ensure the dignity and welfare of human participants. Therefore, researcher have handled an approved official permission letter to conduct study by informing the purpose of study for the informants. Respecting the privacy and verbal consent of informants during data collection process has been kept. In the case of professional integrity, the researcher was diligent enough to complete his duties, and do so in such a way that it reflects well on the individual and the profession. Additionally, the researcher has tried to acknowledge other's contribution by properly citing used scholarly literatures and data generated by others.

CHAPTER TWO

2. Review of related literatures

2.1. Concepts of Solid waste management

2.1.1. Solid waste

Solid waste refers to the leaves/ twinges, food remnants, paper/cartons, textile materials, bones, ash/dust/stones, dead animals, human and animal excreta, construction and demolishing debris, biomedical debris, household hardware (Babatunde et al., 2013).

2.1.2. Solid waste management (SWM)

Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations, and that is also responsive to public attitudes (Tchobanoglous et.al, 1993; Bernstein, 2004). SWM is currently one of the most serious challenges in developing country. Most municipalities are incapable to manage the growing volumes of waste generation. Realizing this solid waste management is serious issue for protecting urban environments, public health and the image of cities. A fast urbanization rate brings a challenges relating to the collection and disposal of solid waste in years to come, and therefore there is an urgent need to resolve the existing problem pertaining to waste management (Zaman & Lehmann, 2011).

A sustainable waste management philosophy should encompass basic principles of solid waste management hierarchy which includes (reduction in the generation of waste, waste streaming at source, recycling and reuse to minimize the volume of residual waste in landfill (Allen, 2001). The hierarchy ranks those waste management operations according to their environmental or energy benefit and the purpose is to make waste management practices as environmentally sound as possible (Diaz et al, 2005).

2.1.3. Landfill

Even though, landfill is the least in the waste management hierarchy, it is one of the most common solid waste management methods used in many countries. Landfills provide for the environmentally sound disposal of waste that cannot be reduced, recycled, composted, combusted or processed in some other manner. Hence, landfill of solid waste will continue to be a necessary part of integrated solid waste management systems, since there will always be a need to dispose of waste that cannot be economically reused or recycled or incinerated for energy recovery (Chang et al., 2008). According to (Allen, 2001) landfill is critical to most waste management strategies because it is the simplest, cheapest and most cost-effective method of disposing waste relative to other waste management methods. However, if not suitably sited and managed it can lead to serious contamination of the environment. These adverse negative impacts from landfill can be minimized through selecting an appropriate site, which minimizes potential environmental impacts and provides a sound basis for effective management (Zain et al., 2009). The harmless and dependable long-term disposal of solid wastes is an important part of integrated waste management. Although source reduction, reuse, recycling, and composting can reduce quantity of solid waste to be dispose at dump site, still the remaining wastes are need to be placed in landfills (Ahsan et al, 2014).

2.2. Solid waste management in developed and developing country

Developed nations have severe environmental challenges about solid waste management because of fast urban development. The rising of population number and better status of living in complex cities and urban parts has led to the production of mixed types of trashes. As life standard became improved in cities due to better income or job at the same time population will be attracted to urban area looking for better life, proportionally the waste generation rises. As reviewed in different literatures there is positive correlation of waste generation and income. This can be manifested as the waste generation has been rising with increasing wealth and economic development. In unindustrialized countries, the waste generation is growing fast and may keep growing more due to betterment in standard of living, economic activities and population number growth (Zaman & Lehmann, 2011).

In contrast, most urban centers of poor countries municipal solid waste management (MSWM) is very inadequate and beyond the abilities of their economic situation for management and disposal (Rushbrook, & Pugh, 1999; & World Bank, 1999). Most of the municipality in developing countries spends the highest proportion of their yearly budget for solid waste managing. Solid waste management (SWM) often represents a significant proportion of the total recurrent municipal budget in cities of low- and middle income countries (Scheinberg et al., 2010). Despite the high financial burden, the local authorities often struggle to provide adequate and reliable services for all. According to the World Bank and USAID, it is common for municipalities in developing countries to spend 20–50% of their available municipal budget on SWM, which often can only stretch to serve less than 50% of the population (Henry et al., 2006 & Memon, 2010).

Also, in some African states, one to two thirds of the solid waste produced are thrown irregularly. Because of this practice of irregular waste throwing, usually end up in the surrounding environment or drainage or open dump. They are confronted with many aspects of difficulties such as, insufficient facility availability and functioning inadequacies of services, limited use of reusing activities and poor landfill dumping (Zaman & Lehmann, 2011). Therefore, more hard work are required to pass this difficult that leads different agencies and establishments to find joint limits to protect human and environment from these consequences(Clark et al, 1998).

2.3. Solid waste management in Ethiopia

Solid waste management is one of the basic services that are currently receiving wide attention in many cities and towns of Ethiopia. However, studies conducted in most major towns and cities of Ethiopia indicated that solid wastes that are generated are not appropriately handled and managed, mainly due to institutional, regulatory, financial, technical and public participation problems (Regassa et al, 2011; Mekonnen, 2012; Hagos et al, 2012; Hailemariam, & Ajeme, 2014). Changing economic trends and rapid urbanization also complicate solid waste management (SWM) in developing countries. Consequently, solid waste is not only rising in quality but also changing in composition (from less organic matter to more paper, packing materials, plastics, glass, metal, and other substances), which is exacerbated by low collection rates (Medina, 2002 & Kuma, 2004).

The random survey study indicated that large and medium urban areas of our country shown the status 86.6 percent used open dump to dispose waste, while the rest used holes. Most of the other urban areas in Ethiopia are believed to use open dump for disposal (Brike, 1999). Since open dumping sites pollute surface and ground water, soil and the natural environment as a whole waste management in Ethiopia is important issue because only a small percentage of the country's inhabitants have access to safe drinking water: 21% in rural areas, 84% in urban areas, and 30% country wide. Additionally, only 7% of populations in rural areas, 68% in urban areas, and 15% of people country-wide have adequate access to latrines or other improved human waste disposal options (Aden, 2016). For instance, solid waste management system in Sodo town is very poor and inefficient. Only half 50.5% of the households have access to solid waste collection service, indicating the remaining half of the waste remains uncollected. Majority waste collected, sometimes, may stay 4-15 days, but only 4.0 % said waste was transported once per week. Due to this, majority of the residents practice open dumping outside disposal site of the town. Such practices are also an immediate risk for environmental pollution (Solomon, 2018). Moreover, only 7% of populations in rural areas, 68% in urban areas, and 15% of people country-wide have adequate access to latrines or other improved human waste disposal options (Kuma, 2004).

2.3.1. Existing solid waste management practices and disposal in Hosanna

The rapid population growth and spatial expansions of the towns of developing countries often result considerable damage to the environment. Use and management of public parks, urban open spaces, and solid and liquid waste management have great environmental effect in urban areas setting. Accordingly, in case study area waste management system is poor as it is manifested with splattered wastes along streets, drainage and residential area. Almost all households dispose solid waste on their compounds, road sides and any available open spaces. Not only the informally settled areas, but also the formal settlements of the town have no scientifically recommended solid waste disposal system rather very one disposes domestic household wastes at every open spaces, road sides and ditches(Seyume, 2015).

In Hosanna town since the last two decades the population number has increased dramatically and the current population number of the town has reached about 177, 228 (HTFED, 2018). This increment of population number coupled with economic development activities have contributed a lot for more volume of solid waste generation and this in turn challenges waste management system due to requiring additional infrastructure and community participation for management.

In Hosanna town about 30.14 tons of solid waste per day are Produced and the majority of wastes generated in the town are left uncollected on the street, drainages and open spaces which is 83.2% and the rest of these are collected and transported to open disposal site (Lemma & Tekilu, 2014). Many towns in Ethiopia lack the financial resources and institutional capacity to provide the most basic municipal infrastructures and services, including solid waste management. Likewise, management of solid waste in Hosanna town is a history of institutional trials and abandonment with most issues remaining unsolved. The new established town's Municipality, Cleaning and Beautification Core Process has the responsibility for the management of solid waste. Unfortunately, this core process is struggling with limited budgets, lack of qualified manpower, and experience in waste management (Mokennen,2012).

As it was observed and as indicated in (Mokennen, 2012; Lemma & Tekilu, 2014) the current solid waste landfilling site of the town is an open type found adjacent to Ajo river (Appendix II, photo5). This site has a lot of problem in respect to siting criteria, especially concerning to surrounding ecosystem. Topography of this site is not suitable for the disposal and also no natural or manmade barrier between this site and the surroundings. In addition to this, unacceptance by nearby community due to bad odor and fear of scavengers raises the current site problem more sever due to fear of attack by scavengers (Lemma & Tekilu, 2014). Being open type, the site is exposed to rain and sun without soil cover it has negative consequence to environment and healthy of society due to being washed to enter water body in heavy rain time and also not being fenced entry of humans like the poor's and children's searching for left things from the site put at risk of their health. In general, the site is not scientifically studied by considering different environmental and socioeconomic factors the dump site may bring in environment, society, waste management and disposal process.

In Hosanna town waste management service provision is very poor and doesn't kept in pace with the town's solid waste generation. The municipality owns only one tractor with capacity of 5 m^3 which collects wastes from different places like hotels, streets, some vacant areas and finally disposed to open dump site which is located far from urban center (Mokennen, 2012). Since, the site is far from waste generation center, this makes difficulty to meet daily petrol consumption and rounding trip to reach different places for collection.

Waste disposal is one of the most important management activities which need to be carefully planned. With regard to waste disposal, the study identified that almost all solid waste generated in households is disposed together i.e. there is no sorting habit of organic wastes from others at the household level. Therefore, disposing of household wastes into a river system, drainage system and any open place is a common practice and the result is threatening both surface water and ground water which provides a breeding ground for disease carrying pests and create problems to human health and the surrounding environment (Mokennen, 2012).

2.4. Landfill site selection criteria

In selecting a new landfill site, there are many criteria which need to be considered before the selection process was conducted such as road access, residential areas, airport, slope and soil type and so on. The criteria emphasized in literatures for landfills selection process are different in different countries. Based on literature reviewed, the most commonly used selection criteria includes:

Land cover and land use: 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 (Gostin, & Hodge, 2002); & (Yaw et al*.,* 2006). Also according to (Ebistu & Minale, 2013) Open land is most suitable for landfill sitting and According to (Aden, 2016) farmland, built up area, and wetland are moderately suitable, less suitable, unsuitable respectively

Surface water Distance: The waste disposal areas should not be in the vicinity of rivers, lakes or swamps. This criterion has a direct relationship with land suitability for being used as landfill. The farther landfill site from streams and river banks is more suitable. In some literature reviews, the researchers have suggested a distance up to 500 m away from a freshwater body(Elahi & Samadyar, 2014).

Borehole: Proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection process so that wells can be protected from runoff and leaching of the landfill (Chang et al., 2008). Otherwise, it can have irreversible human and environmental impacts. Also (Elahi & Samadyar, 2014) suggest, Landfill site must not be next to any water Resources or groundwater resources where the ground water table is shallow. If fortunately, waste mixed with water this may have irretrievable human and environmental consequences. So by determining suitable buffer distance from landfill will minimize the adverse effect.

Local topography: The topography of an area is an important factor on site selection, structural integrity, and the flow of fluids neighboring to landfill site because it has important consequences for landfill volume, drainage, eventual land use, surface and groundwater contamination control, site access and interrelated actions(Asha et al, 2016). land forms located in flat or undulating land, in an empty extract are suitable for waste disposal. Major landfills must not be sited in hill areas, those with ground slopes nominally greater than ten percent. However, (Gostin, & Hodge, 2002) recommends that 15 % slope or less 10 %. Additionally, regarding topography suitability, the areas which have high altitude or high slope are not proper for waste disposal. Moreover, the flat areas are not good either (Akbari et al, 2008). The best places for waste disposal areas are the ones with medium altitude surrounded by hills with no more than 20% slope. (Ebistu & Minale, 2013) also suggest slope > 20% are unsuitable and <10% is high suitable.

Geology: is an environmental factor that should be considered in landfill selection process. Impermeable strata and consolidated material are suitable for landfill site as they do not allow movement of leachate and hence minimize the risk of groundwater contamination from landfill leachate (Simsek,2006).

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 (Gostin, & Hodge, 2002 & Sener, 2004). Soils having high rate of permeability (district cambisols, haplic and gleyic solon chalks, cambic podzols with karst formations, etc.) are considered unsuitable for being used as a landfill while soils with very low permeability (clayey soils, shale, calcaric fluvisols, etc) most suitable to site a landfill(Elahi & Samadyar, 2014).

Distance from road network: Landfill location must be near the roads in order to facilitate transportation and consequently decrease the costs. Distance greater than 1 km from main roads and highways should be avoided. On the other hand, the landfill site should not be placed too far away from the existing road networks to avoid the expensive cost of constructing connecting roads(Elahi & Samadyar, 2014). The work of (Ebistu & Minale, 2 013) shows the two extreme distance of 0-500m is unsuitable and 1500-2000m is highly suitable.

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 highly suitable to surround an environmentally sensitive area(Gostin, & Hodge, 2002). As (Ebistu & Minale, 2013), distance of 0-750 is unsuitable whereas distance of 3000m away from sensitive sites are recommended highly suitable.

In Ethiopian particular case, the works of (Kabite et al., 2012; Ebistu & Minale, 2013) for Addis Ababa city and Bahir Dar town have used the criterions for landfill siting evaluation includes: geology, slope, proximity (to rivers/ streams, to faults, to airports, to roads, boreholes, & protected areas), soil type and land use/ land cover.

2.5. The role of GIS, RS and MCDA for landfill site selection

2.5.1. Application of GIS and RS for landfill site selection

Geographic information system (GIS) ideas and know-hows are being used widely in optimal site choice and construction for landfill and are moving the procedure for these doings to be held and monitored in a sustainable manner. Even though resources are scarce, the impact of human activities in degrading the existing resources are more. In such circumstances, the best tools available must be used to characterize the environment, predict impacts, and develop plans to minimize impacts and maximize sustainability. GIS skills, tools, and methods have considerable aids for resource records, showing, discerning and announcement(Johnson, 2009). The use of GIS and RS technology helps for the identification of suitable solid waste landfilling site with minimal environmental and human health risks from the site (Minalu, 2016).

Application of GIS tools in waste management is most important in landfill site selection process. As well, GIS tools are also used for distribution and to distinguish places for other essentials of waste management system such as transfer station network, waste selection and treating centers, for identifying transport ways and also offers the spatial analytical abilities to quickly exclude tract of land unfitting for landfill site and hence reduce cost and time of placement processes (Kumel, 2014). 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) in time and cost effectively. To determine an suitable landfill site, GIS is a very powerful tool that can provide a speedy assessment of the study area. In this study, landfill site selection was performed with the help of GIS and RS integrated with AHP techniques. GIS was used to prepare spatial statistics and clustering processes to reveal the most suitable areas for landfill site selection, which was ideal for this preliminary study as it enabled us to manage and analyze large volumes of spatially resolved data from a variety of sources (Sener et al, 2010). To determine the most suitable landfill site, an analytical hierarchy process (AHP) was combined with a GIS to examine several criteria. Each criterion was evaluated with the aid of AHP and mapped by GIS (Sener et al, 2010). Remote sensing offers a synoptic observation of large area and it has a multispectral ability of providing suitable contrast amongst different natural features, and its repetitive coverage provides evidence on the dynamic fluctuations taking place over the earth surface and the natural environment (Choudhury & Das). The data attained from RS benefits in identification and finding such landfill sites by checking the variations in land-use within and neighboring to hazardous waste and sanitary landfill (Asha et al, 2016). RS techniques were applied for data preparation as an input to GIS.

As it was reviewed in different scientific literatures, most of the research works done with respect to landfill siting are limited to northern and central parts of Ethiopia especially Amhara and Addis Ababa. For instance, the study by (Kabite et al, 2012; Ebistu & Minale, 2013). But, in the current study area, such landfill site selection research works are uncommon and this was identified as one academic gap. In general talking, there were no researches done concerning dump site suitability study in the area. The other gap was most of research works related to solid waste management has neglected landfill site suitability issue in process of solid waste management process and the disposal practices impact on environment, society, and economy are undermined. For instance, work of (Mokennen, 2012 & lemma & Tekilu, 2014) in case of Hosanna tow in their study they have focused on issues like attitudes toward waste, waste quantification and challenges of waste management. Although, these are important themes to be considered for solid waste management, but solid waste landfilling site suitability must have to be at the core of solid waste management which was undermined by many researchers. For instance, according to (Desta et al, 2014) in case of Addis Ababa, with new landfill site plan the dumping site was changed into landfill site constructed some 35 km away from the city centre around Sendafa. However, after 6 months' service the local farmers opposed and conflict broke out. Now the city government has returned to the old site despite the site has reached its full capacity. This indicates the need of solid waste management decisions on how to handle wastes in a way that must take into account the environmental, economic and social dimensions (Desta et. al., 2014). GIS can illustrate which areas are better or less suitable for landfill site selection and it can be used to select landfill sites in the shortest possible time and least costs (Al-Anbari et al, 2018). Despite GIS and RS are ideal techniques for solid waste management decision making, there are no investigations on GIS and RS based solid waste landfilling site analysis in the current study area. Land filling needs special consideration and standard procedures should be implemented to control pollution of surface and ground water as well as air (Regassa et al, 2011). But none of these considerations are actually carried out in the current solid waste dumping site of Hosanna town. The present study was initiated to find solid waste landfilling site with minimal environmental and socioeconomic impact from the site, using GIS and RS based approach. This is the main gap which needs great attention from researchers, urban planners, environmental experts and from any other concerned bodies. Thus, waste management sector needs great attention to apply GIS and RS technology since these technologies are very powerful for solid waste management planning decisions and dump site managing without causing significant environmental and socioeconomic impacts. The above explained problems has initiated the researcher to do the current study.

2.5.2. Integration of Geographic Information System and Multi Criteria Decision Making (MCDM) for landfill site selection

The mixed use of MCDM and GIS offers a well-organized stand for consistent ranking of a different evaluation criteria, together with effective data management and presentations of those criteria involved in the selection optimal sites for landfill. Analytic hierarchy process (AHP) is one of the GIS-based MCDM that combines and transforms spatial data (input) into a subsequent judgement (output) in a structured and perfect way. The way encompasses the application of spatial data, the manipulation of data according to the decision maker's feelings and identified decision guidelines, debated to as factor and constraints. AHP is applicable as an agreement building tool in situations comprising a single or group of decision-making, such as landfill site selection. Its power lies in its ability to develop weights related with the attribute of map layers, and also combine priority for all level of the hierarchy structure including the level representative alternatives(Fagbohun & Aladejana, 2016). AHP is a powerful tool for solving complicated problems that may have interactions and correlations among multiple objectives. Therefore, the integration of GIS and AHP methods provides a mechanism to thoroughly explore complicated problems and provide instant view for decision makers (Sener et al, 2010).

The critical aspect of spatial multicriteria analysis is that it involves evaluation of geographical events based on the criterion values and the decision maker's preferences with respect to a set of evaluation criteria. This implies that the results of the analysis depend not only on the geographical distribution of events (attributes) but also on the value judgments involved in the decision-making process.

Accordingly, two considerations are of critical importance for spatial multicriteria decision analysis: (1) the GIS capabilities of data acquisition, storage, retrieval, manipulation, and analysis, and (2) the MCDM capabilities for aggregating the geographical data and the decision maker's preferences into unidimensional values of different decisions. The large number of factors necessary to identify and consider in making spatial decisions and the extent of the interrelationships among these factors cause difficulties in decision making. The difficulty is that in attempting to acquire data and to process the data to obtain information for making decisions, the complexity of the problem may require processing at a level that exceeds a decision maker's cognitive abilities. To this end, the role of GIS and MCDM techniques is to support the decision maker in achieving greater effectiveness and efficiency of decision making while solving spatial decision problems. It is argued that the combination of GIS capabilities with MCDM techniques provides the decision maker with support in all stages of decision making, that is, in the intelligence, design, and choice phases of the decision making process(Malczewski, 1999).

2.5.3. Spatial multi criteria decision making analysis (SMCDM)

Spatial multicriteria decision making requires an expression of the decision maker's objectives and an identification of attributes useful for indicating the degree to which these objectives are achieved. An attribute is used to evaluate the performance in relation to an objective. The objective and underlying attributes of evaluation criteria form a hierarchical structure of evaluation criterion for a particular decision problem of required goal. Both single criterion and a set of criteria have to retain properties to adequately represent the multicriteria nature of a decision problem. Each criterion has to be all-inclusive and quantifiable to avoid subjectivity. A set of criteria should be complete, operational, decomposable, non-redundant, and minimal not to be complex. Once the hierarchical structure of objectives and attributes is established, each criterion should be represented as a map layer in the GIS database. The set of criterion maps is a representation of a particular decision situation or a particular segment of the actual world geographical system. Given the variety of scales on which a criterion can be measured for instance slope criterion layer may be in degree and elevation may be in meter in order to standardize these factor layers multicriteria decision analysis requires that the values contained in the various criterion map layers be transformable to comparable units (Malczewski,1999).

The main goal of MCE analysis using GIS techniques is to look at a number of probable choices with reference to several criteria and conflicting aims and takes in to consideration expert knowledge of judgement in decision making. (Khan & Samadder, 2014).

CHAPTER THREE

Description of study area and research methods

3. Description of study area

3.1. Location of study area

Hosanna town is located in Hadiya Zone in Southern Regional State and is found at distance of 230 km to the south of Addis Ababa. Astronomically, Hosanna located extending from 7^{0}30'40"N-7^{0}37'50" N latitude and 37^{0}47'40'E'-37^{0}55'40"E longitude.

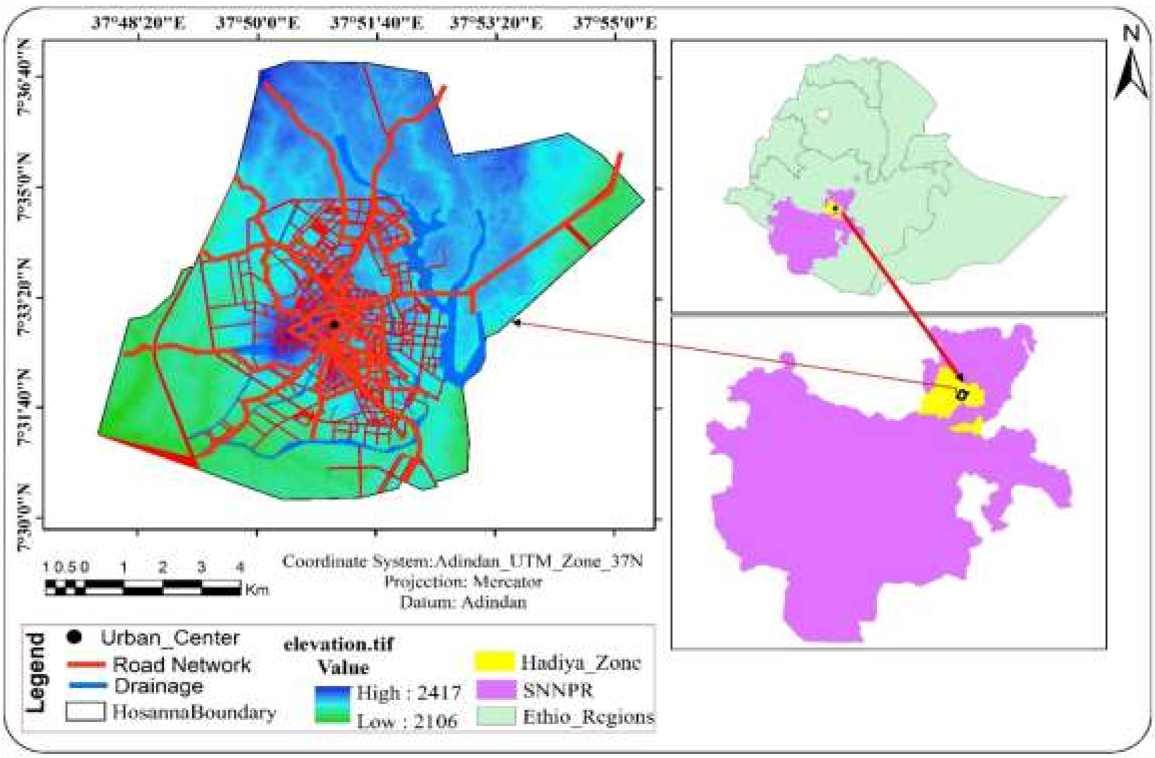

Figure 1. Location map of study area

3.2. Physical characteristics

Physically, Hosanna covers about 10,061 hectare of land with Alternatively changing horizontal and vertical landscape orientation. It includes some ups and downs, small hills and plain which can commonly be said that town is inclined dominantly from west to east, so that drainage pattern of the town is from west to east direction covering 25% of the land to be within the slope classification range of 4-7%. According to (Tamirat, 2005) the present day landscape of hosanna owes its actual surface from the past volcano, tectonic activities with the slight modification by local thick soil formation, soil erosion and to some extent by gulley formation. Its elevation within the town ranges from 2400m a.m.s.l around central part of the town to 2100m a.m.s.l around southern part of the town. The slope characterizes the town which gradually descends from the north to south elongated and highly elevated land mass to the east and west. Generally, about 75% of the town is with slope less than 15% and most built up areas are within the slope between 5–10%. To some extent the town is prone to flooding and soil erosion due to high gradient from its peak from the site of the hospital to the low land of the open market area during the rainy seasons (HTFED, 2013). The type of soil in Hosanna is very fertile and favorable for urban agriculture. It is reddish, thick and sandy-loam in general and therefore easily erodible (Teketel, 2015). There is no perennial river that crosses the town, but there are intermittent or seasonal rivers called Ajo, Shilansha and Batena on south western, northern and north eastern part of the town respectively(Desta, 1994).

Hosanna has access road that links the town with Addis Ababa, Buttajira, Wolayita Sodo and Wolikete town with asphalt road and other surrounding wereda's with gravel road. Major roads that are coming from Butajira, Welekite, Gimbichu and Sodo directions are inter connected at the center of the town and form radial structure with Hossaena being the center. These roads have regional and intra-town connections. Therefore, they have relatively intensive traffic loads. The existing road network in the town varies in width from 2 to 25 meters and there is about 304kms of road network. From the total about 15kms is asphalted, 5.6kms is gravel and 0.9kms is paved by cobble stones and the remaining was earthen road until 2011(Seyume, 2015). But since very recent time existing earthen roads has started to be paved by cobble stone.

3.3. Economic activity

The main economic activities of the town are trade, public services, transport, and the like. 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 rundown around Arada and without the essential services; however, there are newly emerging housing units at the center and periphery of the town. Its proximity to Addis Ababa, Butajira and Wolita Sodo towns believed as it creates a good opportunity of the future development of the town. There is increasing migration of peoples from rural parts to the town which is in turn responsible to population number increment as well as waste generation. In fact, migration of people from rural to urban is common everywhere. But there is some recent event that makes different for unusual migration of people to hosanna town from surrounding rural parts which may pose fear to future waste generation condition, waste handling condition and land availability for landfill site. Practically from present existing situation the town has become the destination for many rural migrants and due to this the population number is increasing more. The reason for this increased rural to urban migration in the town is due to remittance sent from South Africa (Teketel, 2015). There are many migrants in South Africa from the surrounding rural parts of the Hosanna town and they send money back for investment and to meet other needs of the family. With the money sent back, the family left at homeland will move to the town looking for better education to their children, better life expectation and other interests. It's believed that as the economy improves and the population number increases, the solid waste generation quantity also increases proportionally. So this has implication in waste management process for the town.

3.4. Climate

The whole study area is lying within a tropical climate as a humid region (Ethiopian meteorological Agency, 2008 as cited in Chakebo, 2017). The climate of Hosanna town is characterized by four distinct seasonal weather patterns; that are the main wet season "*kiremt*" which extends from June to August, a minor rainy season *mehir* extends from September to October, a little rainy season *belg* extends from March to May and more likely no rainy season *bega* extends from December to February. In general, based on local climatic classification, Hosanna town is grouped under *woeina-dega* climatic zones (HTFED, 2017).

The meteorology recorded of Hosanna station indicate that for rainy seasons the minimum and maximum monthly record of temperature ranges from 15°c to 17.9 °c respectively and from 16°c to 23°c for dry seasons (Fig 2). The highest temperature is experienced in January whereas the lowest temperature is recorded in August (Fig 2). Similarly, the highest rain fall is recorded between July and September and the lowest is between December ember and February (Fig 3). The temperature and rainfall characteristics of the study area are provided in graph below (Fig 2 & 3).

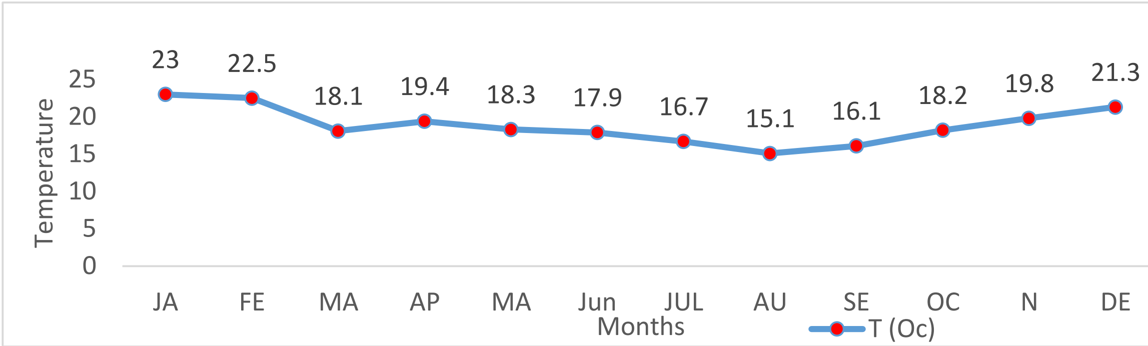

Figure 2. Annual monthly temperature variation in hosanna town (HTFED, 2017)

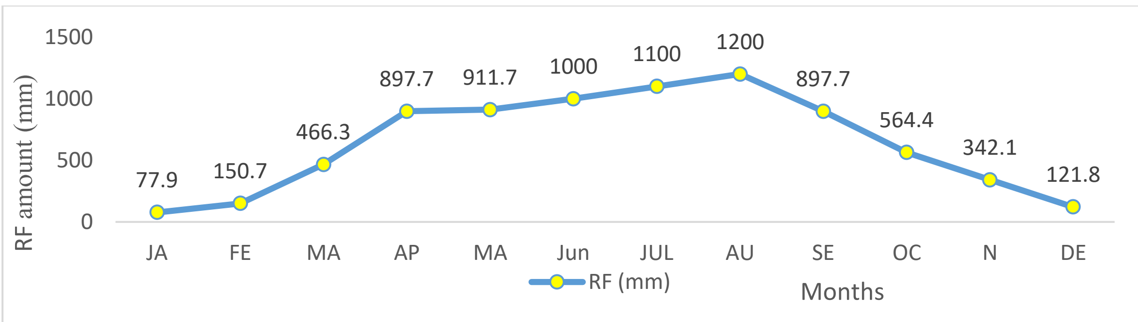

Figure 3. Annual monthly rainfall distribution of hosanna town (HTFED, 2017)

3.5. Population

The total population of Hosanna town was 13,467 and 31,701 in 1984 and 1994 respectively (CSA, 1984 & 1994) and it has increased to 69,995 in 2007 (CSA, 2007) which indicates it has increased more than twofold with in the past 13 years. It is estimated that migration of people towards Hosanna town from neighboring district town and rural kebeles will continue in the next decades(Ashenafi, 2015). The current population number of Hosanna town is about 177, 228(HTFED, 2018) which indicates with in the past 10 years the population of the town has increased by about 107,233(Fig 4). So with this fast growing number of urban population trend the municipality authorities must have to get prepared to the challenge they may face in waste management sector.

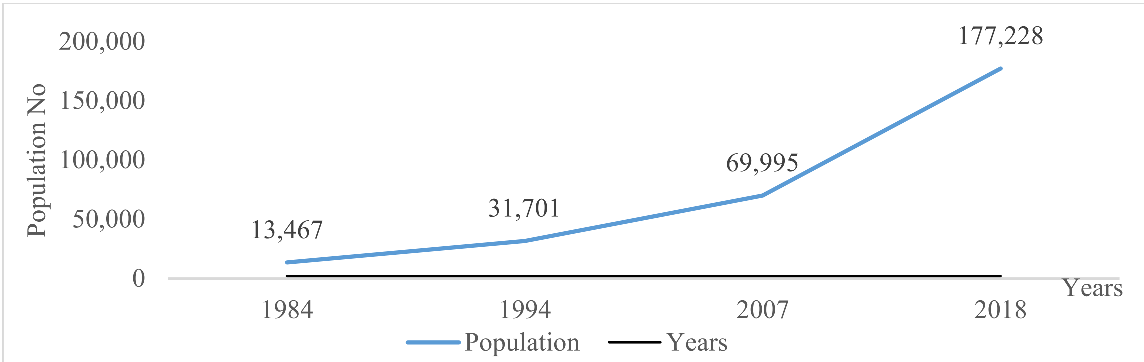

Figure 4. Population growth of hosanna town from 1984-2018(CSA, 2007 & HTFED, 2018)

3.2. Methods and Materials

3.2.1. Research design

This study was based on semi mixed sequential dominant quantitative (technical) analysis followed by qualitative interpretation. To supplement this, the statement developed by (Powell et.al., 2008) describes it as quantitative/technical and qualitative phases occur one after the other, with the quantitative/technical phase being given more priority and mixing of qualitative occurring at the data interpretation stage. Similarly, (Burke et al., 2007) argues more relied on quantitative or technical logical procedures while at the same time recognizing qualitative explanations. The technical phase of research dealing was with the identification of suitable site for landfill with the suitability factors being evaluated using ArcGIS 10.5 and also for multi criteria evaluation using IDRIS selva version17. As technical phase completed, the experts were involved in rating relative importance of landfill siting suitability evaluation factors. Also, the research was a cross sectional type study.

3.2.2. Data types and sources

The data types used for this study includes Structural plan of hosanna town, Land use/land cover, Aerial photo, soil type, ASTER DEM(slope), Road network, Drainage network, Boreholes GPS point data, protected area, and Geology. Primary data used for the analysis were Aerial photo and expert interview. The experts with environmental and urban planning background were interviewed from potential government institutions around the study area. They were interviewed for rating of landfill siting evaluation factors according to their significance in local area context and at the same time their rating was informed and cross checked by researcher by reviewing literatures from other areas context. Secondary sources of data (Structural plan of the town, ASTER DEM, Soil, recorded boreholes GPS point data, published and unpublished literatures were used for this study.

Table 1. Data types and sources

No	Types of data	Source of data	Purpose
1	ASTER GLOBAL DEM(30m)	USGS(website): http://earthexplorer.usgs.gov/	For slope analysis
	1.1.Slope	Generated from ASTER Global DEM(30 m)	To prepare slope factor suitability map
2	Structural Plan of hosanna town (2016), which was originally prepared from Ikonos satellite Image(1m)	Hadiya zone municipality, plan preparation core processing unit	For LU/LC type suitability analysis
2.1	Aerial photography(2016)	Hadiya zone municipality	To prepare drainage network factor map
3	Road networks	Hadiya zone municipality	For proximity analysis
4	Drainage network	Digitized from Aerial photo	For proximity analysis
5	Protected area	Digitized from structural plan	For proximity analysis
6	Boreholes	Hosanna town water office(recorded GPS point data)	For proximity analysis
7	Geology	Bought from Ethiopian Survey of Geology	For geological suitability analysis
8	Soil	Hadiya Zone Agriculture Department	For soil type suitability analysis

3.2.3. Soft wares used

ArcGIS 10.5 was used to prepare evaluation factor data into thematic suitability map, to restrict parameters (values or attributes that need restriction), topographically related analysis, proximity analysis, weighted overlay analysis, to display their map, land use land cover analysis and so on. Erdas Imagine 2014 was also employed to do land use/land cover related analysis. IDRIS selva version17 was used to derive weight for each factors and to evaluate consistency ratio. Additionally, mendeley Desktop software for referencing purpose, Excel for GPS point data preprocessing, digital camera to support the qualitative analysis of observations and google earth for some output result validation purpose.

3.2.4. Data analysis

3.2.4.1. Selection of evaluation criteria

For this study different determinant factors that could possibly pose adverse impact associated from landfill siting were considered and analysis was made using GIS procedures for suitability analysis integrated with AHP were applied. Selection of site is a very important process for effective operation of a waste dumping in landfill as such it involves a wider assessment process in order to identify the best available dumping site and this location also must be sound environmentally, economically and socially. Actually, different scholars have used varying criteria for site selection determinations due mainly to the fact that different criteria apply to different region and data availability (Balasooriya et al, 2017).

Relevant case studies and government documents can be used as a guide for selecting the evaluation criteria for a particular problem. Many of the studies survey the evaluation criteria that can be used in the situation of a specific decision problem. For instance, several previously done works for landfill site selection evaluation have used factors like Slope, elevation, Aspect, geology, ground water table, surface water, land use/land cover, fault line, distance from road, and distance to residential area (Aksoy & San, 2017; Gbanie et al., 2013) offers an excellent source for selecting the evaluation criteria for landfill sitting.

Given the objectives, for this study eight evaluation factors were decided by reviewing relevant scientific literatures to define the factors for landfill sitting and these factors are believed to be expressive of the environmental, and socioeconomic characteristics of the study area. Yet, other factors may be taken based on the local areas conditions or may be changed based on the geographic and other limitations of the of the study area.

Reviewing relevant scientific literatures for similar problem, the following factors were used for evaluating landfill siting and some identified constraint values or attributes from these factors has been also restricted from further analysis in weighted overlay interface.

Table 2. Decided biophysical and socioeconomic suitability factors for landfill site selection evaluation based on scientific literatures.

Factor	Group	Factor	Group
1. Land use/land cover	Biophysical factors	7. Road network	Socioeconomic factors
2. Slope		8. Protected areas	
3. Drainage network			
4. Boreholes			
5. Soil			
6. Geology			

3.2.4.2. Generating suitability factor maps

Having established a set of factors for evaluating landfill site selection, each factors was represented as a map layer in the GIS database as evaluation factor in relation to the study objective. In generating factor maps all non-raster dataset layers were converted into raster format in which to facilitates the reclassification of layers based on values and attributes. Reclassification helps to know which range of criteria value is suitable or not and also helps to know the count of some features. Owing to this, each layer of factor map was reclassified and their suitability map were produced. The decided eight evaluation factors (Table2) were assumed as it can characterize the research study area's local condition and also it is believed that, the specified objectives could be answered if being analyzed with these thematic factor maps (layers of information) as listed below sequentially.

3.2.4.2.1. Generating biophysical suitability factors maps

A. Land use /land cover suitability factor map

The structural plan of the town that was obtained in vector format from Hosanna municipality was used for land use /land cover thematic factor map analysis and it was identified that structural plan of the town was originally developed from very high resolution Ikonos satellite image. For instance, the work of (Kabite, 2011, p31 & Kumel, 2014, p.25) have used the structural plan of the city/town for land use/land cover analysis for landfill siting analysis. Then, the vector format of these LU/LC classes from structural plan was converted to raster format for factor map usage and analysis. From the structural plan of the town 13 land use/ land cover classes were used for the study purpose which includes (roads, recreational areas, administration areas, mixed residential, residential, general service areas, industrial areas, urban agriculture, commercial areas, transport parking areas, river, bare areas, and roundabout). The thematic layer of land use/ land cover was then resampled into nearest neighbor resampling in order to facilitate analysis with other data sets. In ArcGIS 10.5 weighted overlay interface the suitable LU/LC class for landfill siting were assigned with new values 0, 1, 2, 3, 4, & 5 as their suitability indicator in which 0 represents (restricted), 1(very low), 2(low suitable, 3(moderate suitable), 4(high suitable) & 5 (very high suitable) whereas the unsuitable LU/LC types for landfill siting identified from literature review were restricted using restrict command in weighted overlay interface. According to (Ebistu & Minale, 2013) open land was the most suitable because the land value for compensation to owner is low and water body like pond or marshy area are unsuitable for landfill siting, and agricultural lands are moderately suitable. Different LU/LC types suitability for landfill siting were decided based on scientific literatures.

B. Slope suitability factor map

The topography of the land surface is one of the most landfill siting controlling factor. Due to this, topographic related information like slope, drainage basin are valuable data for the current study. So the slope of the study area has been extracted from ASTER GLOBAL DEM (30m) and processed in ArcGIS environment using the surface analysis tool. Then reclassification was done to obtain the required slope range for landfill sitting and their suitability classes were represented with values of 1, 2, 3, 4, & 5 in which the values correspond to very low suitable, low suitable, moderate suitable, high suitable, & very high suitable respectively. The slope suitability classes cut off were determined based on reviewed scientific literatures.

C. Proximity analysis to drainage network factor

In landfill siting, proximity analysis is a critical process undertaken on some of the datasets like drainage, road, urban center, and settlements (Kimwatu & Ndiritu, 2016). The drainage network data was developed in ArcGIS environment by digitization technique. The aerial photo obtained from zone municipality of year 2016 was used as a back drop to digitize drainage network. Drainage proximity analysis was employed to analyze its buffer distance suitability for landfill siting then drainage network buffer distance suitability factor map was produced using drainage thematic map and reclassifying has been conducted by representing suitable buffer distance. While, reclassifying indirectly ranking their suitability is done by representing with new numeric values by reversing or leaving as it was depending on suitability of values and subsequently this helps not to update the values as we add in weighted overlay tool. The safe buffer suitability distance for landfill sitting was categorized based on literatures and were represented either numerically or qualitatively as 1(very low suitable), 2(low suitable), 3(moderate suitable) and 4(high suitable) and 5(very high suitable). Finally, the reclassified layer was combined with other datasets in weighted overlay tool.

D. Proximity analysis to borehole factor map

The proximity analysis to ground water well point is a determining environmental factor for landfill siting. Since landfills create noxious gases and leachates, proximity of borehole location has been considered in the analysis in order to minimize risk of contamination of boreholes drilled for human or animal use. To prepare borehole suitability layer map, four GPS point borehole data were collected from the Hosanna town water office that have been already spatially referenced and kept as recorded data. For GPS data shape file was produced and referenced to fit with other layers. Then using a buffer tool, proximity analysis was carried out and a different buffer distance was specified around each borehole locations. Finally, it was reclassified into suitability classes and represented either numerically or qualitatively as 0(restricted), 2(low suitable), 3(Moderate Suitable), and 4(high suitable), and 5(very high suitable). The suitability class were determined based on the standard set by (Erosy & Bulut, 2009; Bababola & Busu, 2011) and the reclassified data was combined in weighted overlay for further analysis.

E. Soil type suitability factor map

Soil type data obtained from Hadiya zone agriculture department was resampled to fit the cell size of data with other layers, then it was reclassified to their suitability class by using Arc GIS reclassify tools. To categorize the suitability class of soil types for landfill siting a published literature were used and their suitability were represented numerically or quantitatively as 2(low suitable), 3(moderate suitable), 4(high suitable), and 5(very high suitable).

F. Geological suitability factor map

A digital Geological factor map obtained from Geological Survey of Ethiopia(GSE) were digitized in ArcGIS environs. Accordingly, its thematic map was prepared and the geological classes of study area were identified. The geological data layer was then reclassified into different suitability classes. According to (Gbanie, 2013) areas that have poor geological conditions were given lower suitability score which is an indication of its poor suitability whilst those that are supposed best were given higher scores. Also (Demir et al., 2016) suggest most suitable area for landfill siting are the sites that containing clay are preferred. Considering this higher suitability score value was given to geological class which contains clay material and low permeable.

3.2.4.2.2. Generating socioeconomic suitability factor maps

G. proximity analysis to road network

A digital road network data obtained from hosanna town municipality was used for road suitability analysis. Afterwards geo-processing techniques of buffering was applied to it. After buffering operation, it was converted in to raster format to make it ready for reclassification and then it was reclassified according to its suitability classes. Then the suitability buffer distances were represented with values for further analysis as 3, 4, & 5 in which the values correspond to moderate suitable, high suitable, & very high suitable respectively. The suitable safe distance cut off from road to landfill site were determined based on scientific literatures.

H. Proximity analysis to protected areas (Institutions & public areas)

The sensitive areas in the town such as religious centers, schools, general service areas, recreational areas, & etc. were developed in GIS environment using digitization technique from structural plan of the town and these data were imported in to Arc GIS software and different buffer distances have been computed around these polygon features. After buffer distance computed for each protected areas, the buffer distances were reclassified being represented with values 0(unsuitable/restricted), 2(low suitable), 3(Moderate Suitable), 4(high suitable), and 5(very high/highly suitable). Then the reclassified suitability values were added into weighted overlay and their suitability distance cut off were determined based on literatures and finally the identified unsafe distance for landfill siting was restricted using restrict command in weighted overlay interface.

The determinant suitability factors considered to select optimal suitable landfill site and their suitability standards were decided based on scientific literatures (Table 3).

Table 3. Suitability factors and their suitability standards for landfill site selection from consulted literatures

1. Biophysical suitability factors	LU/LC types	Bare areas (Very high suitable), built up areas like infrastructures(restricted), cultivated lands (moderate suitable), mixed residential area(restricted).Generally land with low economic values are more suitable	(kabite et al., 2012; Demir et al., 2016; Kimwatu & Ndiritu, 2016; Debebe, 2017).
	Slope	< 5% (very low suitable), 8-12 % slope (best for landfill siting), > 20% (very low suitable). Depending on local slope condition different scholars set varied slope suitability criteria	(Kabite et al., 2012; Kimwatu & Ndiritu, 2016; Lin & Kao, 2005; Mekuria, 2006;Wang et al., 2009; Gostin & Hodge, 2002; Akbari, 2008; Ebistu & Minale, 2013).
	Drainage network	<500m (Very low suitable), >2000m (Very high suitable). Generally, the suitability of landfill siting increases as distance from drainage network area increases & vice versa	(MUDC, 2012; Sunder et al, 2014;Wang et al, 2009; Ebistu & Minale, 2013; Elahi & Samadyar, 2014).

	Boreholes	< 500m (unsuitable/restricted), >2000m (highly suitable) Generally different scholars suggest its suitability increases as distance increases & vice versa	(Kabite, 2011; Elahi & Samadyar, 2014).
	Soil	Generally, soils with very low permeability with high clayey contents are more suitable. vertisols (very high suitable), luvisol (moderate) Nitisol (high suitable), Cambisol (low suitable)	(Gizachew, 2011; Khan & smadder, 2015; Gostin & Hodge, 2002 & Sener, 2004; Baha et al., 2011; FAO, 2014).
	Geology	Ignimbrite (very high suitable), rhyolite (high suitable). Generally most suitable for landfill siting are geological classes with less degree of weathering and fracture	Ayenew et al., 2008; Kabite, 2013 & Demir et al., 2016).
2.Socioeconomic suitability factors	Road network	<300 m and >1500 m (very low suitable), 1000m-1500m(high suitable)	(Kumel, 2014; Khan & Smadder, 2015; Babalola & Busu, 2011)
	Protected areas	<300m(restricted), 300-500m (low suitable), >2000m (very high suitable)	(Gostin & Hodge, 2002; MUDC, 2012; kumel, 2014; Kimwatu & Ndiritu, 2016 & Debebe, 2017)

3.2.4.3. Expert Interview and literatures

A non-probability purposive sampling method have been used to conduct interview with experts for rating the relative importance of landfill evaluation suitability factors numerically using AHP pairwise technique using 1-9 scale definitions (Appendix, Table

18) for landfill site selection purpose. The analytical technique proposed here have helped the experts such as town planners and environmentalists to properly rate the factors relative significance numerically in a pairwise way for the landfill siting. The subjective evaluations are converted into numerical values that are ranked on a numerical scale (Bhushan & Rai, 2004). The experts were interviewed from believed potential government institutions like zone municipality and Wachemo University. Two experts were interviewed, one from municipality and another environmental expert from Wachemo University were purposively contacted after being informed the potential person by the institutions director. At their best level of knowledge and local condition, the experts have rated factors relative importance in provided interview questionnaire (Appendix III, 1) using 1-9 scale definitions(Appendix III, Table 19) in a pairwise comparison techniques then by normalizing the pairwise matrix subsequently the weight for each factors were derived after being the experts rating filled into a computer package called Idris weight derivation module and this has helped to know whether experts rating judgment were logical or not to the acceptable level according to (Saaty, 1980). The AHP technique provides a means of decomposing the problem into a hierarchy of sub-problems that can be more easily comprehended and subjectively evaluated. At the same time the researcher also has reviewed literatures for rating the importance of the suitability factors as a percentage of influence. For instance, the study by (Kabite et al, 2012; Khan & Smadder, 2015 & Debebe, 2017) were used to substantiate the rating done by the experts. To rate the factors, both expert's judgments were made using pair-wise comparison technique and literature consultation was done by researcher as a cross check of their rating and subsequently weights were derived using Idris software package. The factors were hierarchically sorted according to expert's knowledge. From the factors rated, the relative importance of land use/land cover dominates all others followed by protected area, road, slope, drainage, and boreholes with their relative importance decreasing, respectively. Soil and geology were rated as least important because of these factors have not that much direct influencing to areas local community directly. Their response for rating land use/cover as most important is because it has direct influence to the local community relative to other factors. Finally, the weights for each factors were decided to use from the expert's rating found with lower consistency ratio and used as an

input as a percent of influence in weighted overlay analysis for each corresponding factors.

3.2.4.4. Pairwise comparison and determining factor weights

The municipality expert's rating of factors in 1-9 continuous scale using AHP techniques were used as an input to fill into Idris software for subsequent weight derivation. The main objective is to design of mathematical tools to support the subjective evaluation of a finite number of decision alternatives under a finite number of criteria in order to find the best choice avoiding bias (Pournamdarian, 2010). As this idea also supplemented by (Fagbohun & Aladejana, 2016) AHP is one of the GIS-based MCDM that combines and transforms spatial data (input) into a subsequent judgement (output) in a structured and perfect way. The pairwise comparison method involves three steps:

(1) Development of a pairwise comparison matrix.

(2) Computation of the weights: involves three steps. A) summation of the values in each column. Then, each element in the matrix are divided by its column total. In this way, all values in the matrix are normalized. Then, the average of the elements in each row of the normalized matrix are computed by dividing the sum of normalized values for each row by the number of criteria used. The averages provide an estimate of the relative weights for each criteria.

(3) Consistency ratio(CR): The aim of this is to determine if the comparisons are consistent or not. As suggested by (malczewski, 1999) the following operations are done to obtain consistency ratio(CR):

(a) Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows.

(b) Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously.

(c) Compute lambda(λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and the formula is: CI= (λmax- n)/(n-1), where n is number of criteria and λ is the average value of the consistency vector.

(d) Calculation of the consistency ratio (CR) which is defined as follows: CR = CI / RI Where RI is the random index and depends on the number of elements being compared. If CR< 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if CR ≥ 0.10, the values of the ratio indicates inconsistent judgments.

In case of current study, according to (Saaty,1980) the corresponding random index (RI) for 8 by 8 matrix is 1.41 and the consistency ratio obtained using Idrisi computer module was 0.03(Fig 14) which was <0.1 and it was acceptable to take the expert's suitability factors relative rating judgment.

3.2.4.5. Weighted overlay analysis

Multicriteria method needs that all criteria are expressed in the same scale. So before adding reclassified input raster to the weighted Overlay tool, the common evaluation scale was set from 1 to 5 by 1. That common measurement scale is what determines how suitable is a particular location. This was done, to make comparison of one criterion with other criteria meaningful. The higher pixel values (5) indicates more suitable locations and lower pixel value (1) indicates less suitable locations. Since different input factor maps have dissimilar measurement units it is not possible to compare layers with different measure units. For instance, slope was measured in degree, road in meter, and land use/land cover as class type. For this study all locations to be comparable, all reclassified datasets were transformed into the common unit of measurement scale 1 to 5 in weighted overlay.

For this study, eight evaluation factors for landfill site selection were used for stated objectives realization and each reclassified dataset were added in ArcGIS weighted overlay tool with their respective weights derived in pairwise comparison matrix earlier and the identified suitability were represented with numerical score value like 0(restricted), 1(very low suitable), 2(low suitable), 3(moderate suitable), 4(high suitable), and 5(very high suitable).

3.2.4.5.1. Restricting of constraint values or attributes

In many literatures of previously done works, the screening method was mostly Boolean logical method for instance, the works of (Cheng & Thompson, 2016) assigned value 1 for suitable and 0 for unsuitable. In this way, 0 have been used as area unsuitable(restricted), but this way doesn't give the continuous suitability degree for the area rather it leaves with only option suitable and unsuitable area. But suitability is continuous process in the given area with the degree of variation like unsuitable, less suitable, moderate suitable, and high suitable. Unlike the Boolean logical method, the weighted overlay tool facilitates such continuous suitability level analysis and gives different suitability distribution extremes ranging from restricted to low suitable & high suitable.

In ArcGIS the weighted overlay interface, restriction tool was used for restricting some attributes or values of suitability factors that are unsuitable for landfill siting and were restricted from further suitability analysis. Finally, score value of '0' have been assigned to the restricted attributes in weighted overlay tool after being all datasets were combined. The restriction of certain criterion's values or attributes were decided based on literatures. For instance, land use/ land cover type like rivers and different infrastructures were reclassified as unsuitable(restricted) in the work of (Aklilu, 2015 & Minalu, 2016).

Similarly, for the current study, the restricted land use/land cover attributes include such as road, river, residential area, administration area, recreational area, general service area, commercial and roundabout and from the protected areas layer the values for buffer distance < 300m and for boreholes data layer a buffer distance value <500m were restricted from the consideration of the analysis for landfill siting. So such unsuitable attributes and values were restricted from consideration whereas suitable value or attributes were overlaid in weighted overlay with their respective relative weights to achieve the required objective. After all the unsuitable attributes and values were restricted in weighted overlay the weighted overlay thematic map was obtained.

To meet the ultimate required objective of the study, from the weighted overlay thematic suitability map, only very high suitable (highly suitable) potential areas were extracted and further landfill site analysis were carried out to these locations only. Since, with the considered suitability criteria these locations were found highly suitable. Therefore, it's not worthy to spend analysis in other locations with suitability distributions like less suitable, moderate suitable & high suitable. Rather, further analysis was only focused on the very high (highly) suitable potential areas. So, extract very high suitable thematic areas, the weighted overlay result was converted into vector format and then by querying select by attribute for grid code value 5 (which represents very high suitable) was selected and exported. Very high suitable sites were generalized by applying post processing techniques such as con, filter, boundary clean, region growth and nimble in ArcGIS. Then small discontinuous parcels < 20 hectare were excluded from further analysis because they were very tiny in size and were not connected pixels. Taking into account the importance of size from above discussions, for the current study the minimum threshold of parcels size 20 hectares was decided as requirement for solid waste landfilling in Hosanna town. Accordingly, the result of the analysis has shown four candidate landfill sites with their parcels size > 20 hectares were obtained and further landfill suitability analysis were carried out to these sites. Finally, using AHP procedure very high suitable candidate sites were prioritized and ranked according to their suitability to decide the best single suitable solid waste landfilling site for Hosanna town.

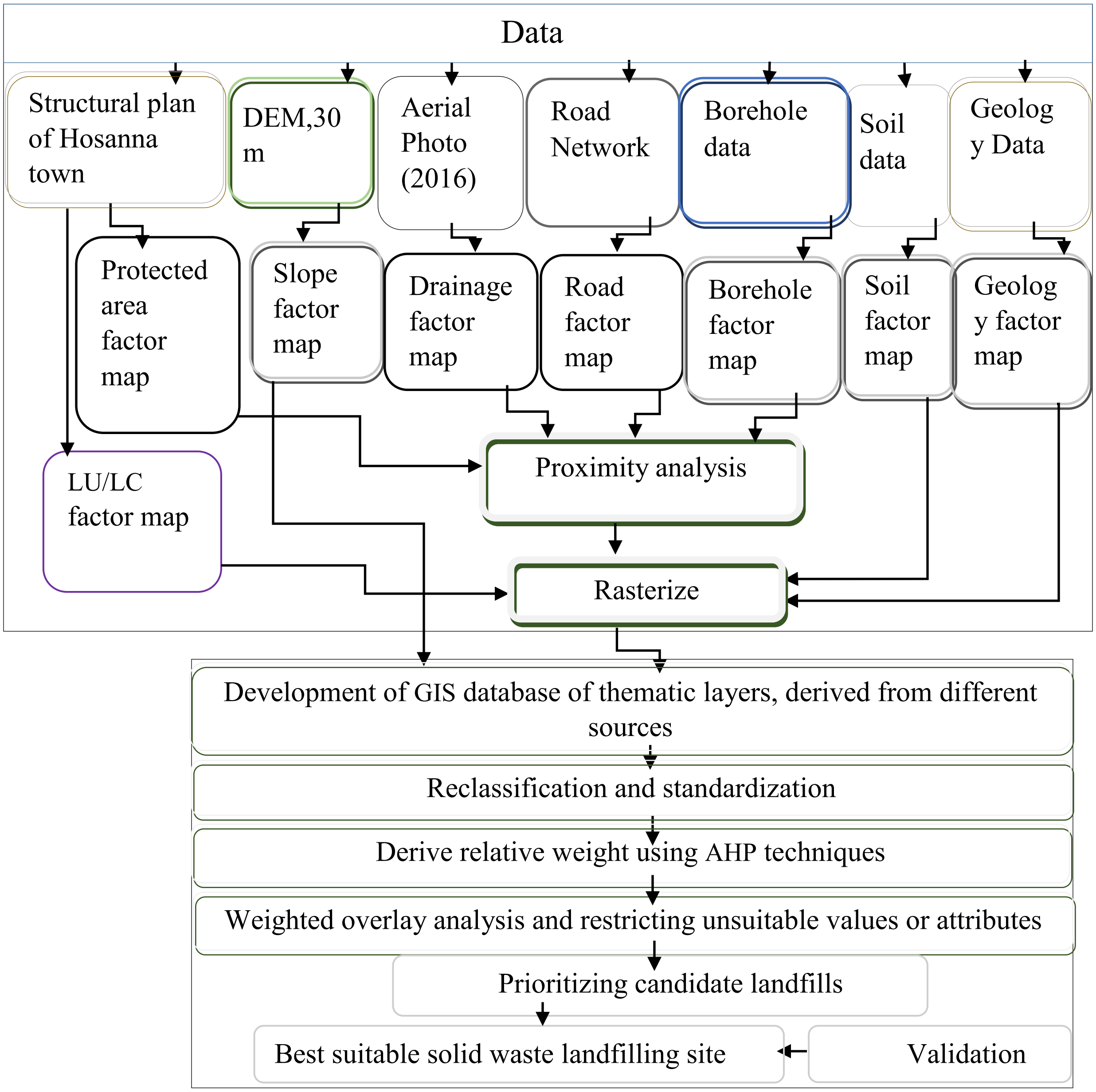

Figure 5. Methodological framework for optimal solid waste landfilling site selection

CHAPTER FOUR

Result and discussion

4. Analysis of suitability factors for selecting potential landfill site

4.1. Biophysical suitability factors analysis

4.1.1. Land use/ land cover suitability analysis

Land cover/ land use is an important factor in landfill siting because excavation of landfill site may lead disturbance of land cover or land use and if a waste disposal site is once introduced to a given area, the land value of the surroundings and other locations would change soon (MS Consultancy, 2013). So the negative effect of landfill on land value should possibly be minimized in the current site selection process by choosing suitable land use/cover type.

For this study, the land use/land cover was analyzed from the structural plan of the Hosanna town which was originally developed from Ikonos satellite image by digitization techniques. For instance, the work of (Kabite, 2011, p.31 & Kumel, 2014, p.25) have applied the structural plan of the city/town for land use/land cover analysis for landfill siting analysis. Since, the LU/LC class accessed from structural plan was already stored in a vector format it was converted into "tiff" raster format in order to facilitate analysis and about 13 land use/land cover classes were used for landfill siting suitability analysis. The land use/land covers extracted from structural plan of the town for the current study includes (roads, recreational areas, administration areas, mixed residential, residential, general service areas, industrial areas, urban agriculture, commercial areas, transport parking areas, river, bare areas, and roundabout).

Land use/ land cover information was analyzed for landfill siting from direct & indirect effects on environment, society, and economic value of the land. As (Kabite, 2011; Aklilu, 2015; Minalu, 2016; Kimwatu & Ndiritu, 2016 & Demir et al., 2016) suggest bare lands are the most suitable for landfill siting whereas built up areas like infrastructures and service areas and water bodies are unsuitable/restricted. Based on this, from the available land use/ land cover classes (Table 4 & Fig 6) bare lands with its areal coverage of 16.3% was reclassified as very high suitable for solid waste landfilling because in bare areas no any development activities are undergone before as such its economic value of the land is low.

Out of study area total, about 3273.16 hectare of LU/LC was restricted from the consideration for landfill siting analysis. These LU/LC were restricted because of their unsuitable nature for landfill siting as consulted in different literatures. The results were shown in (Table 4) below.

Table 4. Land use/ land cover areal coverage and suitability (Technical own processing)

LU/LC Class	Area(ha)	Area share(%)	Score Value	Suitability Level
Road	632.7	6.3	0	restricted
River	502.8	5	0	restricted
RA	212.7	2.1	0	restricted
ADA	25.5	0.3	0	restricted
MRA	362.1	3.6	1	very low
RSA	1220.1	12.1	0	restricted
GSA	442.8	4.4	0	restricted
IA	206.1	2	2	low
UA	4575.5	45.5	4	high
CA	236.16	2.3	0	restricted
TP	6.6	0.1	3	moderate
BL	1637.5	16.3	5	very high
Roundabout	0.4	0.004	0	restricted
Total	10,0061	100%		

Where, RA= recreational area, ADA=administration area, MRA= mixed residence area, RSA=residential area, GSA= general service area, IA=industrial area, UA= urban agri, CA=commercial area, TP=transport parking, & BL=bare land.

By reviewing the LU/LC suitability for landfill siting, for the study area the following land use/ land cover classes were restricted which includes road, river, residential area, administration area, recreational area, general service area, commercial and roundabout (Table 4). These land use/ land covers were restricted because of their social values fixing solid waste landfilling site in these mentioned LU/LC areas are unsuitable.

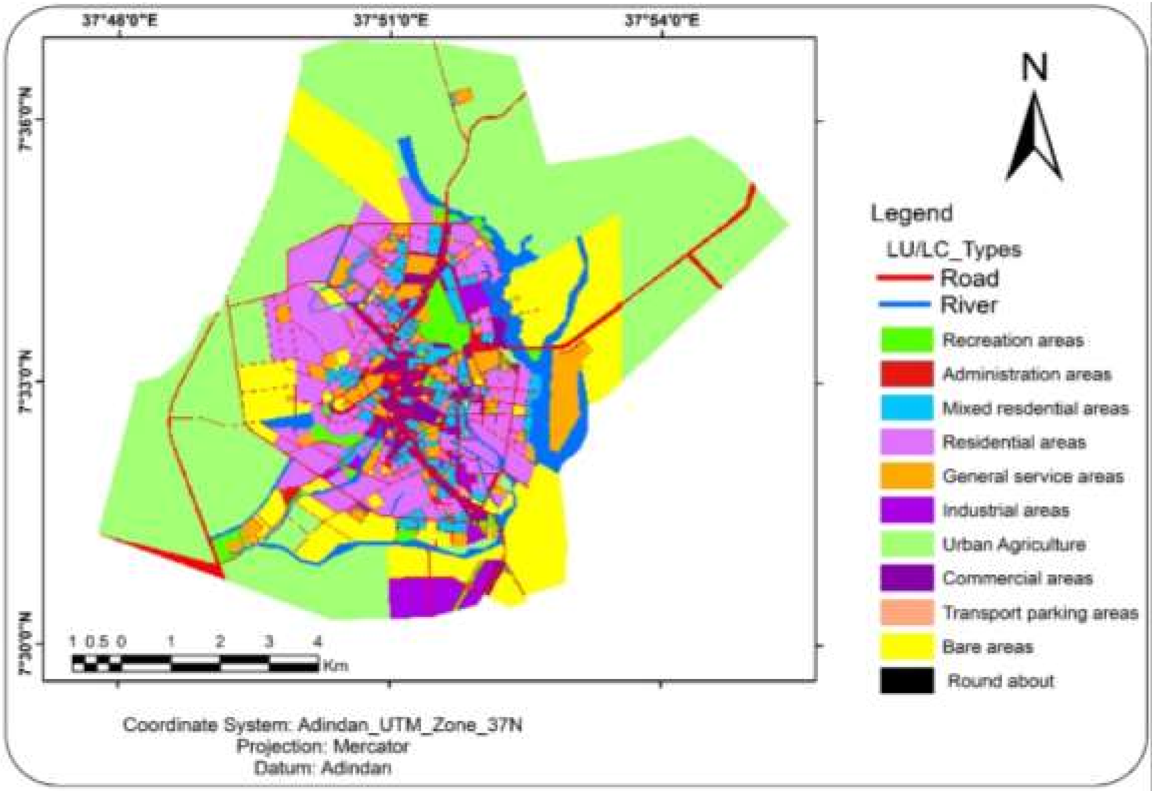

Figure 6. Land use/ land cover thematic map

4.1.2. Slope suitability analysis

Slope has been identified as one factor for landfill site selection analysis because the surface runoff and movement of pollutants are governed by it. In addition to this, slope also have an indirect connectivity to soil type formation and thickness. Due to this it can influence the hydrological characteristics the area. Flat land and depression topography are not recommended for landfill siting due to risk of runoff and subsequent contamination of nearby water bodies and ground water. Also, high slope area is not preferred for landfill facility because of additional excavation cost incurring in first construction time and later maintenance; increased leachate movement, and difficulty of vehicle movement to the site. Therefore, the best slope for solid landfill should be gentle slopes, which enable easier storm water control, leachate control, site stability and easy operation of the site (Mekuria, 2006; Wang et al., 2009; Lin & Kao, 1998, 2005). Slope of 8-12% is best for landfill siting (Lin & Kao, 2005).

For this study, suitability of slope class for landfill siting was determined based on (Kabite et al., 2012; Kimwatu & Ndiritu, 2016). To know the suitable slope range for landfill siting the slope of the study area was reclassified into six classes (Table 5).

Table 5. Slope class areal coverage and suitability (Technical own processing)

Slope Class (%)	Area(ha)	Area share(%)	Score Value	Suitability Level
0-5	395.3	3.9	1	very low
5-10	1981.3	19.7	5	very high
10-15	3903.3	38.8	4	high
15-20	2300	22.9	3	moderate
20-25	953.3	9.5	2	low
>25	527.8	5.2	1	very low
Total	10,0061	100%		

As the analysis revealed (Table 5) the topography of the area was dominated by a slope class of 10–15% which accounted for about 38.8% of the study area total whereas The slope class of 5-10 % (gentle slope area) covers about 19.7 % of the study area and it was ranked as very high suitable because of its optimal suitability for easy control of runoff and other operations. As a result, high rank value of 5(very high suitable) as a preference indicator was assigned to this slope class whereas the slope class of 10-15% were analyzed as the second suitable option for landfill siting.

Locations with slope class <5% were found very low suitable for landfill due to water logging problem and also slope class of >25% was ranked as the last option (very low suitable) for landfill site because as steepness increases the cost of excavation for landfill infrastructure construction and also high probability of transportation of polluted materials through flooding (Gostin, & Hodge, 2002, Akbari, 2008; Ebistu & Minale, 2013).

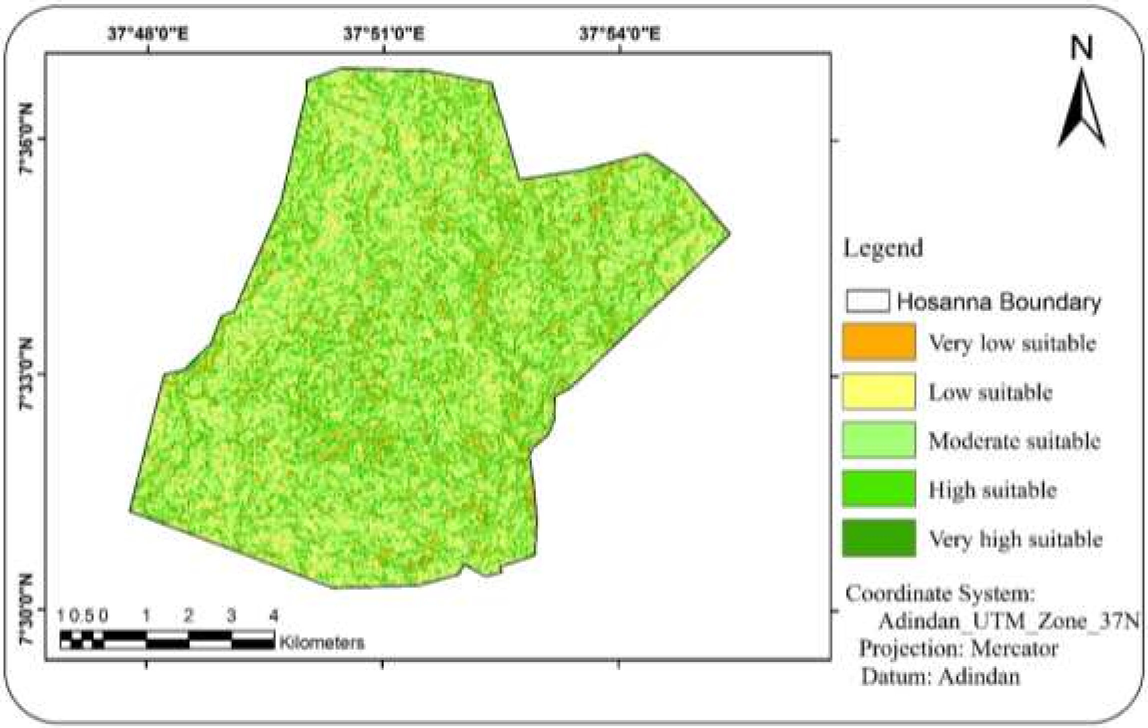

Figure 7. Slope suitability map

4.1.3. Proximity analysis to drainage network

Drainage system of an area was found an important parameter for landfill site selection because runoffs from a landfill may adversely affects the surface water such as streams, and swamps. As (Sunder et al, 2014) drainage areas have more infiltration capacity than non-drainage area. So landfill siting in areas with low drainage network is more preferable. Particularly, during raining time due to flooding the water level may increase to causes the over flow of flood and the flood may find way to enters to landfill site to carry away wastes to the surroundings. To prevent this, a buffer zone has to be kept around the drainage channels. The presence of some perennial and seasonal rivers in the surrounding of the study area such as Ajo, Shilansha and Batenna which are also the main sources of water supplies have to be protected from unexpected runoff flush by maintaining buffer distance.

Table 6. Drainage network buffer distance areal coverage and suitability

Drainage Distance	Area(ha)	Area share(%)	Score Value	Suitability Level
0-500m	3964.3	39.4	1	very low
500-1000m	2355.4	23.4	2	low
1000-1500m	1513.3	15	3	moderate
1500-2000m	1035.1	10.3	4	high
2000-2500m	1192.9	11.9	5	very high
Total	10,061	100		

As it is shown on (Table 6) drainage distance suitability analysis for landfill siting reveals that majority of the study areas (39.4%) was very low suitable and only 11.9 % of buffered distance from drainage channel was found very high suitable. Since, very high suitable drainage distance class was smaller in areal coverage drainage network suitability factor was a significant criterion to some extent in determining landfill sitting for the study area.

To determine the suitable distance between drainage network and landfill sites the work of (MUDC, 2012; Wang et al, 2009; Ebistu & Minale, 2013; Elahi & Samadyar, 2014) were used. Areas that are far from drainage network were given higher preference in reclassification for landfill site fixing. In the current study, a buffer distance was specified around all drainage channels in order to identify suitable distance range for landfill siting. Then a buffer distance of 2000-2500 was reclassified as very high suitable being scored with higher value 5 and a buffer distance of 0-500m was reclassified as very low suitable being scored with lower value 1. For the rest of buffer distances their respective suitability scores were allocated (Table 6 & Fig 8).

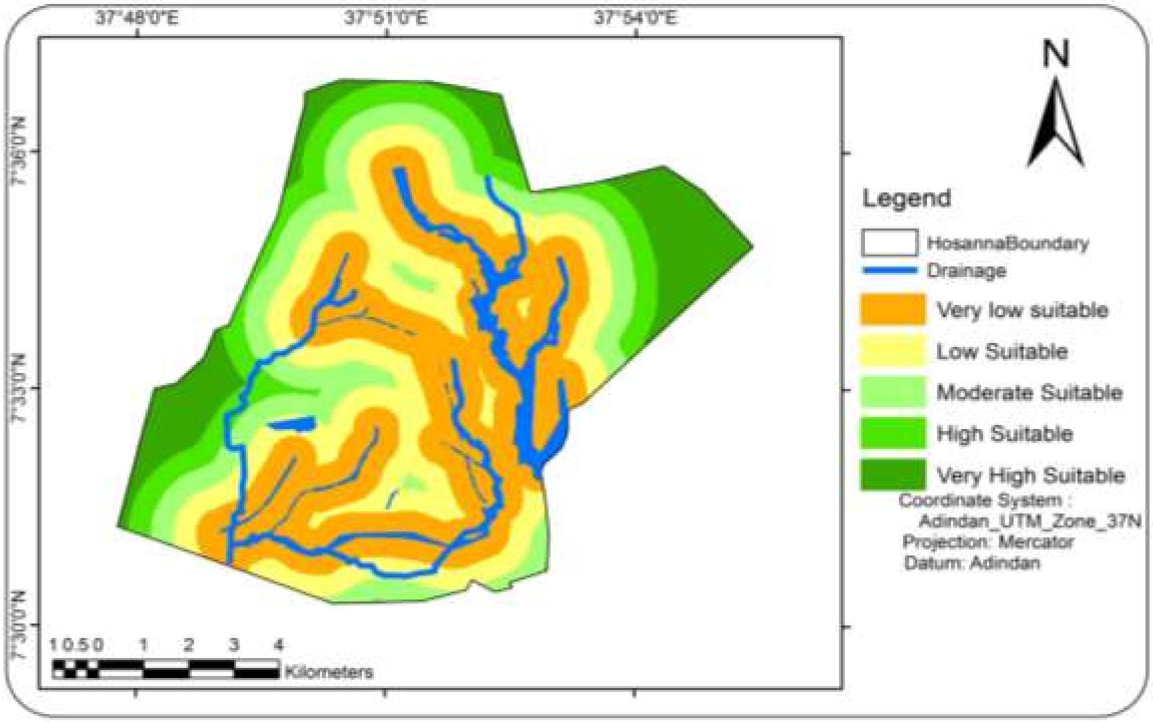

Figure 8. Drainage network suitability map

4.1.4. Borehole suitability analysis

From water department of Hosanna town four drilled boreholes GPS point data were collected. Using these point data, borehole layer was produced in ArcGIS environment. In order to protect the safety of ground water contamination by leachate from landfill site a buffer distance was specified into borehole layer. Accordingly, to know suitable buffer distance for landfill siting the buffer distances from borehole layer was categorized into five suitability buffer distances which includes <500 m, 500-1000 m, 1000-1500 m, 1500-2000 m and >2000m being assigned with new score values 0, 2, 3, 4, & 5 respectively (Table 7).

Table 7. Boreholes buffer distance areal coverage and suitability

Distance to borehole	Area(ha)	Area share(%)	Score Value	Suitability Level
<500m	278.2	2.8	0	restricted
500-1000m	695.4	6.9	2	low
1000-1500m	855	8.5	3	moderate
1500-2000m	868.8	8.6	4	high
>2000m	7364.1	73.2	5	very high
Total	10,0061	100%		

As shown in (Table 7) the suitability buffer distances >2000m from boreholes locations were very high suitable for landfill site selection and covers majority of study areas which accounts about 73.2 % whereas the suitability buffer distances <500m from boreholes were restricted for landfill siting (Fig 9).

To protect ground water from potential threat from landfill sites boreholes location is the main environmental criteria that should be considered during landfill site selection processes. The leachate from landfill may percolates deep into the ground and hence pollutes the ground water in the long run. Such effect can be minimized by avoiding landfill site in close proximity to ground wells. To analyze the suitability of boreholes to landfills, the above buffering suitability distance was used as per (Kabite, 2011, Elahi & samadyar, 2014).

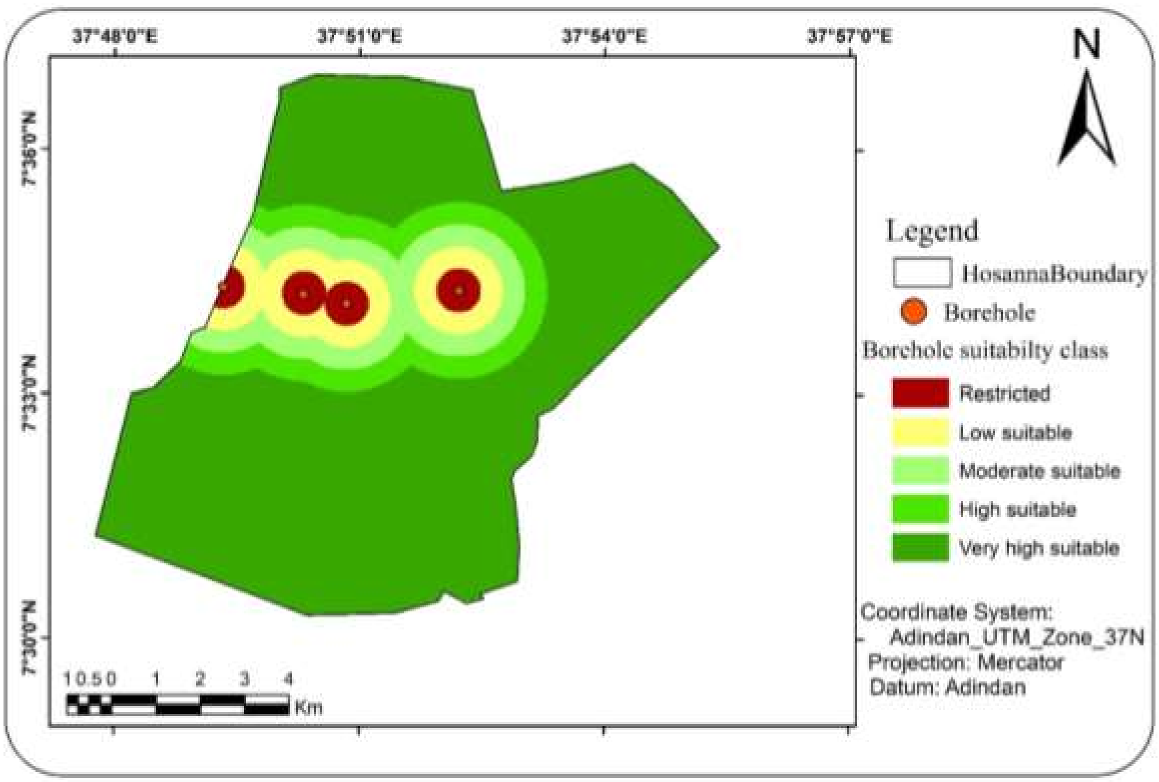

Figure 9. Borehole suitability map

4.1.5. Soil type suitability analysis

A digital soil layer data obtained from Hadiya Zone department of water, mineral and energy was used to prepare soil suitability thematic layer and the identified available soil types of the study area includes: - cambisols, luvisols, nitisols and vertisols (Fig 10) and from it the locations with good soil class coverage for construction of landfill sites were analyzed.

Table 8. Soil type areal coverage and suitability

Soil Class	Area(ha)	Area share(%)	Score Value	Suitability Level
Cambisols	2516	25	2	low
Luvisol	5844.5	58.1	3	moderate
Nitisol	1644	16.3	4	high
Vertisols	56.5	0.6	5	very high
Total	10,0061	100%		

From the table 8, it was obvious most of the study area was covered by luvisol which accounts the share of 58.1% and spatially found distributed in west, south west & north eastern part (Fig 10). Cambisol holds the second place in areal share with about 25% out of study area total and it's found distributed from central part to north whereas only 0.6% of study area was underlain by vertisols.

The suitability of soil types for landfill siting was evaluated through its permeability and porosity to the movement of pollutants as well susceptibility to erosion. Because these characteristics of soil governs the percolation of pollutants into sub surfaces and washing in time of flooding. Soil should be of sufficiently low permeability to ensure very slow movement of leachate from the landfill site towards groundwater. Thus, sites on clayey soil having low permeability should be preferred for landfill siting (Gostin & Hodge, 2002; Sener, 2004; Khan & smadder, 2015). Study by (Elahi & Samadyar, 2014; Baha et al., 2011 & Gizachew, 2011) shows that vertisols were identified as highly suitable for landfill because of its high clay content, which is about 60% and also being very deep it can be used as a cover material to minimize the odor from the site but Soils having high rate of permeability like district cambisols and cambic podzols with karst formations are considered unsuitable.

For the current study, by reviewing the above discussed literatures verisols was reclassified as very high suitable for landfill siting and nitisol was reclassified as the second best suitable following vertisols whereas cambisols was reclassified as low suitable because of its high rate of permeability (Table 8).

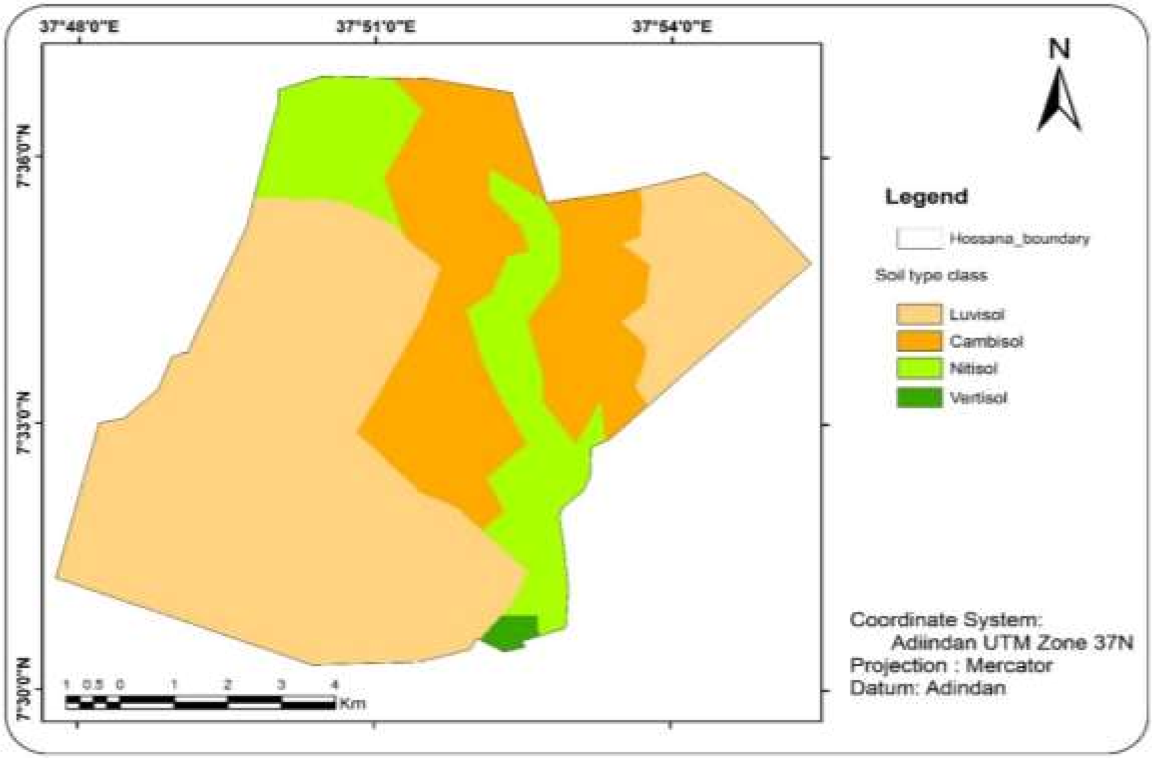

Figure 10. Soil type thematic map

4.1.6. Geological factor suitability analysis

The geological factor map analysis was used for landfill site selection analysis because the geological formation of the site controls degree of weathering and fracture of underlying rocks. Unconsolidated lithology is not suitable for landfill siting (Ersoy & Bulut, 2009). From the geological data three geological classes were identified for the study area which includes (Nazretpyroclastic, Ignimbrite, and Rhyolite with some trachyte lava flows).

According to (Peter et al., 2013) areas that have poor geological conditions were given lower scores which is an indication of its poor suitability for landfill siting whilst those that are supposed best were given higher scores. The study by (Ayenew et al., 2008) have indicated Ignimbrite and rhyolite are very low permeable due to less degree of weathering and fracture. Due to this, such areas are the best preferred for protection of ground water pollution from landfill sites.

Table 9. Geological class areal coverage and suitability

Geology Class	Area(ha)	Area share(%)	Score Value	Suitability Level
Nazretpyroclastic	9734.3	96.8	3	moderate
Ignimbrite	152.5	1.5	5	very high
Rhyolite with some trachyte lava flows	174.2	1.7	4	high
Total	10,0061	100%		

Table 9 shows that almost all parts of the study area were underlain by nazretpyroclastic geological class with areal coverage of 96.8% except other geological class being confined amazingly in north west part. Despite its small areal coverage (1.5%), ignimbrite was found very high suitable class for landfill siting because it is less susceptible to weathering and also it is low permeable so it can prevent the percolation of leachates further down to the ground water.

By reviewing the work of (Ayenew et al., 2008; Peter et al., 2013; Demir et al., 2016; Kimwatu & Ndiritu, 2016) ignimbrite was reclassified very high suitable geological type whereas nazretpyroclastic geological was reclassified as moderate suitable for landfill siting(Table 9). Higher score value 5 was assigned to ignimbrite as an indicator of better preferred and lower score of 2 was assigned to nazretpyroclastic layer because of its higher susceptibility to infiltration. Generally, the suitability of geologic type for landfill siting decreases as its permeability increases and vice versa (Fig 12).

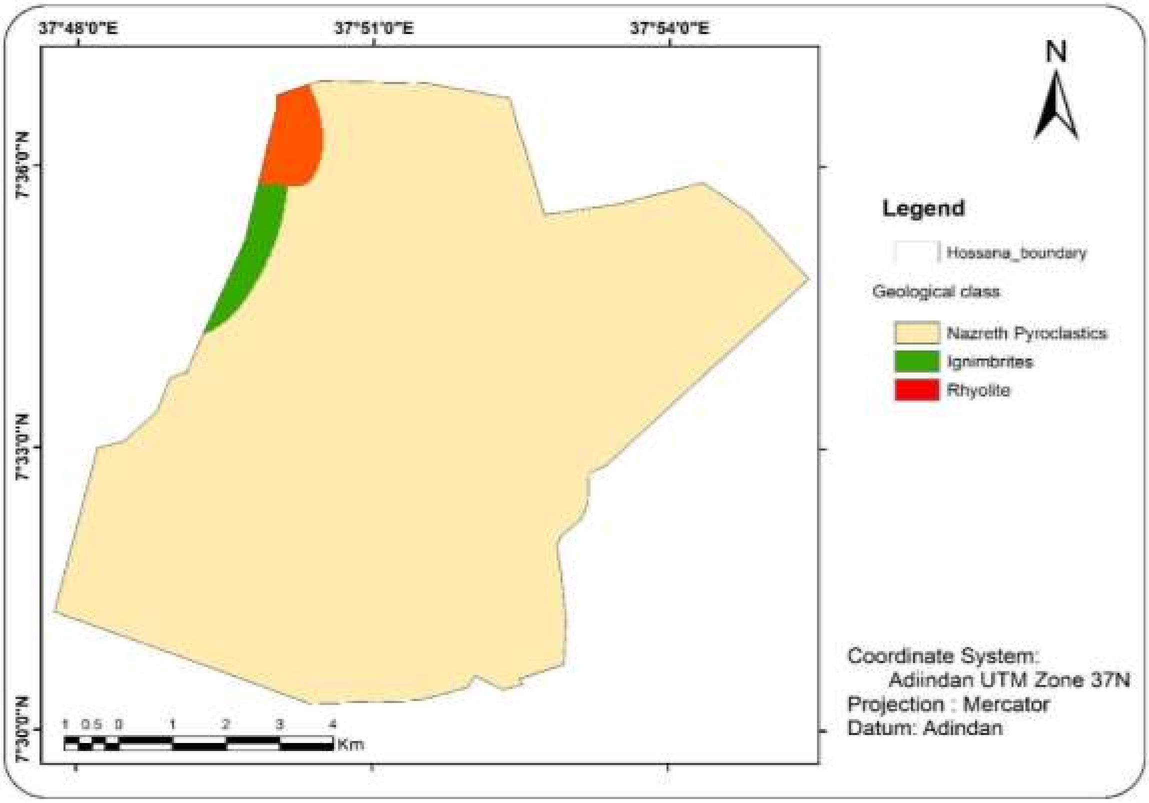

Figure 11. Geological type thematic map

4.2. Socioeconomic suitability factors analysis

4.2.1. Proximity analysis to road network

Selection of new landfill site needs considering the existing road network to avoid construction of new accessible road to the site. The site must have to consider accessibility for vehicles movement to transport waste to the site with the view of economic efficiency to reduce fuel consumption. Moreover, the site also needs to consider acceptable distance from road users in order to avoid bad odor from the site. So to site a landfill, the suitable acceptable distance from the road network need to be decided. As reviewed in literatures, landfill sites are neither located very close to road network nor very far, but it has to be at medium acceptable distance why because if it is too near to road it creates aesthetic and bad odor problems for road users and also influences the economic development of the areas and if it is too far from accessible road it creates difficulty for waste collectors as well as it causes economic inefficiency due to high fuel consumption by vehicles for hauling in its operational period of the site.

Realizing these above mentioned problems, the distance suitability criterion from the road network and landfill site was evaluated on the basis of these considerations.

Table 10. Road network buffer distance areal coverage and suitability

Road Distance	Area(ha)	Area share(%)	Score Value	Suitability Level
0-300m	6896	68.5	1	very low
300-600 m	1701	17	2	low
600-900m	749.2	7.4	3	moderate
900-1200m	435	4.3	4	high
1200-1500m	233.4	2.3	5	very high
>1500	46.4	0.5	1	very low
Total	10,0061	100		

From the table 6, it was obvious that the very low suitable road layer buffer distance for landfill siting has covered 69 %(68.5+0.5) of the study area total. These areas were buferr distances <300m & beyond 1.5m from the road network layer. Since buffer distance < 300m from landfill site were closest to the roads it was reclassified as very suitable due bad smells from site may cause health problems and also it influences economic development of the area and activities of the society whereas > 1500m was reclassified as very low suitable because of increased waste hauling cost to the site and the remoteness of the site form existing road may lead to construct a new additional road. Very high suitable road layer buffer distance for landfill siting has covered 2.3 % of the study area total. As seen in (Table 10) the areal coverage of very high suitable buffer distance from road layer was small. As a result of this, road layer becomes a significant suitability determining factor for landfill site selection.

In this study for road network distance suitability analysis, a buffer distance was specified around road network layer based on work of (Kumel, 2014) and it was reclassified into five suitability classes (Table 10 & Fig 12). Therefore, taking into account the spatial extent of the town, the landfill location with a buffer distance of 1200-1500m from existing road was decided very high suitable being assigned with highest suitability score value as a preference indication. Very low suitable buffer distance from existing road network was identified to distance of 0-300 m (Fig 12) due to its very near to road it can pose some socio economic problems stated above. Also, very low suitable class was identified to buffer distance of > 1500m from road network from economic point of consideration because transporting the waste in daily basis to far away landfill site is not economically efficient as seen in long run service time of the site. If any possibility of finance shortage comes into existence to the waste management sector its sustainable steady progress of waste disposal and management process may be hampered. So taking into consideration these expectations, the site must have to be at acceptable distance of neither too far nor too close to existing road network. Similarly, (Khan & Smadder, 2015, Asha et al, 2016) suggest landfill site should not be placed too far from the existing road networks for reducing the cost of new road construction, transportation and collection costs of solid wastes. For this study, the acceptable buffer distance from road network to landfill site was decided based on (Kumel, 2014). The results are shown in (Table 10).

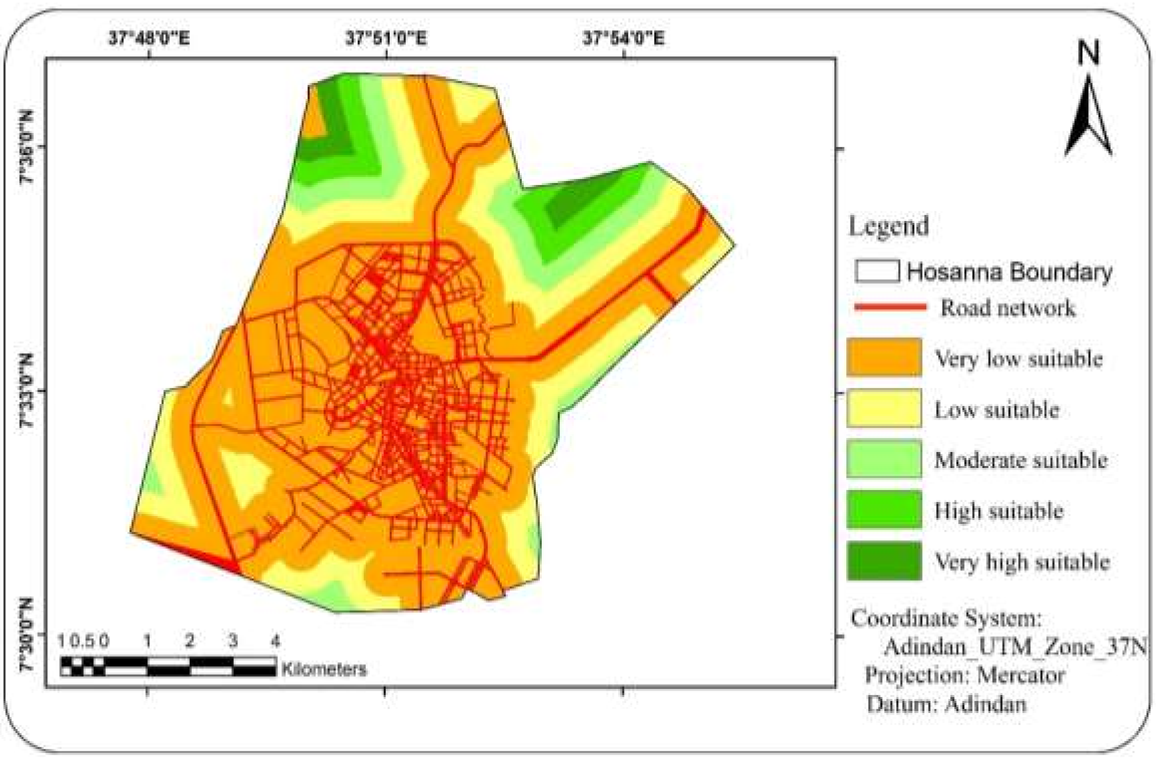

Figure 12. Road network suitability map

4.2.2. Proximity analysis to protected areas

In the current study, locations near to sensitive areas such as different religious centers, public schools, parks, wetland, general service areas, and recreational areas were restricted from landfill siting analysis whereas locations far away from these protected areas were reclassified as suitable for landfill siting. Similarly, (Ersoy & Bulut, 2009; Babalola & Busu, 2011) suggest landfills should not be located in close proximity to sensitive areas. As shown in (Table 11) majority of protected areas which accounts about

36.4% of study area total fall under a buffer distance of >2000m form environmentally sensitive areas and these locations were found very high suitable for solid waste landfilling. From study area total about 26.5% of sensitive areas were restricted for landfill siting analysis (Table11 & Fig 13). Generally, the suitability of landfill siting increases as distance from sensitive areas increases and vise-versa.

Table 11. Protected area buffer distance areal coverage and suitability

Distance to PA	Area(ha)	Area share(%)	Score Value	Suitability Level
0-300m	2668.4	26.5	0	restricted
300-500m	1453.3	14.4	1	very low
500-1000m	901.9	9	2	low
1000-1500m	697.2	6.9	3	moderate
1500-2000m	676	6.7	4	high
>2000m	3664.2	36.4	5	very high
Total	10,0061	100%		

Landfill site should be sited far from the existing sensitive area due to the environmental consequence that might result from locating it near (Kimwatu & Ndiritu, 2016). Different researchers set different suitability buffer distance for landfill siting from environmentally sensitive areas. For this study, the work of (kumel, 2014; Kimwatu & Ndiritu, 2016) a suitability buffer distance from the protected areas was applied for landfill siting. The area located at the distance greater than 2000m from environmentally sensitive area were selected as very high suitable for solid waste landfill siting whereas areas <300m was restricted from the consideration into the analysis. Due to this, a score value of (5) which represents very high suitability was allocated to farthest buffer distance whereas for a buffer distance of <300m from sensitive area it was restricted and score value of (0) was allocated to it. The results are shown in (Table 7) above.

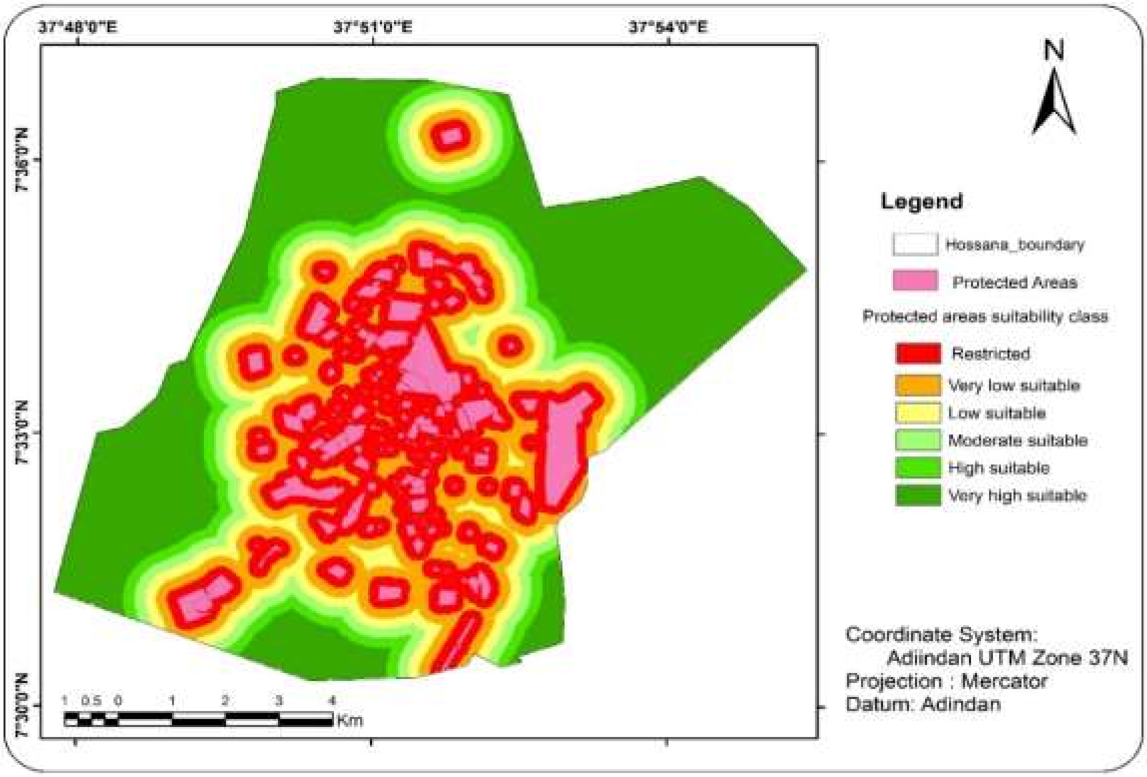

Figure 13. Protected area suitability map

4.4. Weighting criteria and pair wise comparison matrix (evaluating landfill siting using AHP)

In practice, it is usually unsuitable to give equal importance to each of the criteria being combined. Factors need to be weighted depending on their relative significance and their weights and scores were assigned based on previous knowledge of the study area (Asha et al, 2016). The pair wise comparisons associated with the AHP the factors have been used to weight the relative importance of factors involved. The method was known to be used in scientific study of decision problems. The expert's pair wise rating of the relative importance of factors was used to derive the relative importance weight for each considered landfill site evaluation factors. To derive the relative weight for each factors the expert's pairwise rating of factors was filled into computer package in order to obtain weight and the consistency ratio. The consistency ratio obtained was then used to check whether the judgment of the expert in rating the relative importance of factors was logical or not. Accordingly, the result in the Idris AHP module indicated that consistency ratio was 0.03 (Fig 14) which is <0.1 and the judgment of expert was acceptable based on (Saaty, 1980).

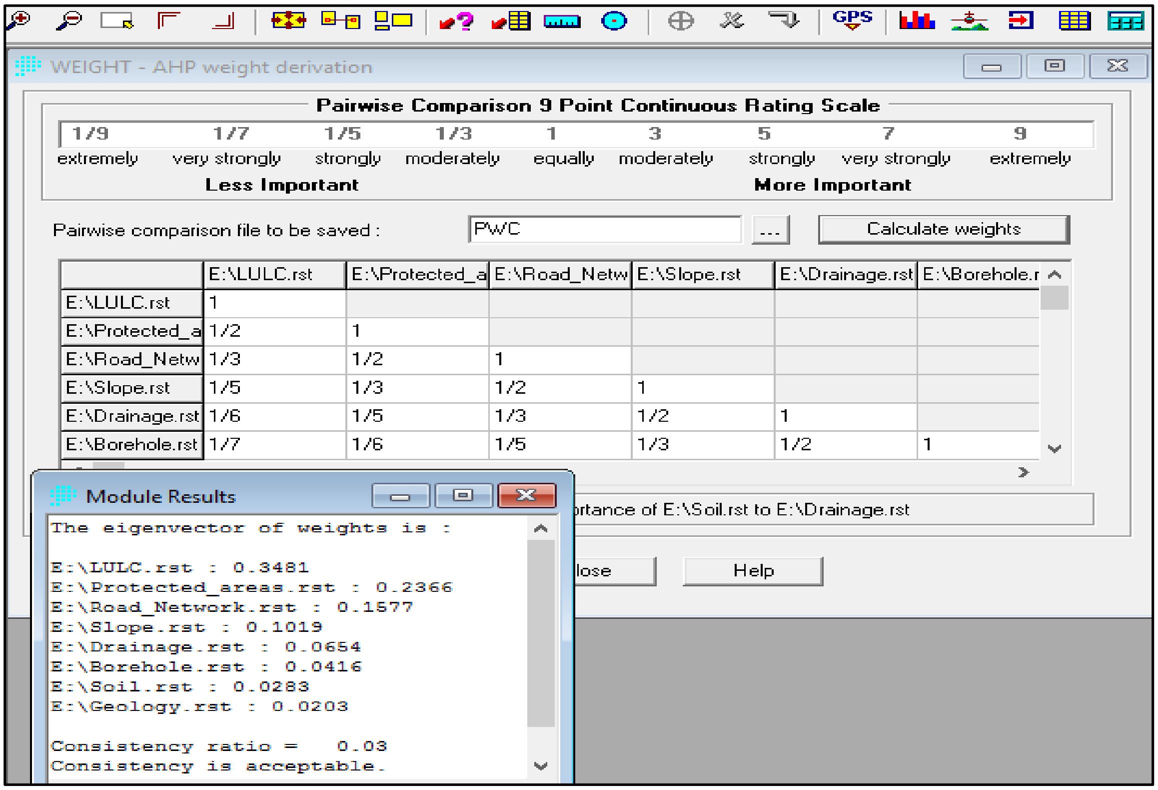

Figure 14. Municipality expert pairwise rating of the relative importance of factors being filled into Idris weight derivation module

After being the expert rating filled into Idirisi AHP weight derivation module as shown in the above screen shot (Fig 14) the following eigenvector weights were generated for each considered factors for landfill site evaluation (Table 12).

Table 12. Eigen relative importance weights derived for each suitability factors

Factor/Layer	Relative Weight	% of Influence
LU/LC	0.3481	35
Protected Area	0.2366	24
Road Network	0.1577	16
Slope	0.1019	10
Drainage Network	0.0654	6
Boreholes	0.0416	4
Soil	0.0283	3
Geology	0.0203	2
Σ	1	100%

→ Consistency ratio = 0.03, Consistency is acceptable.

4.5. Weighted Overlay Analysis

In order to make comparison of criteria one with other, being the different input factor maps have dissimilar measurement units. for instance, slope in degree, land use/land cover in class type & distance in meter so the comparison to be meaningful all values were transformed into the same unit of measurement scale *1 to 5* evaluation scale in which scale values of layers are weighed so they are comparable with previously reclassified datasets. The reclassified outcomes generated through the different GIS analyses were added into weighted overlay to identify coincidence of areas that can satisfy the specified suitability's ranging from restricted to very low suitable, low suitable, moderate suitable, high suitable, and very high(highly) suitable.

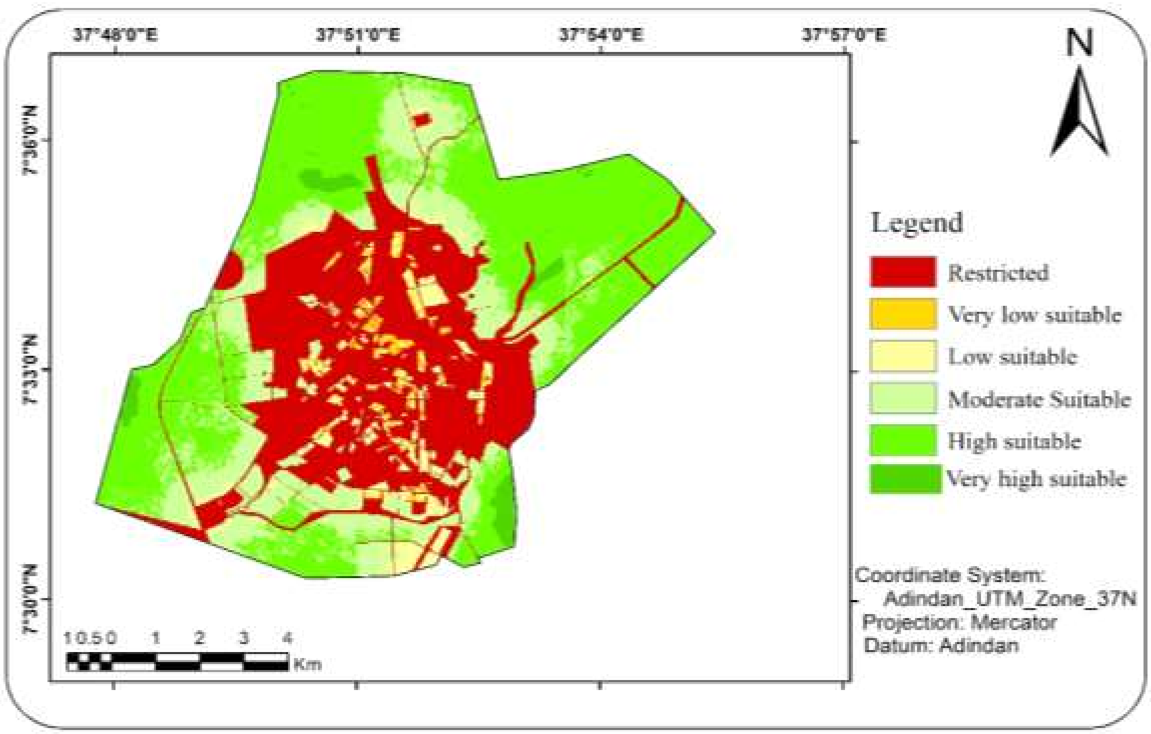

Figure 15. Weighted overlay suitability distribution thematic map

Table 13. Weighted overlay suitability distribution results

Suitability class	Areal coverage(ha)	Areal share(%)
Restricted	3392.72	33.72
Very Low suitable	163.65	1.63
Low suitable	383.79	3.81
Moderate suitable	2016.66	20.04
High suitable	3912.18	38.89
Very high suitable	192	1.91
Total	10,061	100

4.6. Highly suitable landfill sites thematic map

The finding in weighted overlay has shown only 192 hectares (Table 13) from the study area total was found very high(highly) suitable landfill site (Fig 15). This implies, the rest of 9, 869 hectare of area were in different suitability distributions ranging from very low suitable to restricted. From the analysis the available very high suitable potential sites areal coverage was significantly enough to obtain enough parcel of land for landfill siting. Provided this, the next further landfill siting analysis was carried out to these sites

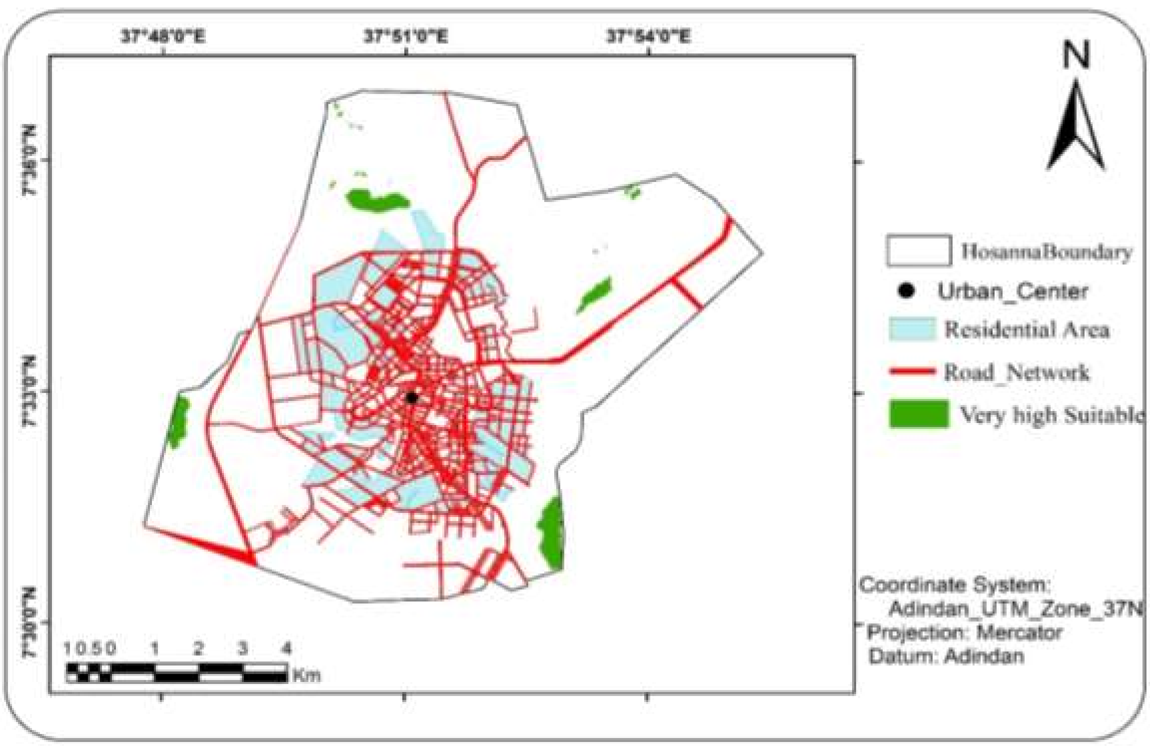

Figure 16. Very high suitable areas thematic map

4.7. Prioritizing highly suitable candidate landfill sites

In the landfill siting process, it is necessary to rank suitable sites and choose the best one in the next stages and analytical hierarchy process (AHP) can be applied to overcome such problems (Alavi, 2013). To make the selection more precise, candidate sites have to be further compared with most significant criteria (Khan & Smadder, 2015). The basic criteria used for prioritizing candidate landfill site by (Kimwatu & Ndiritu, 2016) were size and proximity to the urban center.

Likewise, for the current study, after very high suitable potential sites were identified in weighted overlay GIS environment to prioritize and rank very high suitable candidate sites the most important socioeconomic sub-criteria like distance from nearby residential area, distance from the urban center of the town, and size capacity of the landfill were used. The prioritization was carried out to find the best site among each candidates that can satisfy the required objectives of safe from environmental and socioeconomic perspective.

From economical point of views larger sized landfills can give long time service than small sized one. As such it facilitates not to construct new landfill in short time. Demand for future landfill space should be considered during the site selection process by ensuring that adequate size exists for the present and future waste holding capacity (Zaman & Lehmann, 2011). Bearing this in mind, to know the size of parcels the weighted overlay result (Fig 15) was converted into vector format and then very high suitable sites were extracted from other suitability distributions of weighted overlay. Then the thematic map of very high suitable sites was obtained (Fig 16).

Very high suitable sites were generalized by applying post processing techniques in ArcGIS. Taking into account the importance of size from above discussions, for the current study the minimum threshold of parcels size 20 hectares was decided as requirement for solid waste landfilling in Hosanna town. Accordingly, the result of the analysis has shown four candidate landfill sites with their parcels size > 20 hectares were obtained and further landfill suitability analysis were carried out to these sites (Fig 16).

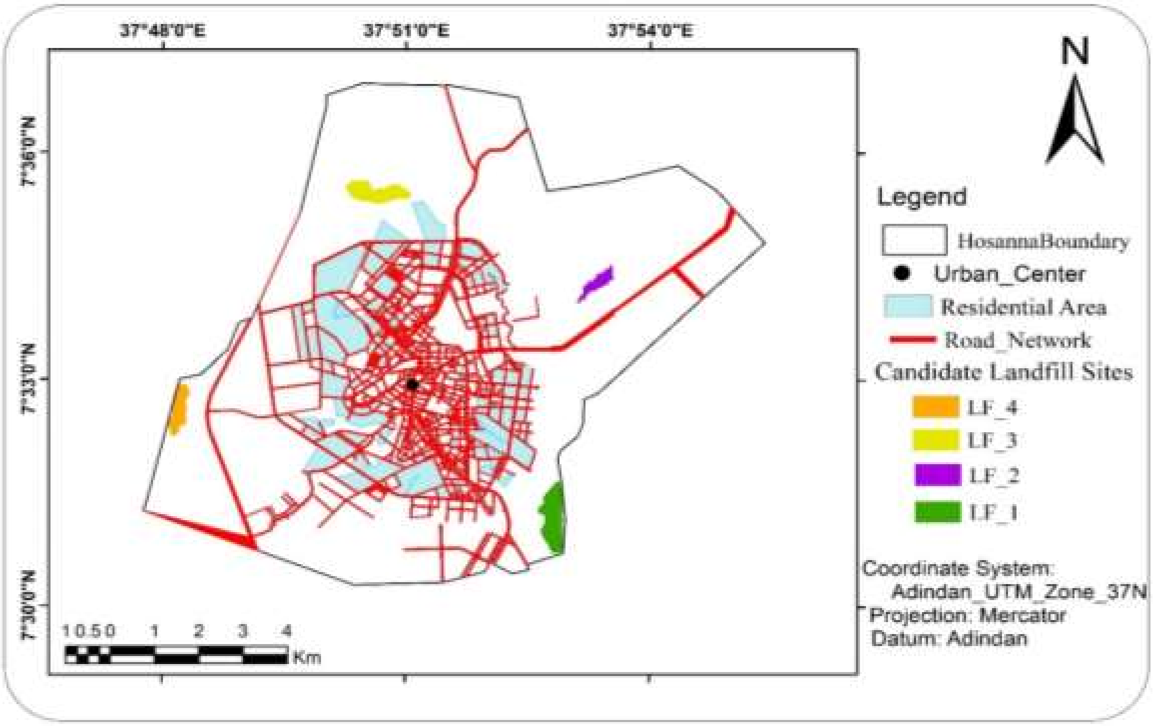

Figure 17. Candidate landfill sites location in light of urban center, residence, and road

Evaluation of candidate landfill sites in light of size shows that *LF1* with areal coverage of 68.25 hectare (Table 14) was the best preferred candidate site. Whereas *LF2* was less preferred from size perspective due to its smaller areal coverage and *LF3* was found relatively better in size capacity next to *LF1* and also it was located at bare ground made the site the second best suitable site but from residential area perspectives the site was less preferred because it's found very near to residential area with about 0.22 km.

Evaluation of candidate landfill sites with respect to urban center was another sub criterion considered from the economic point of view. Since urban centers are the source of wastes generation where hotels are dominantly found the landfill sites selected should have to consider the distance of the site in light of transportation cost in its operational time. As seen from economic view, landfills too far from urban center were less preferable whereas sites in an acceptable distance from the center of the town was more preferable (Kabite, 2011; Kumel, 2014). Accordingly, with regard to urban center evaluation candidate landfill sites with shortest path from the urban center was discovered for *LF1*, which was about 3.9 km (Table 14 & Fig 17) close to the center than other sites whereas *LF4* was found far as compared with the rest of the site which was about 5.23 km (Table 14) away from the center of the town as such it remained not preferable. Therefore, from transportation cost point of view analysis from waste generation sources, *LF1* was discovered a preferred candidate site because of its nearness the daily rounding of vehicles and waste collectors economic cost is low.

Another decided 3rd candidate landfill site prioritization sub-criterion was distance from nearby residential area. This criterion was seen from health risk to nearby settlers, hindrance of their economic activities and land value deterioration due to being new landfill introduced to the area. Landfill should not be located near settlement area as it can raise public opposition, decreased land value during selling and renting and also other health impacts (MUDC, 2012; Ebistu & minalu, 2013). To minimize these adverse impacts from the landfill site, candidate far from settlement area was found more preferred. In doing so, the distance from the nearby residence for *LF4* was found at safe distance which was about 2.5 km far (Table 14) and the site was suitable from residential suitability perspective, but it contradicts the economic consideration view for waste transportation/hauling in daily basis for longer years.

Table 14. Candidate landfill sites measured attributes (size, distance to urban center, & distance to nearby residence)

Candidate Landfills	Area(ha)	Distance to nearby residence(Km)	Distance to urban center(Km)
LF1	68.25	1.03km	3.9km
LF2	23.56	1.79km	4.29km
LF3	52.41	0.22km	4.67km
LF4	35.78	2.5km	5.23km

Where, LF= landfill

In (Table 14) records of measured attribute values of each candidate were obtained using ArcGIS tools like measure and calculate geometry. These measured attributes of each candidate sites were used for later prioritization and ranking of their suitability for landfill siting with respect evaluation criteria (size, distance to center, & distance to residence). As seen from (Table14) the criteria are conflicting to each other. For instance, one candidate site most preferable in light of size may be in conflict with respect to another criterion like nearness to residence or being too far from urban center. To arrive in good decision systematically AHP method was applied to solves such conflicting decision problems so as to choose the most suitable candidate landfill site.

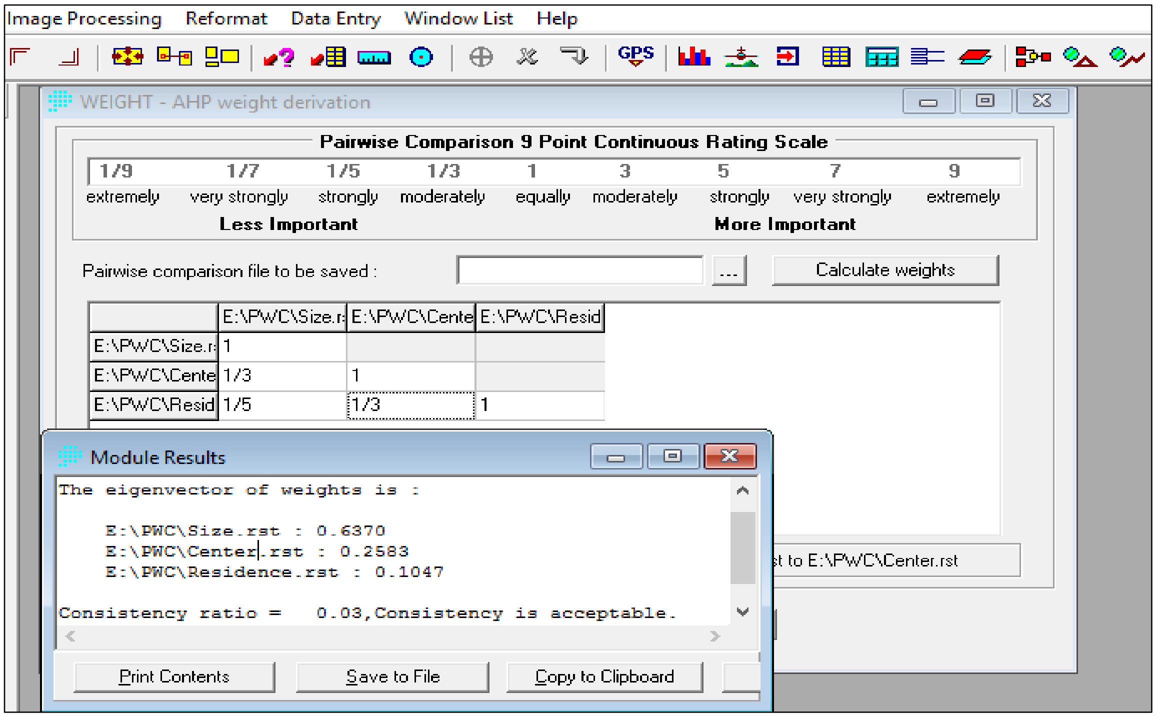

Figure 18. Candidate landfill site evaluation sub-criteria being filled into Idris AHP module to obtain their relative importance weight

Based on the above screen shot (Fig 18) the following candidate site evaluation sub-criteria relative weights were obtained (Table 15).

Table 15. candidate site evaluation sub-criteria and their relative weights

No.	Criteria	Eigen weight	weight(%)
1.	Size of landfill	0.64	64
2.	Distance from center	0.26	26
3.	Distance to nearby residence	0.1	10
Total		1	100%

From (Table 15) the size of landfill site was found most important(significant) for evaluating candidate sites. The work of (Kabite, 2011; Kumel, 2014; Berisa & Birhanu, 2015) were seen to derive their weight in order to identify their relative significance for landfill siting purpose.

Table 16. Candidate landfills pairwise comparisons with each other in light of evaluation sub-criteria (size, distance to center & distance to nearby residence)

❖ Size					
	LF1	LF2	LF3	LF4	Weight
LF1	1	4	2	3	0.4642
LF2	0.25	1	0.5	0.33	0.0975
LF3	0.5	2	1	2	0.2544
LF4	0.33	3	0.5	1	0.1839
Total					1
❖ Distance to urban Center					
	LF1	LF2	LF3	LF4	Weight
LF1	1	2	3	5	0.4849
LF2	0.5	1	2	3	0.2720
LF3	0.33	0.5	1	2	0.1570
LF4	0.2	0.33	0.5	1	0.0882
Total					1
❖ Distance to nearby residence					
	LF1	LF2	LF3	LF4	Weight
LF1	1	0.5	3	4	0.1402
LF2	2	1	7	0.33	0.2737
LF3	0.33	0.14	1	0.2	0.0598
LF4	4	3	5	1	0.5262
Total					1

Note: The consistency ratio(CR) for each respective criteria of size, distance from urban center, and distance from nearby residence (Table 16) were 0.05, 0.01 and 0.07 respectively.

Table 16 shows that *LF1* with weight of 0.4642 is the most suitable site while *LF2* with weight of 0.0975 is the least preferred site in light of size suitability. Likewise, (Zaman & Lehmann, 2011) claim the demand for future landfill space should be considered by ensuring that adequate size exists for the present and future waste holding capacity.

By considering economic advantage of waste hauling to site it is better to site landfill at a minimum distance from waste generation center. But, from environmental and public health perspectives landfills should also be far enough from residential area. Hence, landfill sites were evaluated with acceptable buffer distances from nearby residence. With respect to criterion distance from urban center *LF1* with weight score of 0.4849 is most preferred site whereas *LF4* with weight of 0.0882 was less preferred site (Table 18).

Similarly, (Asha et al, 2016) explained that transport routes to landfill site should be short to allow for multiple trips, efficiency in waste collection and transportation and cost-effectiveness.

As seen from residential area suitability, *LF4* with weight of 0.5262 was the most preferred while *LF3* was the least preferred site with weight of 0.0598(Table 16). As the analysis have shown each candidate sites were in conflict with respect to the three sub-criteria's to decide the most suitable candidate site which would be a preferred in overall suitability. For instance, *LF4* is most preferred as seen from residential area suitability but being it's too far from urban center it contradicts the economic point of view suitability for waste transportation. Also *LF3* is relatively better in size next to *LF1* but it contradicts the suitability from residential area due to its very proximity to settlement area (Table 14 & Fig 17).

It can be noted from (Table 16) that *LF3* has lowest score 0.0740 as being evaluated with residence criteria. As also gauged visually in (Fig 17) the site is very close to the nearby residence. So the site is not compatible with the residence criterion because as (Kumel, 2014; Zulkifli et al., 2015; Khan & Smadder, 2015) suggest in residential areas due to high population density landfill siting in a very close to residence is not recommended due to fearing health problem and public oppositions. For this reason, *LF3* was not at acceptable suitable buffer distance from the nearby residence.

From the above, the analysis of candidate sites with respect to different criteria suitability have shown that the candidates are conflicting in their suitability (one site suitable with respect to one criteria may not be preferable with respect to another criterion). So to solve such conflicting decision problems, the AHP technique was applied (Table 15 & 16) and all candidate sites were evaluated each other with the respective criteria to find the most suitable landfill site. Hence, scores for all candidate landfill sites were subsequently generated by multiplying candidate site evaluation sub-criteria weight (Table 15) and candidate landfill sites relative weight with respect to each other in light of the three sub criteria (Table 16) and finally summing the corresponding products along the row will give the best prioritized suitable landfill site (Table 17).

Table 17. candidate landfill sites suitability prioritizing and ranking based on their overall suitability weight scores

Candidate	Size of the candidate(ha)	Distance from urban center(Km)	Distance to nearby settlement(Km)	Weight score	Weight score in %	Rank
SCW →	0.64	0.26	0.1			
LF1	0.4642*0.64	0.4829*0.26	0.1402*0.10	0.44	44%	1
LF2	0.0975*0.64	0.2720*0.26	0.2737*0.10	0.16	16%	4
LF3	0.2544*0.64	0.1570*0.26	0.0598*0.10	0.21	21%	2
LF4	0.1839*0.64	0.0882*0.26	0.5262*0.10	0.19	19%	3
Total				1	100%	

Where, **SCW**= sub-criteria weight in (Table 15), *(multiply), and Values in yellow colored rectangle are each candidate landfills site relative weight (Table 16).

Table 17 shows that *LF1* with the highest weight score 0.44 was ranked as the 1st prioritized best suitable landfill site exceeding in overall suitability with the considered candidate site evaluation sub-criteria and as such it can satisfy the environmental safety as well as minimal socio economic adverse impacts relative to other candidate sites. Also as (Table 14 & Figure 16) reveals *LF1* was the most accessible from urban center of the town with 3.9 km far than other candidates. This makes it more preferred site from economical point of view relative to other candidates because since urban centers are the source of waste generation the economic feasibility for waste transportation in long run must have to be seen in new landfill siting process. That means, the site was at a location that requires minimum transportation cost and also the site was at safe distance from the nearby residence in which it was 1.03 km (Table 14) away from nearby residence. According to (Kumel, 2014; Zulkifli et al., 2015; Khan & Smadder, 2015) study this distance was safe distance to site landfill from the nearby residential area so the health related impact from the site would be minimal.

In overall suitability, *LF2* with the least score of 0.16(Table 17) was the last preferred site with all parameters being the candidate sites were analyzed. due to being found very near to drainage network and also found along the way to University. Furthermore, candidate *LF3* and *LF4* hold the second and third rank in their overall suitability with the score of 0.21 and 0.19 respectively. Finally, field verification was carried out to the candidate sites and it was found that *LF 3* was actually in conflict with residential area suitability despite it was the 2nd preferred candidate site in size and from urban center point of view (Table 14).

Generally, the best suitable candidate site for solid waste landfilling were identified based on candidate site evaluation criteria weightages and rankings. From the analysis of candidate sites overall suitability, the top preferred suitable site was *LF1* as shown in (Figure 19) and spatially found in the south eastern part of Hosanna town. This site was selected as the best suitable site because of minimal impact from the site on urban economic growth as compared with other sites and also the site was found in bare land which was the most suitable land cover type for landfill due to its low economical land value for compensation to land owners as such it was easy to construct landfill in bare ground than other land cover types. Additionally, the site is at acceptable distance from nearby residence and it's found at optimal distance from waste generation urban center and the site is also underlain by nitisol (Fig 10) which is high suitable for landfill siting.

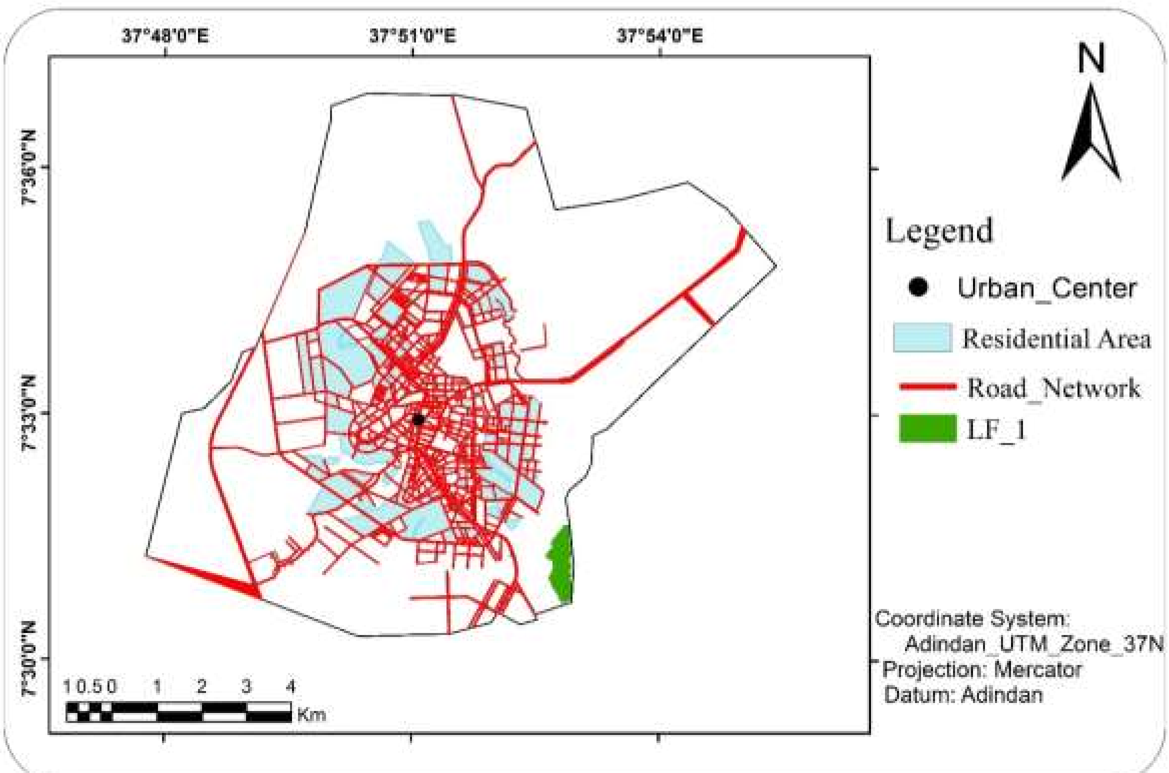

Figure 19. The best suitable solid waste landfilling site for Hosanna town

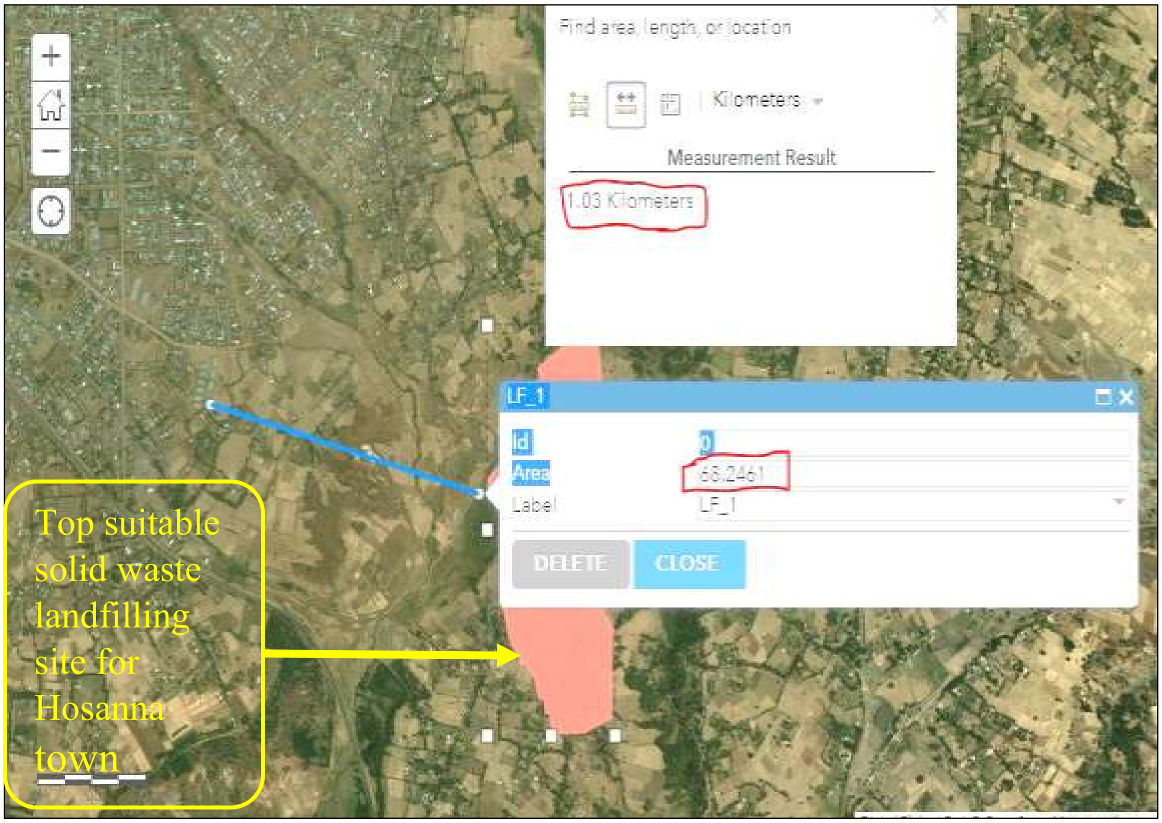

Figure 20. Best suitable solid waste landfilling site for Hosanna town (google earth view)

CHAPTER FIVE

5. Conclusion and recommendation

5.1. Conclusion

Landfill site selection is one of the most important constituents of any solid waste system and it requires to be planned technically using recent advancements in the geospatial sciences. Locating landfill at improper site can result in negative impact to the surrounding environment. This condition is perceived in most developing countries cities and towns including Hosanna town.

The present study was carried out to find the potential solid waste dumping landfill site using GIS and RS techniques for Hosanna town. For the selection of landfill site, eight evaluation factors were considered relevant to the study area condition and among these, the first three most important were land use/land cover, protected area and road network. for the overall suitability of the map. Out of the identified four potential candidate sites, *LF1* was identified as a 1st prioritized suitable candidate site whereas *LF2* was identified as last prioritized suitable candidate. It has been identified that AHP analysis resolves the decision making difficulties by facilitating to arrive at better decision in systematical and logical way. *LF1*(1st prioritized suitable candidate site) was located in south eastern part of the town where with all the considered 8 criteria, the site was found the top preferred for the optimum landfill siting and the site was ranked as 1st prioritized site because the site of its easy to access being it is located at fair distance from urban center and it is also far enough from nearby residence as well as drainage networks. The site is less susceptible to flooding because being it is found in non-recharge(non-source) zone.

Generally, the parcel of land located in south east of Hosanna town was the best site selected in this study for solid waste landfilling and at the same time parcel is also found in bare land within a slope range 5-15%. The evaluation suitability factor maps after reclassified they were combined in weighted overlay according to their importance. The output maps were divided into six classes from restricted to very low suitable and very high suitable extremes. The result of the final suitability map showed that 1.91 % of the study area have highly suitable for landfill site selection. These suitable areas were identified to be found distributed in the South East, South West, North West, and, North Eastern parts of the study area. The restricted area was comprised of 33.72% of the study area. Land use/land cover was the most important factor relative to other factors because it has direct linkage with community as such it is the most critical to the local situation whereas less importance was given to geology which have less impact to the study area context. So, suitability evaluation factors for landfill site selection must have to be selected based on their significance for the area. In this study, four possible candidate landfill sites were identified using GIS.

To obtain best suitable landfill site, candidates were prioritized by considering the most required socioeconomic criteria affecting landfill siting using AHP techniques in Idrisi software package. Finally, the best identified suitable landfill site was confirmed by field visit. It was found to be acceptable with respect to the environmental criteria like land use/cover, slope, far from boreholes and drainage network. Moreover, the study could be validated by considering site's public acceptance and additional field survey such as soil permeability, ground water depth, hydraulic conductivity should have to be conducted before deciding the landfill site.

The findings of this work can be useful to urban planners and researchers in which it can help as a guide for further development and research in the study area. Planning for landfill siting and deciding on best suitable site needs comprehensive analysis and sound judgment. These processes often take longer time to make sound decision but applying knowledge of GIS and RS decision making can be made faster and more dependable. It is hoped that relevant stakeholders and government bodies work in an integrated manner with the GIS experts as shown in this study.

Thus, future studies should aim to understand using GIS and RS techniques can reduce waste management problems that are created due to inappropriate landfill site location. Furthermore, the future studies should have to include additional biophysical and socio economic data for detail analysis. In conclusion, since the current dump site is located along the drainage network and near to newly emerged informal settlements, the landfills should have to be evaluated again in terms of drainage network, distance to nearby settlement and other criteria because the site is not in conformity with the standards indicated in literature. So, the site must have to be located in the South East part of the town, where the current study identified the best suitable site..

5.2. Recommendations

The construction and operation of landfill is costly and difficult task in developing countries like Hosanna. Realizing this, using GIS and RS methods for the selection of appropriate landfill site can be achieved with a minimal risk to environment, human health and also without incurring excessive cost. So every municipality, should have to understand its potential benefit being exploited from using GIS and RS technology.

According to the final output of the analysis, landfills should suitably be located at some areas of south eastern part of the town in which the site was found suitable for waste hauling and it is also found at acceptable distance from nearby residence and at the same time there is enough parcel of land which can give longer year service to the community. However, the current dump site which is found around the south western part of the town which is found close to the drainage network is not in harmony with environmental as well as from socioeconomic point of view for solid waste landfilling. Therefore, the existing open dump of the town should have to be revised and restructured to ensure that the adverse impacts from landfill sites are minimal to environment, society, and economically efficient for site related operations. Only considering the datasets used above is not guarantee it is strongly recommended detailed investigations have to be carried out for the selected best suitable site using additional spatial and other non-spatial data sets. We consider that the present work can be of real help mainly for decision makers in the town, and municipality in choosing the best location for siting new landfill in the town.

The municipality should have to enforce landfill guidelines based on environmental protection procedures and existing local conditions to rescue the town from landfill associated adverse impacts to come. In selecting new landfill sites committee should have to be established from politician, environmental experts, water resources and from the community in order to set suitable criteria to be considered in landfill siting. This research is not only applicable to Hosanna town but also it can be adapted to other surrounding towns for site selection related problems. These site investigations will be critical to the success of the siting and design of the landfill. Landfill sites should be designed and supervised by an experienced geotechnical engineers, supported by a hydrogeologist.

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Appendix I

Latitude and longitude of boreholes

Latitude	Longitude	Depth Value(m)	Kebele
375358	836966	170	Jalo Naramo
372842	836670	208	Bobicho
371878	836915	180	Bobicho
380218	837050	140	JaloNaremo

Appendix II

Photos

Plate: Waste irregularly thrown at water logged areas near to residence (Author, 2018)

Plate 2: Waste thrown at future development areas (Author, 2018).

Plate 3: Waste splattered around residential areas (Author, 2018).

Plate 4: Scenario in which waste being collected by vehicles (Author, 2018)

Plate 5: Hosanna town existing disposal site view and its surrounding characteristics

Appendix III

Expert(Analyst) Interview

Dear respondents I am students of Jimma university undertaking research entitled GIS and RS based landfill site selection in hosanna town, Hadiya Zone, South Ethiopia. This interview is prepared to rate the listed factors here below according to their relative significance to the landfill site selection in the study area context. Therefore, the intention of this interview is to decide which factor is more important among the given landfill site selection determinant factors and it helps to identify which factor may directly affect the community more. I am grateful for your participation and for the time you have devoted. According to fact mentioned above, you are politely requested give dependable and reliable responses to interviews presented below. We are not interested to know your name or any things related to your personality rather than information you provide us. Directions don't write your name on the paper. Please give as much as possible accurate responses to the following questions and provide your response on the space allowed for each.

General information questions

A. Education back ground.

< grade 8 ☐ < grade l0 ☐ <grade 12 ☐ Certificate levels ☐

College diploma ☐ Degree ☐ 2nd degree ☐ 3rd degree ☐

B. Other if any……………………………………………………………………

C. Field of study………………………… specialization………………………….

D. Current position……………………………………………………………….

The Interviews was asked to know the relative significance(importance) of each factors in overall suitability for landfill siting as a percentage of influence. Through this way and literature consultation the most significant and least significant factors for landfill site selection in the study area context were identified.

1.Rate the relative importance of the suitability factors in (Table 18) numerically using scales definition in (Table 19) in light of their significance for landfill site selection in the study area's context at a time taking only pairs.

Table 18. Landfill sitting evaluation suitability factors

Suitability factors
Land use/ land cover
Slope
Drainage network
Boreholes
Soil type
Geology
Road network
Protected areas

Table 19. Saaty's (1980) pairwise comparison scale descriptions

Scale	Definitions	Remark
1	Equally Important	Their reciprocals are the opposite of being compared
3	Moderately Important	
5	Strongly Important	
7	Very Strongly Important	
9	Extremely Important	
2,4,6,& 8	Intermediate value between adjacent Values	

The following two tables result are the relative importance rating done by the interviewed experts from the corresponding institutions.

Table 20. The relative importance rating of evaluation factors for landfill siting by municipality expert

Factor	LU/LC	PA	Road	Slope	Drainage	Borehole	Soil	Geology
LU/LC	1	2	3	5	6	7	8	9
PA		1	2	3	5	6	7	8
Road			1	2	3	5	6	7
Slope				1	2	3	5	6
Drainage					1	2	3	5
Borehole						1	2	3
Soil							1	2
Geology								1

→CR= 0.03

Where, PA= Protected areas

Table 21. The relative importance rating of evaluation factors for landfill siting by Wachemo University expert

Factor	LU/LC	PA	Road	Slope	Drainage	Borehole	Soil	Geology
LU/LC	1	3	4	5	6	7	8	9
Slope		1	3	4	5	6	7	8
Road			1	3	4	5	6	7
PA				1	3	4	5	6
Drainage					1	3	4	5
Borehole						1	3	4
Soil							1	3
Geology								1

→ CR= 0.09

Note: Since the consistency ratio(CR) of municipality expert's relative rating was found lower than Wachemo university expert's relative rating. As a result, for the current study the relative importance rating done by municipality expert was used for subsequent relative weight derivation for each factors considered in landfill site evaluation.

Interviewee

Name………………………………..

Signature…………………………….

Date………………………………….

Interviewer

Name………………………………

Signature……………………………

Date…………………………………