MUNICIPAL SOLID WASTE DISPOSAL SITE SELECTION OF JIGJIGA TOWN USING GIS AND REMOTE SENSING TECHNIQUES, ETHIOPIA

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ABSTRACT: *Municipal solid waste management is a problem that is experienced by all counties in the world. Because of its nature, it has remained one of the major environmental problems man continues to face. Municipal solid waste management is considered as one of the most serious environmental and social problems challenging municipal authorities in developing countries. One of these impacts is raised from location of dumping site in unsuitable areas. This paper deals with selection of suitable site for the disposal of municipal solid waste generated from Jigjiga Municipality using GIS techniques.The existing open dumping systems in the town are not environmentally sound and socially acceptable as wastes have been dumped in inappropriate sites. The present study had integrated environmental and socio-economic criteria like proximity to road networks, distances from residences and important built up areas; surface water (river), boreholes and reservoirs to select the most suitable landfill site in the study area. The result reveals that out of five candidate landfill sites, a site with reasonable size (24 ha), at optimum distance from residences (4.8 km) and accessible to the major roads (1 km) was nominated as the most suitable site*.

KEYWORDS: Solid waste management, Landfill site selection, GIS

INTRODUCTION

Waste was an early problem of mankind, and a growing one that is of major concern to every nation of the world (Allende 2009). It is an issue mostly witnessed in urban areas as a result of high surge in population growth rate and increase in per capita income thus posing a danger to environmental quality and human health (Javaheri 2006). The most common problems associated with improper management of solid waste include diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses (Jilani et al. 2002).

Municipal solid waste management has thus become a major issue of concern for many underdeveloped nations, especially as populations increase (Bartone 2000). The problem is compounded as many nations continue to urbanize rapidly. For instance, 30-50% of population in most developing countries is urban (Thomas 1998) and in many African countries, the growth rate of urban areas exceeds 4% (Senkoro 2003). When the governments of African countries were asked by the World Health Organization to prioritize their environmental health concerns, results revealed that solid waste was identified as the second most important problem (after water quality), less than 30% of

urban populations have access to "proper and regular garbage removal"(Senkoro 2003).

The U.S. Environmental Protection Agency   issued many regulations and limitations to control unfriendly environment projects, among these regulation one is landfill site criteria, and also many agencies in different countries of the developed world were established to control this process (EPA 1996). Developing countries just started to establish such agencies and institutions in this field (PAEA 2006).   The issue of landfill site selection was complicated and time consuming. During the last few decades and particularly when environmental planning emerged this issue became systematic and technical. The evolution of GIS made this field much easier and manageable. GIS has very distinguishing, powerful functions and it is an ultimate method for preliminary site selection as it efficiently stores, retrieves, analyses and displays information according to user-defined specification as a result can play an important role in decision making and planning process(Daneshvar et al. 2005). The fundamental analytical function of a GIS based spatial decision support system include query analysis, proximity or buffer analysis, overlay analysis, neighbourhood analysis and network analysis. Various combinations of these functions are commonly used during the geographical data analysis process (BESR, 2002).

In Africa, rapid urban growth since the 1960s has put pressure on land resources within the areas surrounding cities, and has led to increased generation of waste. The problem is aggravated by the open dump nature of disposing waste especially in the slum areas of most African cities (Hammer 2003). Traditionally, administrations in African states permitted uncontrolled dumping in abandoned quarry sites with no provision for sanitary landfill, causing huge health problems (Martin 1992; Hammer 2003). A large part of the problem is inadequate financial and data resources for site selection and management (Mwanthi et al. 1997).

LITERATURE REVIEW

General Concepts and Definition of Terms
Solid Waste comprises all the wastes arising from human and animal activities that are normally solid and discarded as useless or unwanted. Similarly, solid waste means any garbage, refuse, sludge, and other discarded solid materials, including solid waste materials resulting from industrial, commercial, and agricultural operations, and from community activities, but does not include solid or dissolved materials in domestic sewage or other significant pollutants in water resources, such as silt, dissolved or suspended solids in industrial wastewater effluents, dissolved materials in irrigation return flows or other common water pollutants (Tchobanoglous *et.al*. 1977). Solid waste management (SWM) is one of the basic services that are currently receiving wide attention in the urban agenda of many developing countries. Lack of effective SWM can result in environmental health hazards and has negative impact on the environment. This extends wider than just the geographical boundaries of the town or municipalities. Solid waste management is in crisis in many of the world's largest urban areas as populations attracted to cities continues to grow and this has led to ever increasing quantity of

domestic solid waste while space for disposal decrease (World Bank 1999).

In most cities and towns of developing world, inappropriate handling and disposal of municipal solid waste is the most visible cause of environmental degradation, i.e., air pollution, soil contamination, surface and ground water pollution, etc., resulted from improper disposal of municipal solid wastes (WHO 1996).

Solid waste management in developed countries
Shortage of land for waste disposal and inappropriate landfill site is one of the biggest problems in most of large urban areas in the world which has its negative impact on human, and environment (Mcfaden 2003). Therefore, more efforts are needed to overcome this problem that leads different agencies and establishments to find common limitations to protect human and environment from these consequences (Friedman 1998). The U.S. Environmental Protection Agency issued many regulations and limitations to control unfriendly environment projects, one of these is landfill site criteria, and also many agencies in different countries of the developed world were established to control this process (EPA 1996).   Developing countries just started to establish such agencies and institutions in this field (PAEA 2006).

Solid waste management in Ethiopia
The booming growth of cities of the developing world has outpaced the financial and manpower resources of municipalities to deal with provision and management of services, of which solid waste is the major one. Lack of these services greatly affects the urban poor, women and children who are vulnerable to health hazards. Twenty two human diseases are related to improper solid waste management (World Bank 1999). Moreover, its effects are also reflected in reduced productivity, low income and poor quality of life and deteriorated environment. Similar to cities of most developing countries, provision of required services lags behind the need and development of settlements in urban areas of Ethiopia. Integrated infrastructure and housing development is not widely practiced. Provision of solid and liquid waste collection and disposal is low (most urban areas lack the service). In addition to this, deterioration of the immediate environment in the households and their surrounding is increasing. With the current growth rate of urban population in Ethiopia, it is estimated that the population of most urban areas especially small urban centers is doubling every 15-25 years. As solid waste generation increases with economic development and population growth, the amount in these urban areas will double within a similar time range. Municipalities in Ethiopia have to be prepared for this challenge (Yami Birke 1999) with no exception of Jigjiga Town.
An integrated urban rural development study undertaken in 1988 showed that among the eleven project towns: Addis Ababa, Akaki, Assela, Ambo, Arsi Negele, Goba, Mizan Teferri, Robe, Wolisso, Ziway, and Shashemene, only Addis Ababa had centralized waste disposal system (NUPI 1989). The towns had no waste collection trucks, four of the municipalities assigned other vehicles to collect waste once or twice a week. Among those who have the service the coverage is very low, usually being limited to street and market cleaning. Recently, most municipalities in Ethiopia have become aware of the negative consequences of poor sanitation. Accordingly, they have devised and adopted a

system to collect and dispose-off solid waste.

A survey of present status of the system in fifteen randomly selected: large (Dessie, Bahir Dar, Debre Zeit, Gondar, Mekele, Nazareth) and medium (Woldiya, Axum, Adigrat, Robe, Gimbi, Adwa, Arbaminch, Wolayita Sodo, Debremarkos) urban areas shows that from the sample of urban areas studied thirteen, i.e. 86.6 per cent 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. Open dumps pollute surface and ground water, soil and the natural environment as a whole. Even though, the beginning is encouraging, some technical matters should have been considered in the selection of disposal techniques and also sitting. Almost all municipalities visited did not take the required care in selecting the site for collection and disposal. For instance, in case of Gimbi, and Robe towns, open sites were selected, and holes of about one meter deep were dug and then people started dumping garbage. When the holes are filled they will be covered by soil, and the process goes on like that. In Dessie town, the collected waste is dumped along the main road and its vicinity, where it has been carried away downstream to Kombolcha town. Most of the urban areas have no collection containers, and the number is low in those having. For instance, Gondar, with population of more than 90,000, has five existing $8m^3$ containers and now obtained additional 4 containers. (NUPI 1989).

Locating a Proper Waste Disposal Area

A waste disposal area is a matter of public health concern. Considering the high rate of urbanization, one should take the long term land use planning of suburbs into consideration to locate the disposal area. Moreover, the present and future of garbage trucks traffic should be taken into account. There are many factors which should be considered in locating a waste disposal area. Obviously, the type of ground selected for this purpose directly affects the design, usage and the tools needed for the effective operation (Chang *et.al.* 2007). These factors mainly consist of: public health, extend and topography of the area, hydrology, geology drainage system and weather of the area, the availability of landfills in the area to cover the wastes, proximity to the residential and industrial areas, the distance to and from the city, the weather of the area, the drainage system of the area, cost and the future land use of the area (Chang *et.al.* 2007).

Site Selection Criteria

Identification of the suitability of potential landfill sites, and modifications to existing facilities, requires a comprehensive assessment of site conditions and potential impacts on the environment. This includes consideration of topography, surface water, drainage, hydrogeology (groundwater), geology, climate (including air quality and odor modeling) and flora and fauna, access and distance from the community the landfill will service (DPIWE 2004).

The following landfill site selection criteria detail the key issues that need to be considered when identifying potential landfill sites and planning site investigations and assessing the suitability of a site for land filling. It is unlikely that the majority of sites will meet all necessary criteria, in which case the assessment of the suitability of a site for

a landfill needs to consider and appropriately manage and justify the selection of a site that doesn't meet all the necessary criteria. Consideration needs to be given to the: comparison of site characteristics with alternative locations; Potential for engineered systems to overcome site deficiencies; Methods of operation proposed for the site; and Social and cultural issues associated with the site (DPIWE 2004).

In order to minimize future risk to the environment from landfill activities, primary consideration should be given to key issues and potential fatal flaws with respect to geology, hydrogeology, surface hydrology and site stability (DPIWE 2004).

Site Capacity

The life of the landfill and the demand for future landfill space should be considered during the site selection process. Proponents should consider the type and quantities of waste generated within the area being serviced by the landfill, the current disposal pathways for these wastes, projected quantities and types of waste requiring disposal and the remaining landfill capacity at existing landfills sites which service the area. Landfills should be designed to ensure that sufficient capacity exists for the current and future waste management needs of the community into the foreseeable future. (EPA South Australia 2008).

METHODOLOGY

Description of the Study Area

Geographic Location

Jigjiga Municipality is located in the eastern part of Ethiopia and it is the headquarter of state of Ethiopian Somali. It is spreaded over a land area of about 9218 ha (Structure Plan 2012). The municipality astronomically lies between 9° 16' 30" to 9° 24' 30" N latitude and 42° 44' 0" to 42° 51' 0" E longitude (Figure 3.1).
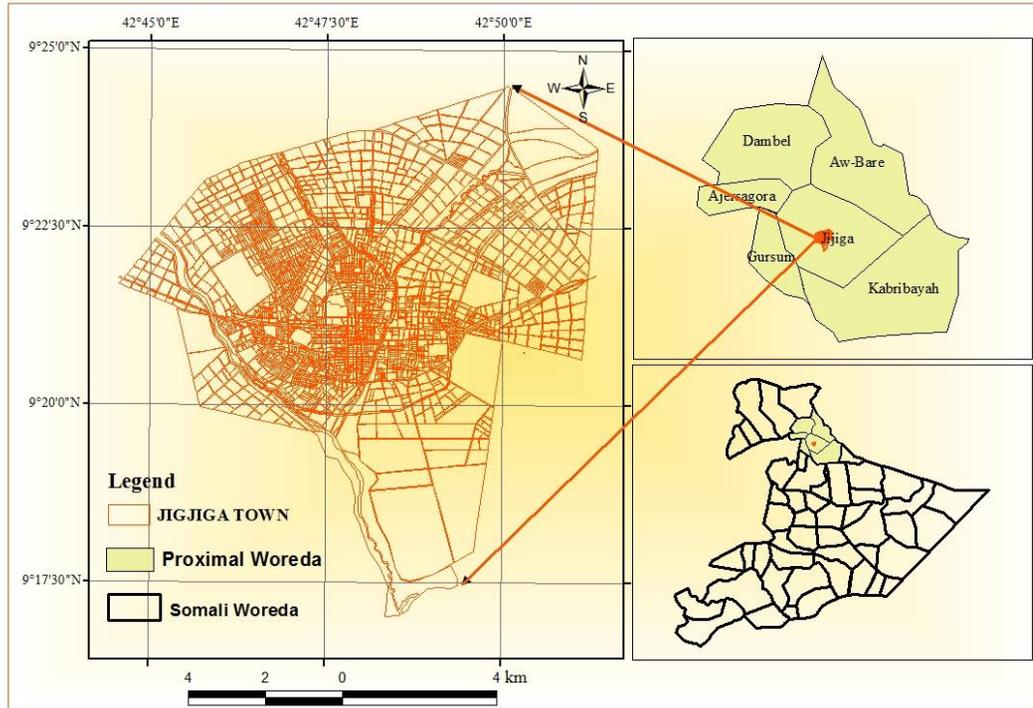
Figure 3.1. Study Area Map

Physiography and Drainage

Jijiga town is almost located on a flat land with gentle slopes. The existing built up and expansion areas are much suitable for urban development. On the other hand, some parts of the town are characterized by poor drainage, gully and swampy land features. Gully areas that are found in the western, southern, southeastern, and northern parts of the town require immediate intervention or remedy measures since they expand to the expansion and built up areas of the town.

Geology and Soils

The topography slopes down from the Karamara Mountain in the northwest spreads out in the southeastern border of the town, with a few numbers of steep-sided valleys and streams. In general, the topography is characterized by gentle morphology and flat land areas. As a result, the stream drains towards southeastern from the Karamara ridge; southeast direction from Cinaksan direction and other elevated areas of the eastern outskirts of the city. Wetlands along Biribiris and Toga streams (including Elbahiy and Biyeda streams) and areas south to the southwest of Elbahiy Dam are the major drainage systems in the town vicinity. Jigjig Town and its surrounding hinterland is characterized by the following three categories of geological features: Alluvial and lacustrine deposit sand, silt clay, diatomite, limestone and beach sand; Hamaneli Formation (Oxfordian limestone and shale) and Jassoma Formation: Late Cretaceous-Paleocene Sandstone.Information from Jijiga Woreda's Agriculture Office reveals that the hinterland of the town is dominated by mixed *eutric cambisols, chromic vertisols*, black *vertisols*,

mixed *Calcic Cambisols* and black *Vertic Cambisols with*clay texture soil types.

Climate
Sub-tropical agro-ecological zone depicting a temperature ranging between 12.27°C and 27°C, and the minimum and maximum rainfall lying between 400mm and 800mm with the annual mean of 712mm is attributable to Jigjiga Town and its vicinity.

Demographic Features
Evidences from various literature reveals that the annual population growth of Ethiopia is at the rate of around 2.6 percent per annum. The high growth rate is as the result of the country's birth rate, which is 4.5 percent which is the highest in Sub-Saharan Africa. By contrast, the death rate has been falling from 3.1 in 1950 to 2.3 in 1975 and further to 1.5 in 2000. Population forecast indicates that over the next 15 years the country's population will double i.e. the 73 million population of today will and becomes 146 million by the year 2025. According to CSA data established in 2008, population of the Jigjiga Town has been estimated to be about 125,876 people of which 67,128 were males and 58,745 were females. Estimating an average of five individuals per household, the town has about twenty-five thousand households. Being the largest town in the eastern rim of the country, it is the hub of various businesses and office establishments and educational institutions including Jigjiga University (Yohanis and Genemo 2013).

Methods
It is evident that, many factors must be incorporated into landfill sitting decisions and GIS is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. GIS efficiently stores, retrieves, analyzes and displays information according to user defined specifications. The methodology utilizes GIS to evaluate the entire town based on certain evaluation criteria for the analysis of landfill site suitability. The criteria were selected according to study areas local characteristics. The principal sub criteria that used for spatial analysis are: major road, high tension line, surface water, residential area, important building, soils, boreholes and reservoirs. The suitable criteria for landfill site selection process were extracted from national and international guidelines. Digital data were obtained from different government authorities. ArcGIS 10 software package was used to create landfill sitting layers. The GIS method used in this paper is outlined in Figure 3.2.

Landfill siting criteria were divided into constraint and factor criteria. Constraint criteria represent the unsuitable areas according to the regulations while factor criteria enhance the placement of landfill of being placed within an area. According to different regulations constraint criterion maps were created for all the six criteria. The unsuitable areas according to constraint criteria are indicated in Table 3.1. All constraint criterion maps were overlaid to create the final factor map.
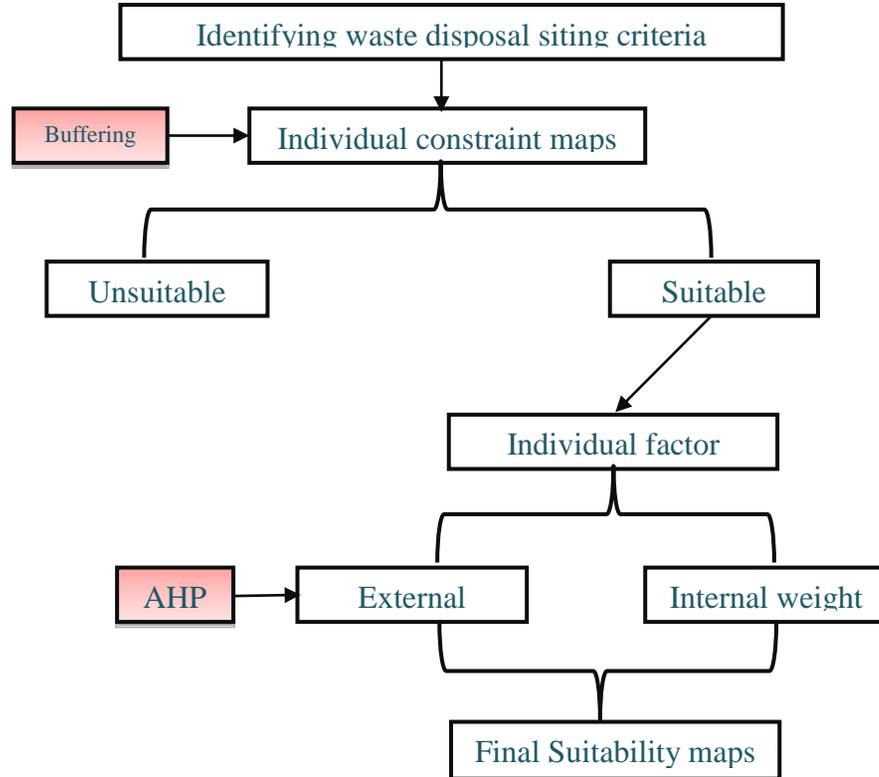
Figure 3.2. GIS Methods flowchart

Determining Unsuitable Areas

The unacceptable areas are locations where due to environmental concerns and/or public health is rejected for the purpose of waste disposal (Lunkapis 2004). To determine these areas, one should enter the collected data into the GIS environment and use geo-processing techniques like buffering. According to various studies, buffer zones of different extent (Table 3.1) from each criterion was considered for this study too.

Table 3.1. Constraint Criteria

Criteria	Unsuitable Areas	Remark
Road Networks	100 m buffer zone	
Surface water (rivers)	200 m buffer zone	
Residential area	300 m buffer zone	
Important building	300 m buffer zone	
Boreholes	400 m buffer zone	
Reservoirs	400 m buffer zone	

Most of the available data for this study are in analogue format. Therefore, they were first digitized into vector format and thereafter introduced to the GIS plat form.The unacceptable areas of different data layers are determined in GIS environment as

following:

Road Networks: The road networking the town consists of main roads, secondary roads and pedestrian roads. The waste disposal areas should not be too close to the road networks. Therefore, a 100 m buffer zone is applied to these networks (Figure 3.3).
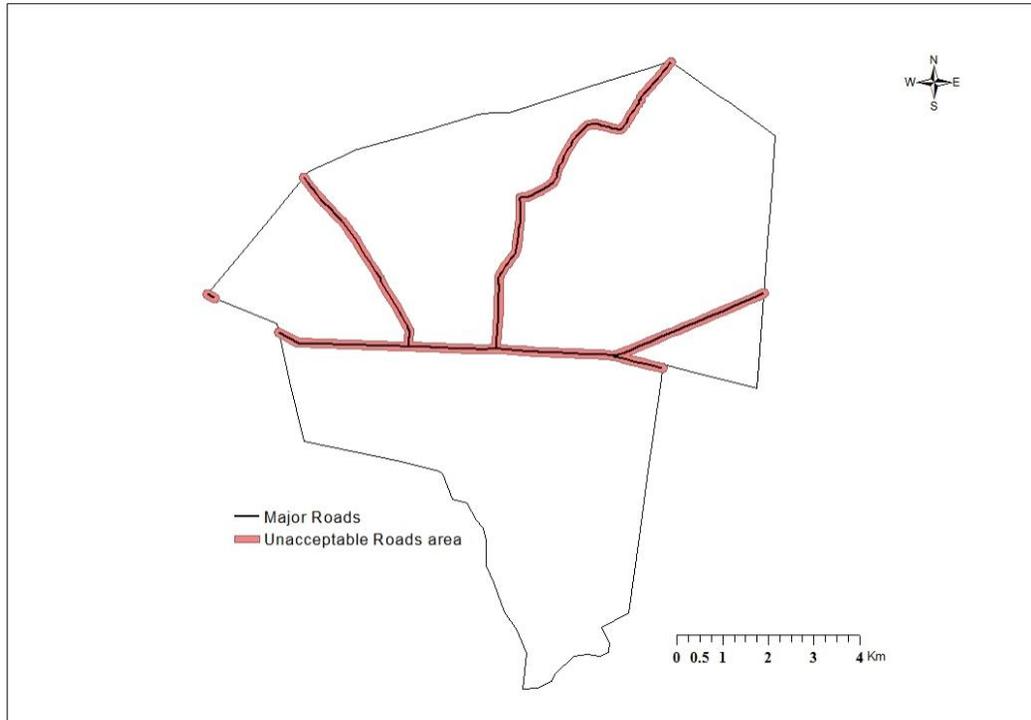

Figure. 3.3. Road Networks Constraint Map

Surface Water Sources: The waste disposal areas should not be in the vicinity of rivers, lakes, or swamps where the underground water level is high. Since major rivers have a higher discharge and greater downstream influence, no landfill should be sited within the floodplains of major rivers (Bagchi, 1994). Hence, buffers of 200 m and 100 m for permanent and temporary rivers are applied respectively. However, in the vicinity of the town permanent rivers are hardly found. Therefore, buffer of 200 m is considered (Figure 3.4).
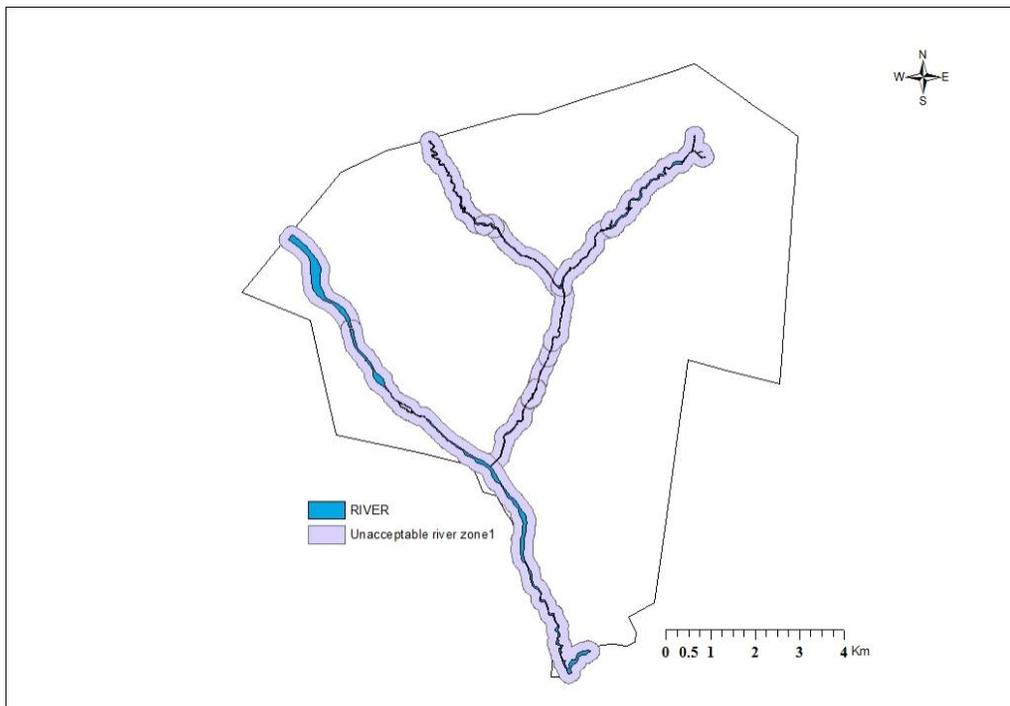
Figure. 3.4. Surface Water (River) Constraint Map

Residential Areas: The waste disposal areas should not be in the vicinity of residential (Populated urban) areas. For this purpose a buffer zone of 300 m from all residential areas (Figure 3.5) is applied to determine unacceptable areas.
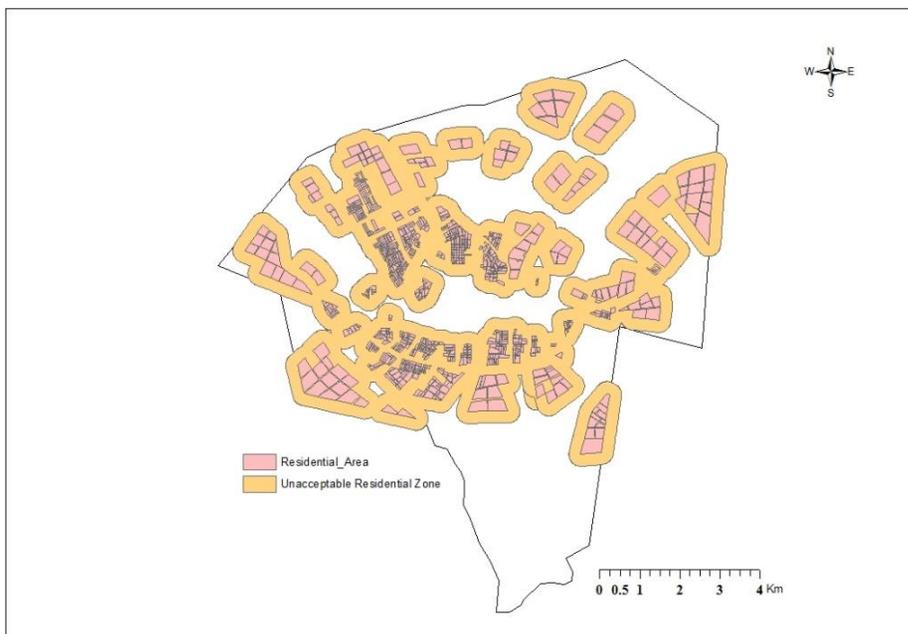

Figure. 3.5. Residential Areas Constraint Map

Important Building: The data layer for important building centers is entered into the GIS function and a buffer zone of 300 m (Figure 3.6) around these areas are considered.
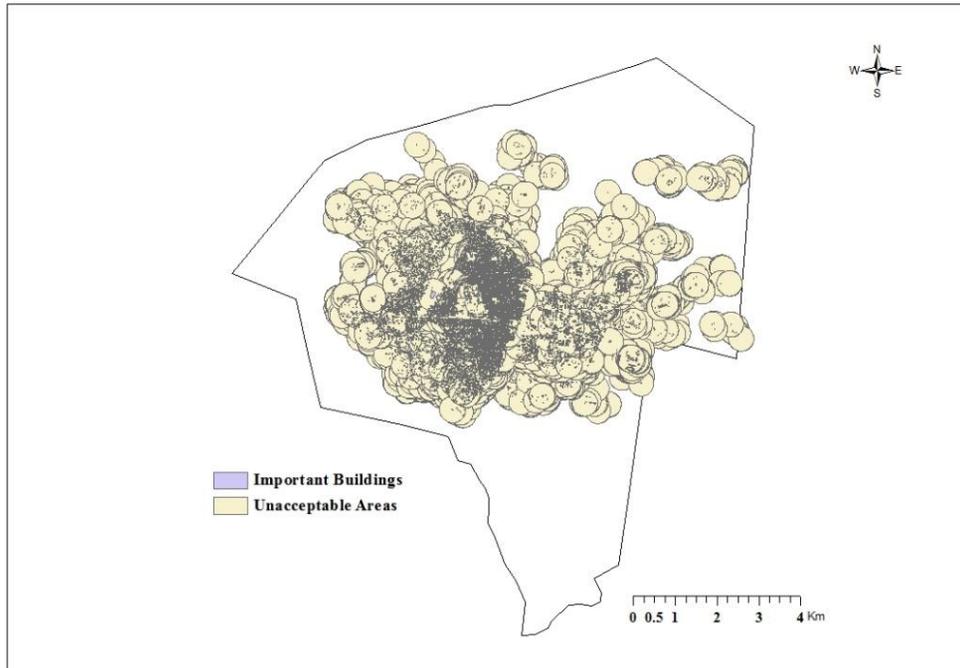

Figure. 3.6. Important Building Constraint Map

Reservoirs: According to Bagchi, 1994, if the regional drinking water is supplied by surface water impoundments, it may be necessary to exclude the entire watershed that drains into the reservoir from landfill sites. A high groundwater level or a nearby high river level will cause more risk to pollute the groundwater or river water. The potential landfill location with the lowest groundwater or river level is more suitable for a landfill. All of the reservoirs in the town are entered into GIS system and a buffer of 400 m is considered for them (Figure 3.7).
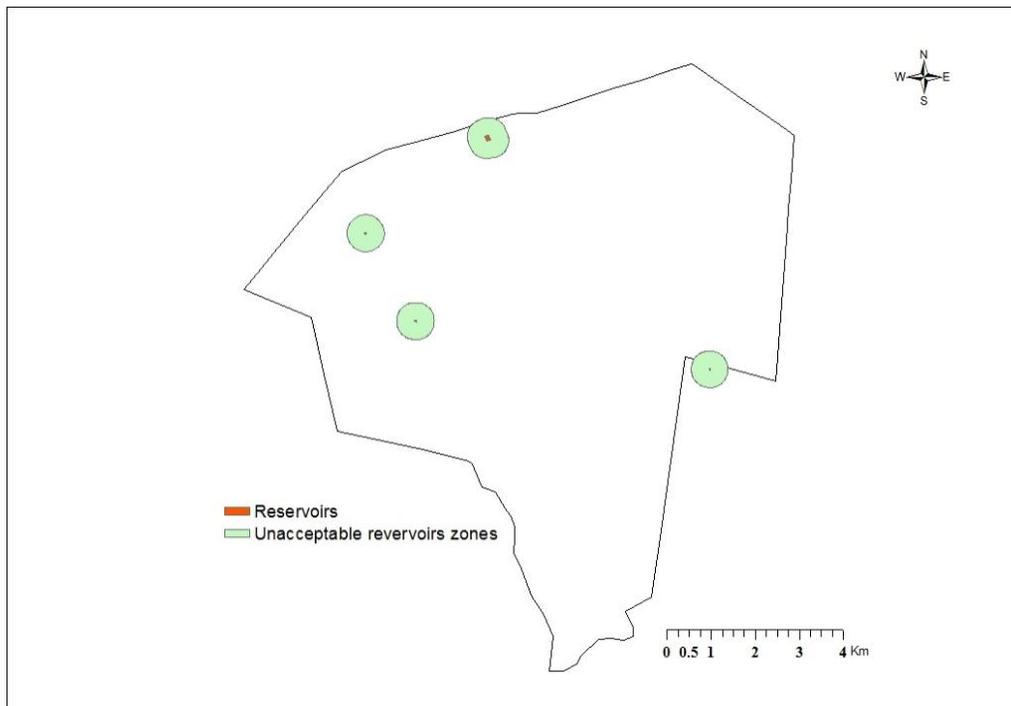
Figure. 3.7. Water Reservoirs Constraint Map

Boreholes: The waste disposal areas should be away from boreholes otherwise it can have irretrievable human and environmental effects. All of the boreholes in the town are entered into GIS system and a buffer of 400 m (Figure 3.8) is considered for them.
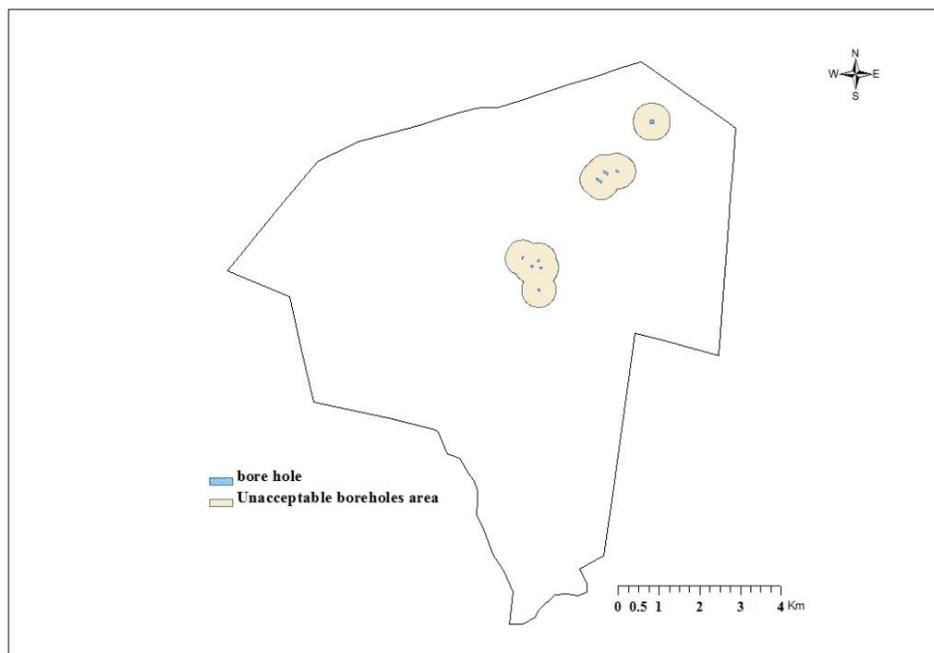

Figure. 3.8. Boreholes Constraint Map

3.2.2. Factor Criteria Setting

After finding out where the unacceptable areas are, the remaining areas should be classified into classes of high and low priority for being used as waste disposal areas. This is done through two steps of weighting process. In the first step, each layer is internally weighted based on minimum and maximum distances (Table 3.2). In the second step, each layer is externally weighted based on the fact that how critical and important the data layer is to the waste disposal problem (Vassiloglou, 2001). Each map layer was both internally weighted based on their direct distance to features and environmental judgment and externally weighted using AHP, based on the relative importance of the criterion.

Table 3.2. Factor Criteria

Factor Map	Marginal Suitability	Moderate Suitability	High Suitability
Road Networks	>1000 m	500-1000 m	100-500 m
Surface water	200- 350 m	350- 800 m	>800 m
Residential areas	300-700 m	700-1000 m	>1000 m
Important buildings	300-700 m	700-1000 m	>1000 m
Reservoirs	400-600 m	600- 800 m	>800 m
Boreholes	400-600 m	600- 800 m	>800 m

The Internal Weighting: In this part, each data layer is studied individually. The locations of each data layer can take a weight between zero to nine based on their direct distance to the features, implementation as well as engineering judgment. As an example, considering the road networks, the locations which are close to the roads have higher weight than the ones far away from the road network. Similarly, for the river, boreholes and reservoirs, the locations which are far from them have high weight and vice versa. For residential and important building areas the locations are weighted based on their distance to these centers. The distance should not be so far that the transportation becomes a problem and not so close that provides an unpleasant appearance to the sightseeing, parks and recreational facilities which are mostly in the vicinity of towns. For residential and important building centers, the highest weight is given to locations with a distance of less than or equal to one km.

The External Weighting: In the previous subsection the locations are weighted within each data layer internally. However, it is obvious that the data layers themselves do not have equal weight for the problem in hand. To obtain the external weights, the method described by Saaty, 1980 was used. First all the criteria were compared against each other according to the comparison judgment scale from Saaty (2006) which is indicated in Table 3.3.

Table 3.3. Comparison judgments scale for assigning values (Saaty, 2006).

Value	Importance
1	Equal
3	Moderately dominant
5	Strongly dominant
7	Very strongly dominant
9	Extremely dominant

Therefore, each data layer is weighted based on the technical, implementation, safety, environmental, economic and other factors. Table 3.4shows the external weighting schema used in this study which itself is based on the ideas of GIS specialists and environmentalists (Economopoulos 2005).

Table 3.4. External Weighting Schema

Data Layer	Weight
Road Networks	0.20
Surface water	0.18
Residential areas	0.16
Important buildings	0.20
Reservoirs	0.14
Boreholes	0.12

The final landfill area suitability map was created by overlaying all six factor criteria. Finally, according to the minimum landfill area requirement in the vicinity of the town, suitable sites for landfills were selected. These sites were visited for field validation.

RESULT AND DISCUSSION

Solid Waste Status of the Town
Solid waste management system in Jigjiga Town includes collection, transportation and disposal. Collection of solid wastes from the whole city is performed by the three collection systems namely: municipal containers, collection from different institutions and house-to-house collection that have been established by the municipality. In municipal container system, large open steel containers (8 m^3) are often located on open spaces near the public schools and commercial areas in the city, where the households and other waste producers deliver their waste to the containers. House-to- house collection system service is available for those households that are located far from the major roads. Hence, solid waste is collected from the households to container stations by the daily laborers and be ready for transportation. However, solid waste from institutions is collected by order via payment per container. The solid wastes collected by the three systems are transported to the final dumping site (Shiek Ali Gure) located at 6km in the South-East part of the town center. It is the only disposal site available for the town to dump all types of solid waste generated from the town vicinity and it has been serving for the last seven years, even though it was designed for a temporary use. The municipality of Jigjiga town has been facing problems related to solid waste management. The problems start from the collection to final disposal due to the increased waste generation,

unplanned city infrastructures and scarcity of dumping site. Moreover, the current open dumping system has been resulted in environmental and social problems.

The study by Yohannis and Genemo (2013) shows that "Shiek Ali Gure" open dumping site has been posing negative impacts on the environment and public health like downstream water pollution, soil pollution and health problems to the surrounding community. The problems resulted due to not considering environmental and social factors during site selection.

The existing waste dumping sites, quite many in number, are located along drainage system and surrounded by residential areas (Plate 1) that have been precipitating adverse effects on human health and other social problems like nuisance, ugly sceneries and hindering economic activities practiced nearby the waste dumping sites due to large amount of waste pickers and rodents are continuously working on the sites. Moreover, the area is vulnerable to ground and surface water pollution as it is located at very highly permeable ground and nearby streams and faults in the region. On top of this, all types of solid wastes from domestic, market, industry, commercial and hospitals, which may contain leachable toxic compounds, have been dumped without any treatment and separation. Furthermore, there are no daily covering of solid waste after disposal to reduce environmental and public health problem.

Plate 1.Samplesof unacceptable open dump sites in Jigjiga Town

These practices signify the risk to the public health and the environment. Hence, the current locations of dumping sites do not satisfy both the national and international landfill standards. Therefore, any of the existing open dumping sites in the town are not acceptable from international and national environmental and humane perspectives. In general, the current solid waste disposal system in the town is not environmentally friendly and socially acceptable.

According to Structure Plan (2012) of the town, Jigjiga Municipality requires a minimum area of 21,600 m^2 (21.6 hectares) for waste disposal sites by 2020. By taking this fact into account, this study tried to assess suitable site for the municipal solid waste disposal. To this end, the Weighted Linear Combination (WLC) techniques in an ArcGIS environment

was employed to come up with the following factor maps showing three classes of suitability levels: marginally suitable, moderately suitable and highly suitable. Figure 4.1 to 4.6 show all the factor maps of six data layers involved in this study.
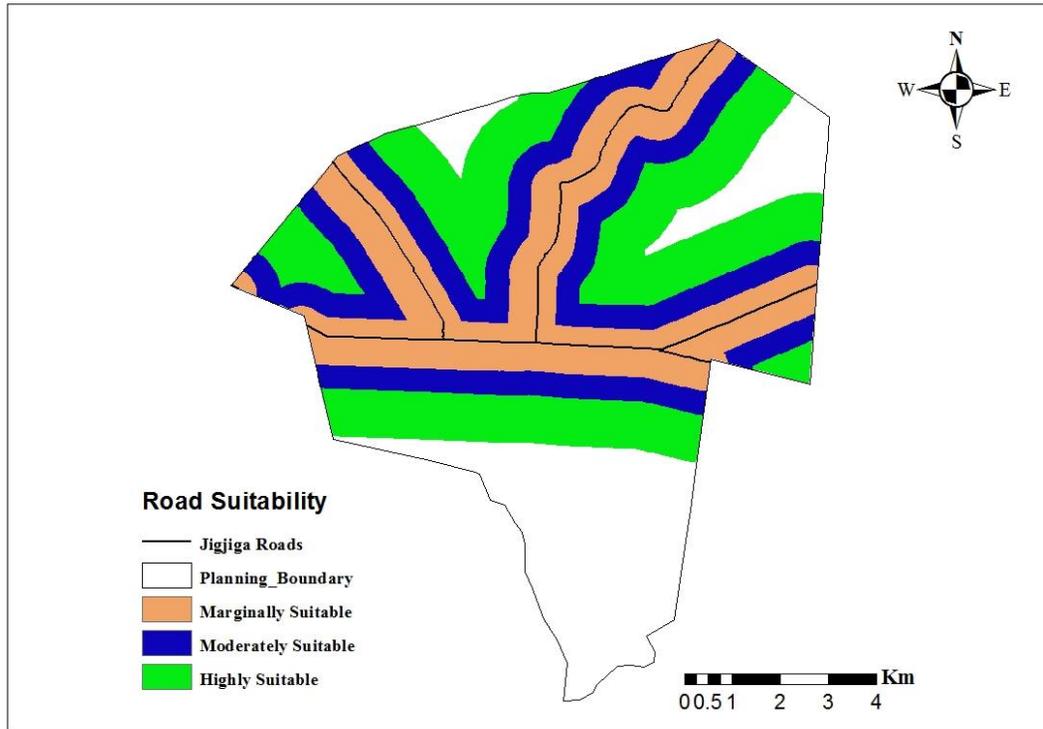

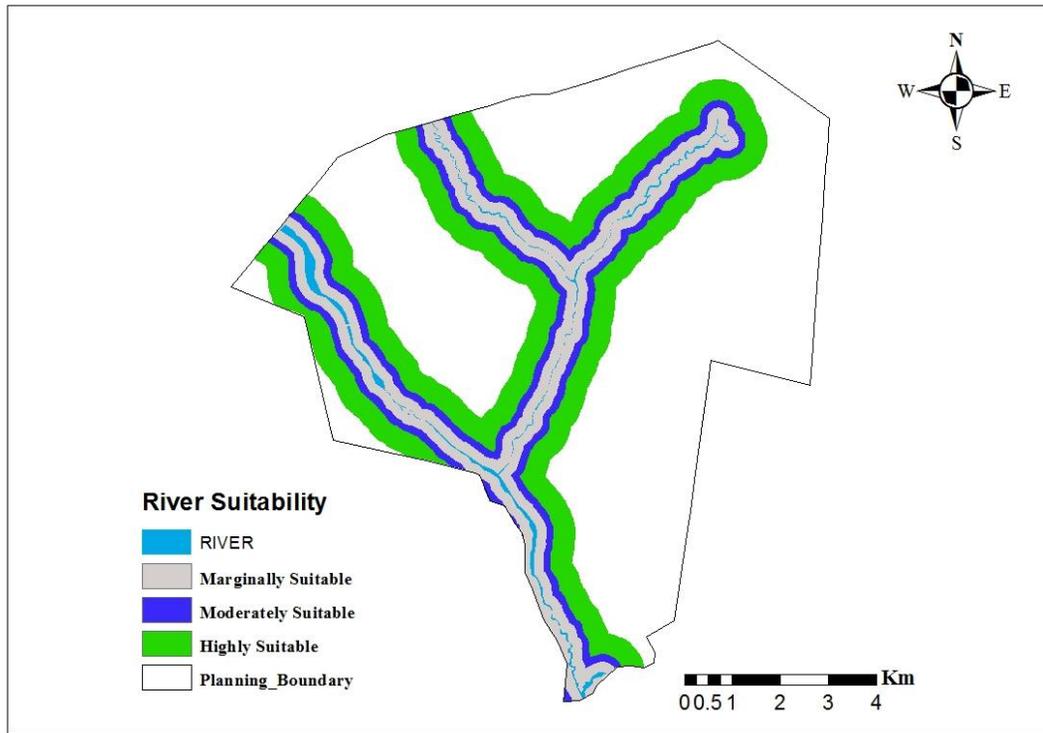Figure 4.1: Road networks factor map

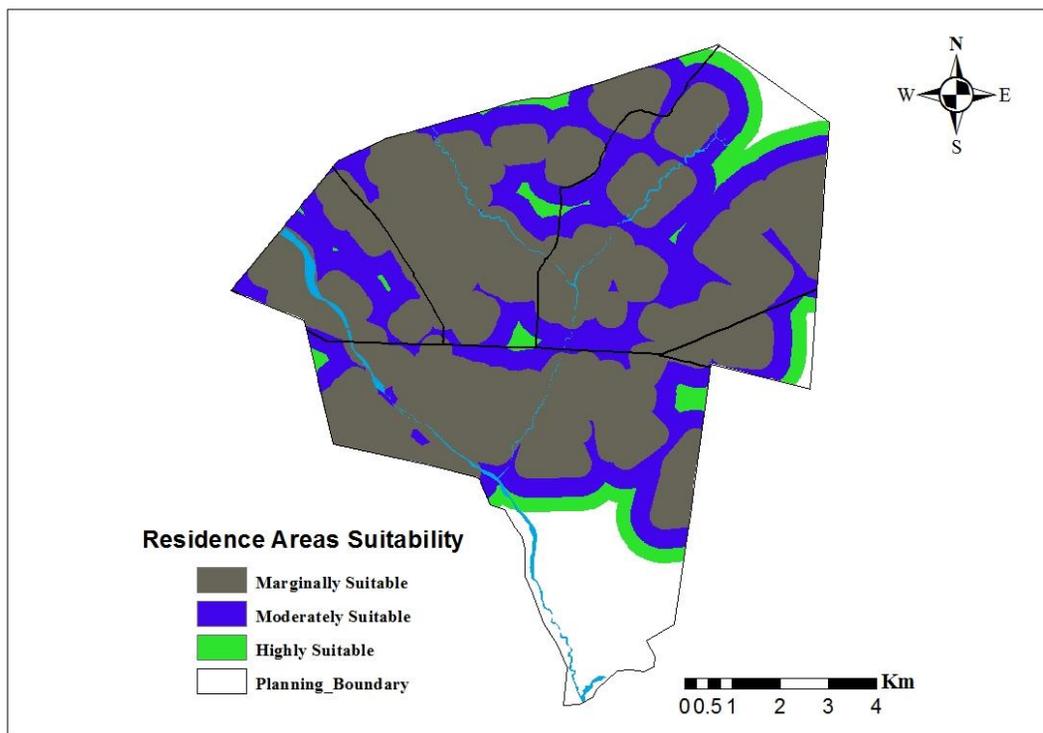Figure 4.2: Surface water factor map
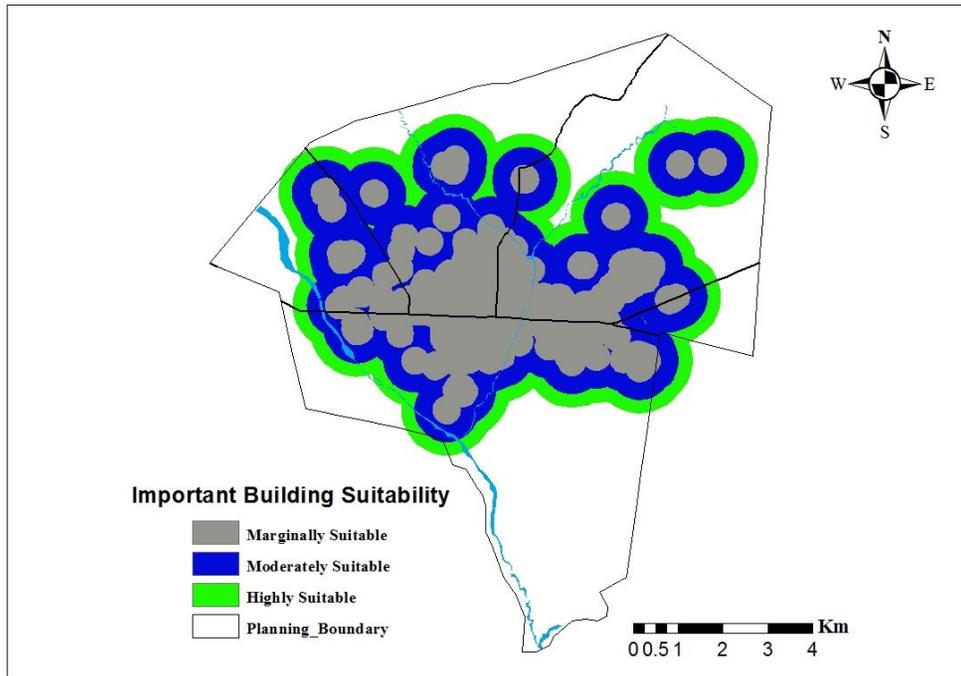
Figure 4.3: Residential areas factor map

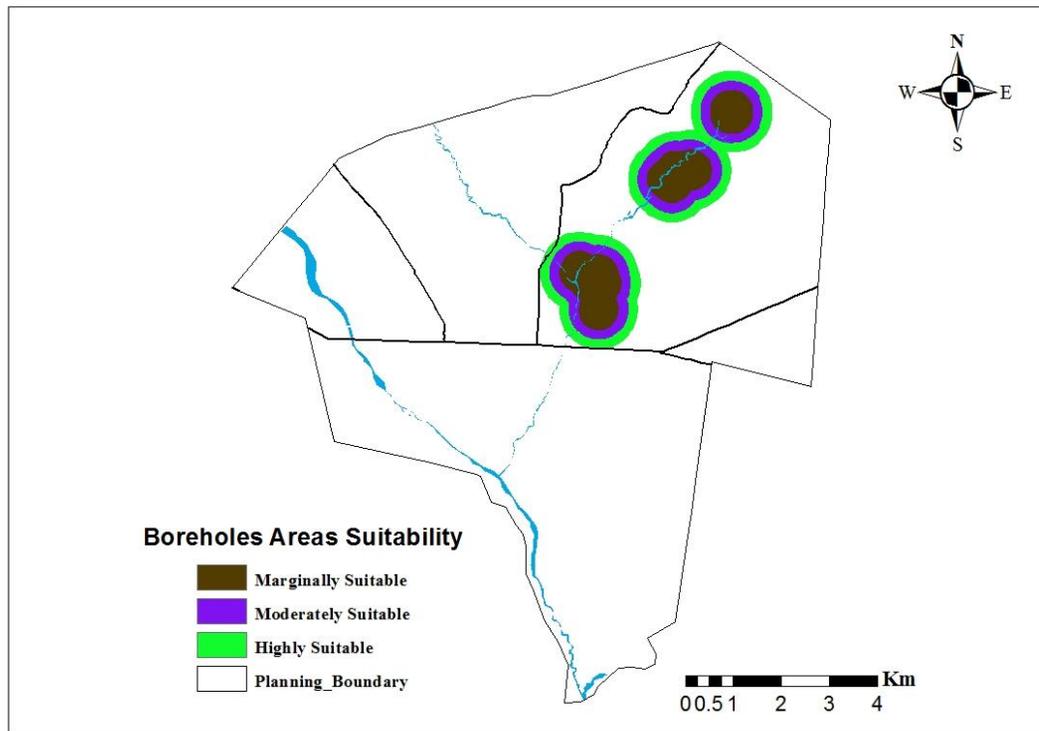Figure 4.4: Important buildings factor map
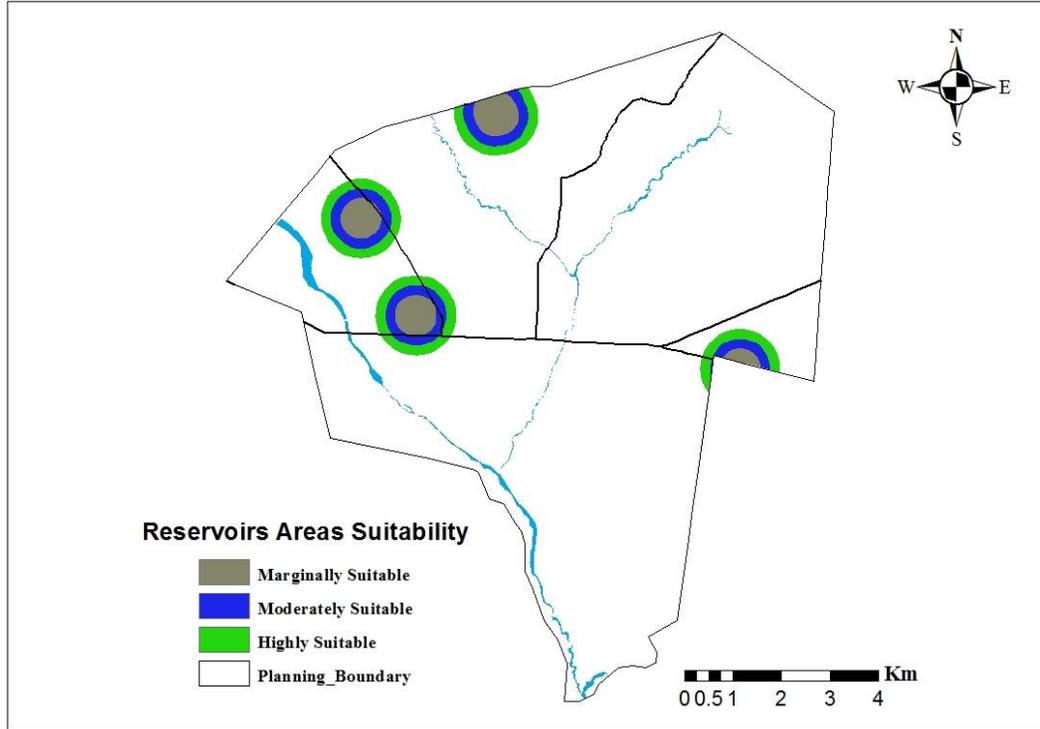

Figure 4.5: Boreholes factor map

Figure 4.6: Reservoirs factor map

Landfill Suitability Evaluation

With different degrees of importance, both environmental and socio-economic factors such as surface water (river in this case), Boreholes, reservoirs, and proximity to road networks, residential areas and important buildings were considered to determining landfill sites. The evaluation of the weight overlay analysis shows that, with a slightly differences, all factor maps (data layers) are equally influential as they are very important to protect water pollution from landfill leachate and safeguard public health. The results from the Weighted Linear Combination assessment in the ArcGIS software reveals three indices of site suitability for the municipal solid waste disposal of Jigjiga Town. These are marginally suitable, moderately suitable and highly suitable sites (Figure 4.7).
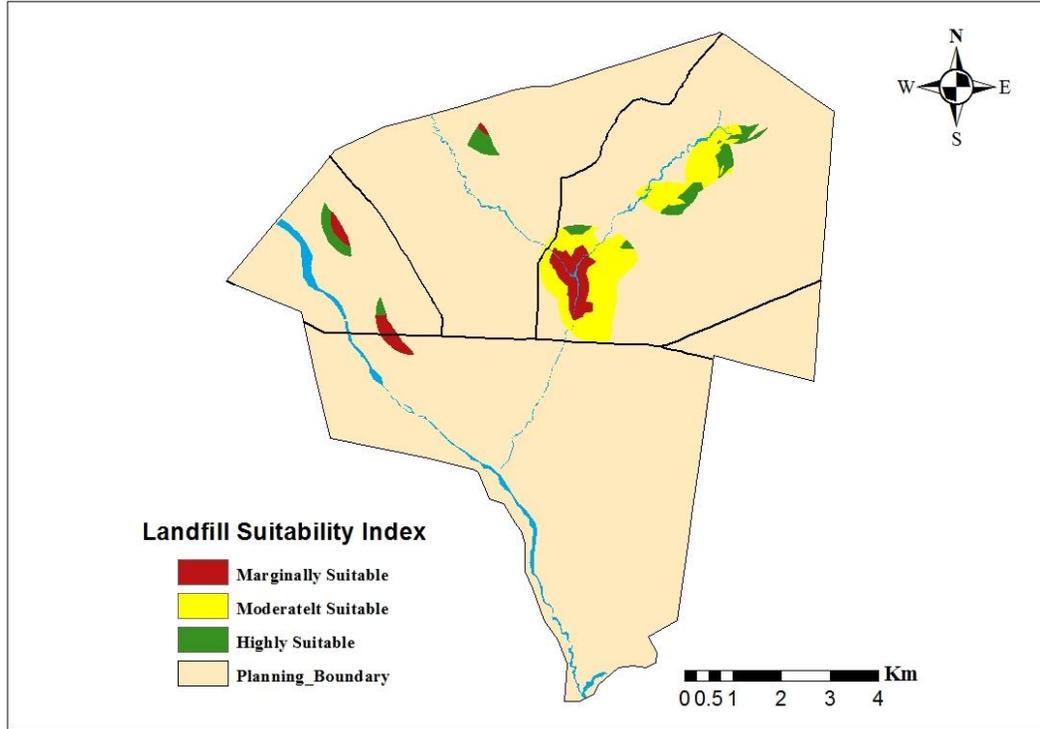
Figure 4.7: Solid Waste Disposal Site Suitability of Jigjiga Town

The area coverage of each suitability class of the sites was calculated in an ArcGIS algorithm after converting raster map into vector. The result showed that 8,694 ha (94.3%) of the total study area is unacceptable for landfill site as the areas are environmentally unfriendly, socially unacceptable and economically impracticable to be proposed as a solid waste disposal site. The unacceptable areas, therefore, include buildups and areas closer to major road networks and water sources. The main purpose of these areas restriction was to protect human health and environment from potential negative effects of landfill as well as to minimize the cost of construction and waste transportation.

However, the remaining areas of about 524 ha (5.7 %) of the town has satisfied the environmental, social and economic criteria set for the landfill site selection, in fact, with different suitability indices (Table 4.1).

Table 4.1: Solid waste disposal site suitability indices.

Suitability index	Area (ha)	Area (%)
Highly Suitable	93	1
Moderately Suitable	352	3.8
Marginally Suitable	79	0.9
Unacceptable	8,694	94.3
Total Area	9,218	100

Source: computed from landfill site suitability map (figure 4.7)

As depicted in the table 4.1, municipal areas of 93 ha (1%) was categorized as highly suitable whereas the rest 352 ha (3.8 %) and 79 ha (0.9 %) were respectively grouped as moderately and marginally suitable for landfill site. Most of the highly suitable landfill sites were identified in the northern and northwestern parts of the municipality (Figure 4.7). The northern part of the town, which is at a relatively higher elevation, is excluded from siting landfill as it is the recharge area for the low-lying area in the southern. Additionally, the southern part of Jigjiga Town is believed to be the potential source of ground water for the town vicinity hence not allowed for landfill site/s where the existing dump site is mistakenly located. Therefore, some of the northern and entire of southern parts of the town were excluded from landfill sites mainly to protect water pollution. Some of the eastern and the western parts of the town where plenty of important buildings such as Jigjiga University, airport, etc. and residences are concentrated were not selected for municipal solid waste landfill site to safeguard public health and town's esthetic values.
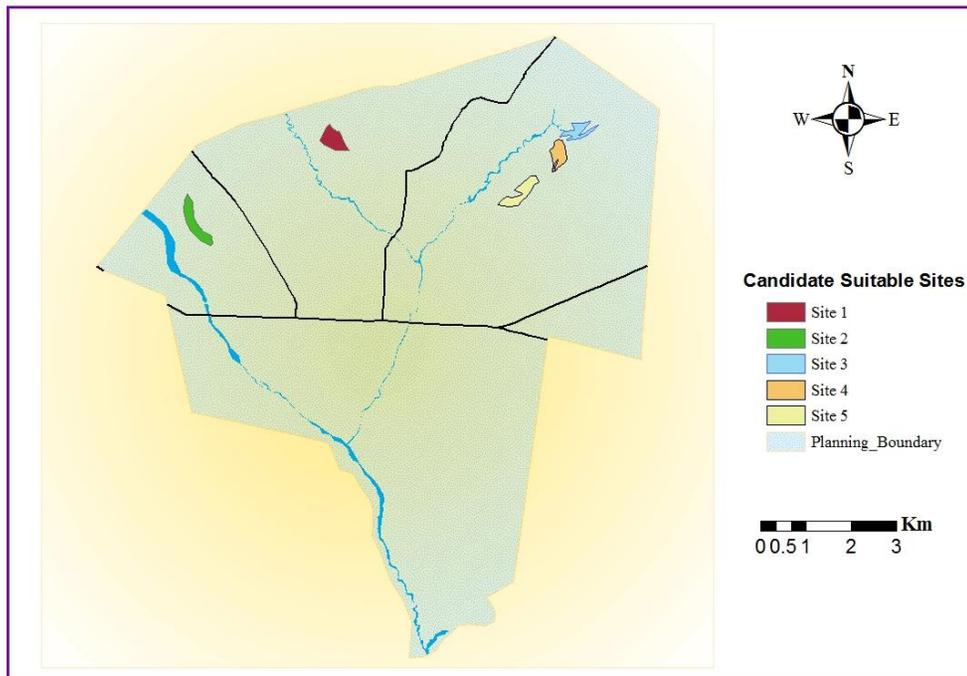

Figure 4.8: Candidate Suitable Sites for Solid Waste Disposal of Jigjiga Town

The moderately suitable areas may be used for landfill site with some careful management system such as lining the base of landfill and constructing leachate and gas collector so as to minimize their negative effects on the environment and public health. In contrary to this, the marginally suitable areas are currently restricted to be used for landfill site due to their close proximity to public services.

The Best Suitable Site   Selection
Areas identified as the highly suitable for landfill site are reevaluated for this purpose. Socio-economic criteria like size of the site, distance from nearby settlements and access

to transportation are some of the determinant criteria used to select potential landfill site so as to choose the best suitable site out of candidate highly suitable landfill sites. Size of landfill is one of the most determinant criteria for sustainable solid waste management system as size of land selected for landfill determines the number of years that the landfill site will last before the end of its lifespan. From sustainability and economical point of views, larger size of land that will serve for at least ten years are more preferable than small sized ones. This is mainly because of large sized landfill site can minimize the cost of another site selection, design and construction over and again. Therefore, further evaluation was made in ArcGIS environment to exclude small sized sites that are economically not feasible owning to their area being less than ten hectares from the sites that are classified as highly suitable (Figure 4.7). After the exclusion of smaller sites, the remaining candidate landfill sites were inter competed by using the aforementioned socio-economic criteria. Accordingly, the result of the analysis shows five candidate landfill sites that were selected for further evaluation (Figure 4.8 and Table 4.2).

For evaluating best suitable landfill site, distance from the settlements land use of the town is also another very important criterion from public health point of view. Landfill sites too close to the center of the town are objectionable due to nuisance and adverse effects on human health. Therefore, candidate landfill sites at farther distances from the center of the town where human settlement is concentrated were given more weight than others.

From economic point of view, landfill sites accessible to transportation facilities are preferable. Hence, by gauging each site's distance from the major road networks, more weights were assigned to sites a good amount of proximity to major roads.

Table 4.2: Sub-criteria evaluation for most suitable landfill site selection

Candidate Landfill Site	Areal Size (ha) 40% of influence	Distance from Settlement (Km) 25% of influence	Distance from transportation (Km) 35% of influence	Suitability score out of 100%	Rank
Site 1	20 (33%)	4.3 (18%)	1.8 (19%)	70	2
Site 2	24 (40%)	4.8 (20%)	1.0 (35%)	95	1
Site 3	14 (23%)	6.0 (25%)	1.7 (21%)	69	4
Site 4	16 (27%)	5.0 (21%)	1.8 (19%)	67	5
Site 5	21 (35%)	4.0 (17%)	2.0 (18%)	70	2

Source: Computed in ArcGIS analysis tools

The result shows that the candidate landfill site 2 is the most suitable site for solid waste disposal of the town, because it's the largest in size, located at optimum distance from the human settlements and the most accessible. Both landfill site 1 and 5 stood second by the summative criteria but the former outweighs the later in terms of transport accessibility and at a reasonable distance from inhabitants. In, general, landfill sites 2, 1 and 5 are the first three most suitable sites to be used for municipal solid waste disposal as per the criteria we devised.

CONCLUSION AND RECOMMENDATION

Conclusion

Solid waste disposal system in Jigjiga Town is open dumping without discriminations. As the result, there are environmental and social problems facing the community from the dumping sites. All types of solid wastes from hospitals, industries, domestic, market and commercial are dumped together which may contain leachable toxic compounds that are harmful to the environment and human health. The absence of any kind of waste treatment and separation has been worsening the situation. Moreover, the popular dumping site at "Sheik Ali Gure' locality is found along the major draining system of the town and is not at a reasonable distance from residential houses whereby it has been posing both social and environmental problems like nuisance, disease and economic disturbances due to a number of waste pickers and wild animals working on the site every day.

Backed by poor waste management systems and the problems associated with it, the present study employed GIS techniques to arrive at the most suitable solid waste disposal site by integrating six factors maps namely: proximity to road networks, distances from residences and important built up areas; surface water (river), boreholes and reservoirs in the study area. The result of the final landfill suitability map showed that 5.7% of the entire study area is categorized as suitable landfill site with various suitability indices ranging from highly suitable to marginally suitable.

Further analysis in ArcGIS was conducted to identify the most suitable site for landfill of the town among the five candidate sites on the basis of their size, accessibility and significant distances from residents. A site with 24 ha area, 4.8 km away from residences and 1 km close to the major roads was nominated as the most suitable site for the municipal solid waste disposal (landfill). This site is located in new kebele ten, north western part of the town.

4.2. Recommendations

Owning to adverse effect of the existing dump sites, the researchers strongly recommend the administrative body of Jigjiga Municipality to put the finding of this study into effect as soon as possible.

The site selected as the best landfill is expected to serve the purpose for longer than 10 years in order to reduce the cost of landfill sites election and construction of another site over and again. Therefore, the rates and volumes of solid waste generated from the municipality should carefully be determined to further decide the dimension of the landfill site during construction.

To protect downstream surface water pollution, runoff must not flow into and out of the sanitary landfill. Hence, drainage system should be constructed around the landfill.

The selected landfill site was only for non-hazardous solid waste. Therefore, hazardous wastes should not be dumped into this site. Hazardous wastes from industries, health

institutions and/or house-holds should be separated from non-hazardous solid waste before disposal. Hence, separate landfill should be selected for such hazardous solid waste as siting parameters and construction of landfill for hazardous solid waste is quite different from that of non-hazardous waste.

The present study considered a few of environmental, social and economic factors for landfill site selection. However, other factors such as geology, elevation, slope, ground water table depth etc. and community preferences were not incorporate as evaluation criteria, partly because of expensiveness of remotely sensed data.   Hence, further study should fill this research gap by including these layers as evaluating criteria.

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