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Solid Waste Disposal Site Selection Suitability Analysis Using Geographic Information System and Remote Sensing for Bahir Dar City, Ethiopia

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Abstract

Bahir Dar city has serious problems in the case of solid waste disposal site selection. This condition demands a scientific approach for the selection of solid waste disposal site for proper city solid waste disposal and management. Therefore, the aim of this study was to select suitable solid waste disposal site for the Bahir Dar city using integrated Geographic Information System (GIS) and Remote Sensing techniques (RS). The main data used for this study were based on primary and secondary data sources. The primary data were obtained through non-structured interview, photo camera, online Landsat image and field observation and secondary data for the study were used for different shape files (soil related data, administrative boundary and master plan), reliable journals and articles, reports and governmental institutional manuals. The criteria used for this study include distance from the water body, distance from built-up areas, distance from main roads, distance from protected area, land use, distance from airport, slope, geological feature, soil type, soil depth and soil texture. GIS software and its environment tools, the satellite image, different shape files and AHP technique were used for map preparation and suitability analysis. The final selected solid waste disposal sites are grouped as high suitable, medium suitable, less suitable and unsuitable. The results from the total area of the analysis show that 2.46% highly suitable, 5.44% medium suitable, 15.14% less suitable and 76.95% unsuitable for solid waste disposal. Based on the results, the most potential and highly suitable areas for solid waste disposal sites are available on Yinsa sositu and Dishet abaraji kebeles where there are least environmental and health risks. Hence, the selection of solid waste disposal sites will help Bahir Dar city municipal authorities make the right and sustainable choice on the selection and planning of landfill sites with minimum environmental risk and human health problems..

Keywords: Suitability, Solid waste, Waste disposal site, Geographic information system, Weighting, Pairwise

Introduction

Solid waste management issues are coming into the main global environmental agenda at an increasing frequency, as population and consumption growth result in increasing quantities of waste in alarming rates in urban area [1]. Appropriate solid waste disposal site selection is an important part of a solid waste management system, which requires much attention to avoid environmental contamination, human and other important living things health and disruption of wealth all over the world in both developed and developing countries [2].

Developing countries like Ethiopia, are facing rapid urbanization leading to overexpansion and the development of slums and informal settlements with poor solid waste disposal and management practices. Urban dwellers generally consume more resources than rural dwellers and so generate huge quantities of solid wastes with the unsuitable disposal site [3]. The major sources of solid wastes in the city/town are homes, hotels and restaurants, barberries, demolition or construction materials, hospitals, different industries and private clinics with absence of the appropriate landfill. Urban communities have been dumping solid wastes around their homes, near to the road and inappropriate common open disposal site (Aden Ali Mohammed 2016). This leads to high potential environmental pollution, human health risk, lower the beautifulness of towns/ cities, risk to animals and plants and the disruption of wealth. So the people living around and along disposal site are at risk in their day to day activities because of these problems [2].

The technique of getting rid of the challenges of solid wastes in an economically viable, environmentally friendly and socially acceptable approach is the most important requirement through suitable solid waste disposal site selection and proper management. Selection of suitable solid waste disposal site has been a big challenge for our country, Ethiopian urban area [4]. Selection of new solid waste disposal site is a great concern for the urban government as old solid waste disposal sites are being filled-up and demand for new sites are increasing garbage (Biruk Abate Fenta, 2017).

Bahir Dar is one of the metropolitan city in Ethiopia facing under such problems for a long period of time due to lack of suitable solid waste disposal site selection and proper management. There is no standard solid waste disposal site in the city. Most of solid wastes generated in the city simply dumped in the open disposal site, while some others dispose their wastes along roadsides, river and lake courses, gullies and drainage lines [5]. The environmental and sanitary conditions of the city have become more and more serious over time and people are suffering from living in such conditions of bad odor resulted in health problems. This demands the necessity of developing integrated, computerized systems for obtaining more generalized and optimal solutions for the selection of urban solid waste disposal site (Kassahun Tassie, 2018). Several studies have been conducted at different levels of town to find the optimum locations for solid waste disposal sites in different countries or its parts, but not for Bahir Dar city that included all the criteria (Kassahun Tassie, 2018). The selection of suitable solid waste disposal site must combine social, environmental, ecological, technical and economical parameters. Also, the location must comply with the requirements of the governmental as well as international regulations in order to be environmentally friendly and socially acceptable [6].

Thus, GIS and remote sensing techniques are important tools for solid waste disposal site selection. The selection of solid waste disposal sites using this technique requires many factors that should be integrated into one system for proper analysis [7]. The selection criteria should consider and combine distance from surface water, soil condition, slopes, built up /settlements, geological formation, protected areas, land use and main road networks [8]. Locating proper solid waste disposal sites, considering the above criteria is the main issue for solid waste management. Hence, identification of suitable solid waste disposal site using GIS and remote sensing techniques is very important that will minimize the environmental risk and human health problems for Bahir Dar city.

Material and Methods

Location of the study area

Bahir Dar is the capital city of Amhara National Regional state located in the highland of Ethiopia. It is located about 556 km north of Addis Ababa along with Addis Ababa to Gondar highway. The naming of the city as Bahir Dar is connected with its proximity to the two water bodies of Lake Tana and River Abay (Nile). Hence, literally explained as Bahir Dar is a city situated on or very close to the shore of Lake Tana and the Blue Nile. It is one of the biggest and dominant political, economic, cultural, and historical cities in the Ethiopian country which served as the administrative center of the Amhara regional state. The location map of the study area is given in Figure 3.1

The study area geographically lied between 1272589mto 1282440m latitude North and 312404m to 333169m longitudes east. The study area covers a total of 36906.52ha. The city is divided into nine sub-cities and each sub-city is again divided into kebeles. The study area includes Bahir Dar city and the surrounding rural kebeles of Zenzelima, Werb kola Tsiwen, Dishet Abaraji, Woramit, Yibab, Yinesa sositu, Wondata and Sebatamit. The selection of these kebeles is based on future Bahir Dar city above 15-20 years' expansion rate as it is one of the fastest-growing and the largest city in Ethiopia.

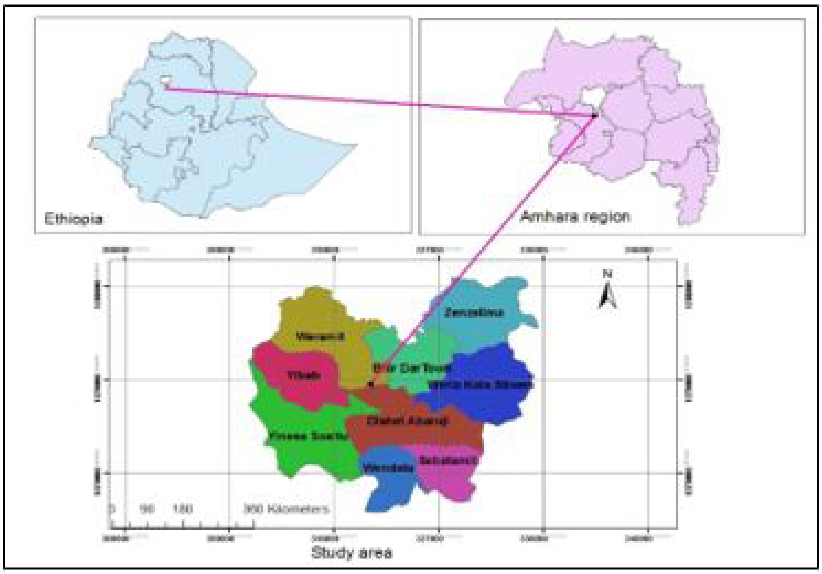


Figure 3.1: Location map of the study area

Primary Data Sources and Methods of Collection

The primary data source was obtained through the non-structured interview, photo camera, and field observation of the existing dumpsites. Interviews with experts of environmental protection officers and residents who are near the existing landfill were made to get more information. Landsat8 download from USGS was used for current land use/land cover supervised classification in the study area and also Landsat image can be downloaded from google earth with the help of ElshayalSmart for saving the image to analyze with Arc-GIS and supervise land use/land cover classification. Road networks and built-up areas are developed from the satellite image using google earth online delineation. GPS data for verification of land use/ land cover map was produced from the image of the satellite. DEM gathered from USGS with a spatial resolution of (30 m x 30m) that were extracted within the study area boundary using spatial analysis tools and it used to generate slope and drainage within the ArcMap environment.

Secondary Data Sources and Methods of Collection

The secondary data were used includes shape files such as soil type, soil texture, soil depth, city master plan and Administration boundary. The new Structural plan of the Bahir Dar city was obtained from Bahir Dar municipality planning unit office and geological map of study area obtaining from a geological survey shape file of Ethiopia (GSE). All the above data were collected, manipulated and analyzed in a GIS environment to be used for solid waste disposal site selection analysis. Moreover, Table 3.2 clarified primary and secondary data in type and their sources.

S.N	Data type	Purposes	Sources
1	DEM	To delineate watershed and generate slope	USGS
2	Landsat8	To generate land use land cover map	USGS
3	Soil related data	To produce soil type, soil depth and soil texture map	BOA
4	Rainfall and temperature	To generate Rainfall and temperature data	NMA
5	Geology	To generate geological map	GSE

Table 3.2: List of data used and their original sources

Methods of Data Analysis

There are different methods of GIS operation for solid waste disposal site selection suitability analysis. Methods like data analysis, buffering, overlay, digitizing, spatial analysis, classification and identification of criteria, and MCDM were the major ones used in this study to select suitable solid waste disposal site.

Data Analysis and Presentation

The methodology utilizes GIS tools to evaluate the entire region based on certain evaluation criteria for the analysis of landfill site suitability. The criteria used for spatial analysis are slope, land use/land cover, geological feature, soil type, soil depth and soil texture, distance from major roads, distance from major residential/built up area, distance from the water body, distance from protected area and distance from airport.

To develop the suitable solid waste disposal site selection, we considered six major steps: (1) selection of environmental decision factors and sub-factors; (2) integration all the criteria in a GIS database; (3) defining and assigning of classes with appropriate ranges and ratings; (4) data standardization to a common scale of measurement and mapping according to its suitability; (5) overlay each map using the AHP technique; and (6) derivation of the final model map using AHP techniques. The steps are shown in (Figure 3.2) in the follows ways. **Soil texture**

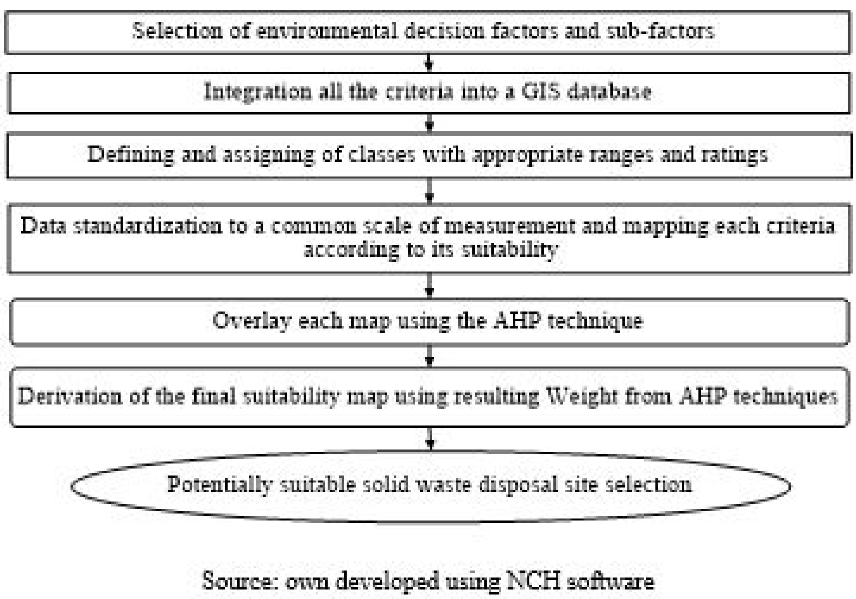


Figure 1: Potentially suitable waste disposal site selection steps

Digitizing

Mapping and developing features such as soil texture, soil depth and soil type were produced from the soil map shape files, land use/land cover from satellite image with supervised classification, road network from the structural plan of the Bahir Dar city and online delineation from google earth, drainage from DEM using SWAT analysis and slope from DEM/30x30/ using GIS environment and its analysis tools.

Buffering

Buffering is a spatial analysis tools and also called proximity analysis. The Buffering analysis was executed for main roads (0-500m, 500-1000m, 1000-2000m and >2000m), water body (0-300m, 300-600m, 600-1000m, and >1000m), airport (0-

3000m, 3000-5000m, 5000-8000m, and >8000m), protect the area (0-750), (750-1500m, 1500-3000m, >3000m) and built up area (0-300m, 300-600m, 600-1000m and >1000m). These values for buffering analysis were assigned after referring to different researches and a new value generated based on the geographical characteristics of the city.

Thematic map preparation

The thematic maps such as distance from surface water/river, land use/land cover, distance from the main road network, slope, distance from built up area, distance from airport, soil type, soil texture and soil depth maps were prepared by using GIS digitization, overlay and buffer analysis with the appropriate criteria and appropriate distance. The methods used have included buffering, overlaying, spatial analysis, 3D analysis and other extensions. These thematic maps were also used as an input for online analytical hierarchy process (AHP) and multi-criteria evaluation analysis (MCDA).

Software used for the analysis

The software used for data pre-processing and preparation, data analysis, editing and output generation were ArcGIS 10.1 and Arc SWAT. ArcGIS 10.1 applied for digitizing proximity and overlay analysis and database creation for all criteria. The application of GIS environment for overlaying thematic layers to establish land databases requires that all the layer maps need to be converted into a common coordinate system. Arc SWAT used for digitizing drainage line in study area delineation within the GIS environment. Google earth used for identification of present environmental condition and land use preparation through Landsat8 image. ElshayalSmart used for image downloading from google earth for ArcGIS environment analysis. NCH software used for flow chart preparation for the study of this paper. The program also allows the user to group or layer objects, keep objects in a database for future use, and manipulate properties of objects.

Classification of suitability score

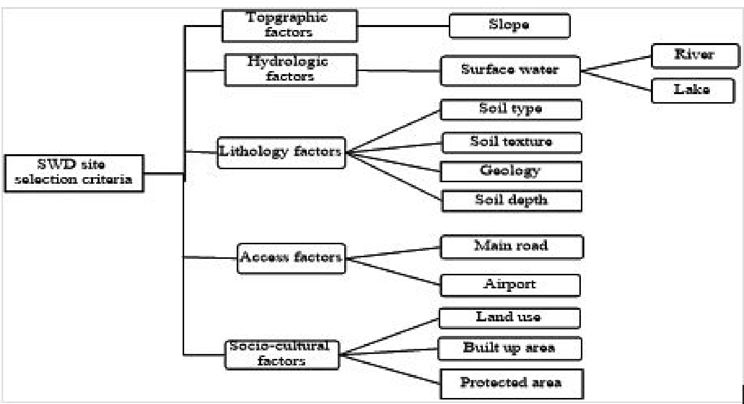
Standardization of all the generated layers was required for further analysis. Therefore, all the layers have been classified with values from 1-4. These numerical suitability scores were assigned to each of the buffers in increasing order of distance, giving higher values (scores) to more suitable attributes and other criteria assigned based their characteristics.

Suitability Class	Suitability scores
Unsuitable	1
Less suitable	2
Medium suitable	3
High suitable	4

Table 3.3: Classification of layers and suitability score for the analysis

Identification and reclassifications of criteria

The main factors and sub factors, including topography, hydrology, lithology, access and sociocultural factors with many different associated sub-factors were used in the model as we have shown in (Figure 3.3).



Source: own developed using NCH software

Figure 3.3: Factors and sub-factors used for suitable solid waste disposal site selection

Slope Classification

The slope is one of the key criteria to be considered in solid waste disposal site section. Slope of the study area was developed from DEM 30mx30m resolutions using special analyst tools in GIS environment. The best places for solid waste disposal sites are the slope range with no more than 20%. Therefore, in this study slope was reclassified into four classes within special analysis tools and extract according to the slope of solid waste disposal suitability [5].

Factor	Criteria class %	Suitability type	Assign value
Slope	0-10	Highly suitable	4
	10-15	Medium suitable	3
	15-20	Less suitable	2
	>20	Unsuitable	1

Table 3.4: Criteria for slope class setting

Water body

In order to reduce vulnerability to ground and surface water pollution from contamination, landfill should not be located near to Lake Tana, River Abay and other tributaries. Surface water drainage of the study area was generated from DEM using SWAT tools and Lake Tana shape file in GIS environment using special analyst tools. In this study area a minimum distance of 300 m was used for site selection process to protect surface water from pollution. This buffering was to identify safety site for a landfill is as shown Table 3.5.

The more distant from surface water, the more suitable for sitting landfill to reduce the negative effect on pollution [7].

Factor	Criteria class	Suitability type	Assign value
Water body	0-300m	Unsuitable	1
	300-600m	Less suitable	2
	600-1000m	Medium suitable	3
	>1000	High suitable	4

Source: (From Lamessa Kenate, 2017)

Table 3.5: Water body suitability criteria classification

Land use/Land cover

The LU/LC map that was produced from the image of Landsat 8 and classify image using supervised/ unsupervised classification and further validation and correction has to be carried out with the help of ground truth data and has to be changed to LU/LC map in a more reliable form. Open land use type is a land use type contain grazing land and lands that did not covered by agricultural, settlement and forest land. It is the most suitable for solid waste disposal comparing with other land use classification [7]. The LU/LC of the study area classified into different classes based on solid waste disposal site selection suitability such as farm land, open area, forest, built up and wetland clearly shown in Table 3.6.

Factor	Landaus type	Suitability type	Assign value
	Road Net	Unsuitable	1
	Wetland	Unsuitable	1
Land use/land cover	Airport	Unsuitable	1
	Built up area	Unsuitable	1
	Farm land/agriculture	Less suitable	2
	Forest/bush	Medium suitable	3
	Open area	Highly suitable	4

Source: (Supervised classification, online delineation from satellite image and city mater plan)

Table 3.6: Criteria for land use/land cover type classification

Soil texture

The study area has four soil texture classes, as shown in table 3.7. The suitability classification is based on the permeability of the soil and its structure. Therefore, the degree of permeability is different in different soil texture from unsuitable to highly suitable.

Factor	Soil texture	Suitability type	Assign value
Soil texture	Water body and rock	Unsuitable	1
	Sandy loam	Less suitable	2
	Clay to clay loam	Medium suitable	3
	Clay	High suitable	4

Source: (Extracted/clipped from soil texture shape file obtained from BoA)

Table 3.7: Criteria classification for soil texture

Soil depth

The Study Area Of The Map Was Georeferenced And Digitized At GIS Environment Obtained From The Soil Depth Shape File. Soil Depth Shape File Obtained From GSE And Then Clip With The Study Area Boundary. The Suitability Classification Is Based On The Depth Of The Soil And Its Drainage Into Waterbody And Ground Water. The Study Area Has Arranged Into Four Soil Depth Classes Considering Its Permeability And Infiltration As Shown In Table 3.8.

Factor	Sol depth class in cm	Suitability type	Assign value
Soil depth	0-25	Unsuitable	1
	25-50	Less suitable	2
	50-100	Medium suitable	3
	>100	Highly suitable	4

Source: (Extracted/clipped from the soil depth shape file obtained from BoA)

Table 3.8: Criteria setting for soil depth

Soil type

Soil characteristics promote a safer and more economical feasible impletion and operation of a dump site. Permeability, effective porosity and workability are important soil characteristics which were considered for site selection. Soil and waste disposal correlated with permeability in its drainage toward the human and animal use area and pollution of surface and ground water. Therefore, in the study area there are four classes of soil types used for solid waste disposal site selection analysis as shown below in table 3.9.

Factor	Soil type	Suitability type	Assign value
Soil type	Rock and waterbody	Unsuitable	1
	Eutric vertisols	Less suitable	2
	Haplic luvisols	Medium suitable	3
	Lithic leptosols	Medium suitable	3
	Chromic luvisols	Highly suitable	4
	Eutric leptosols	Highly suitable	4

Source: (Extracted from soil shape file obtained from BoA)

Table 3.9: Criteria for soil type

Geological feature

Based on the geological map of Ethiopia the study area of geologic map includes basalt related volcanic center, ashangi basalt, termaber basalts, alluvium, and lake. Basalt related volcanic center related to chromic luvisols is highly suitable and ashsangi basalts related to eutric vertisols is less suitable for solid waste disposal. Termaber basalts is medium suitable whereas, alluvium and lake are not suitable for solid waste disposal site. It is recommendable that the geological feature of the selected site has good natural impermeability for reducing the possibility of aquifer contamination (Asked for Geology expert).

Sn	Geological types	Suitability type	Assign value
1	Alluvium	Unsuitable	1
2	Lake	Unsuitable	1
3	Ashangi basalts	Less suitable	2
4	Termaber basalts (2)	Medium suitable	3
5	Basalts related to volcanic center (2)	Highly suitable	4
6	Baselts related to volcanic center (3)	Highly suitable	4

Source: (Extracted from geological shape file obtained from BoA)

Table 3.10: Geological criteria of study area

Main road networks

The main road network of the study area to its nearby was measured by the buffer distance created in the ArcGIS environment using analysis tools. Based on the road network proximity standard areas found below 500 m from highways or main roads were considered as unsuitable(Aden Ali Mohammed, 2016). Therefore, for this study main road network reclassified into four classes as shown below Table 3.11

Factor	Criteria class	Suitability type
Road Network	0-500m	Unsuitable
	500-1000	Less suitable
	1000-2000m	Medium suitable
	>2000m	Moderately suitable

Source: (From Aden Ali, 2018)

Table 3.11: Criteria for main road network

Built up area

The solid waste disposal site should be far from it in order to avoid any types of pollution, waste related disease and social conflict due to disposal of waste around build up area. Built up area was generated from structural plan and directly delineated from satellite image on google earth in the study area and converted kml to layer for further analysis. According to [7] set built up with distance greater than 1000m as the best site for solid waste disposal. In this study built up area classified into four classes are clearly indicated in table 3.12.

Airports

In this study area a minimum distance of 3000 m was used for site selection process to protect different birds attracted to tips may endanger flights from nearby airports (Ministry of Urban Development and Construction Urban Planning, 2010).
Based on the above stated the distance used to prepare a buffer zone ranging as shown in Table 3.13. Therefore, a 3000m buffer was used as the minimum distance for selecting the suitable landfill site(Ministry of Urban Development and Construction Urban Planning, 2010).

Factor	Criteria class	Classification	Assign value
Built up Area	0-300m	Unsuitable	1
	300-600m	Less suitable	2
	600-1000m	Medium suitable	3
	>1000m	High suitable	4

Source: (Developed based on Lamessa Kenate, 2017)

Table 3.11: Criteria for main road network

Factor	Criteria class	Classification	Assign value
Airport	0-3000	Unsuitable	1
	3000-5000m	Less suitable	2
	5000-8000m	Medium suitable	3
	>8000m	High suitable	4

Source: (from Ministry of Urban Development and Construction Urban Planning)

Table 3.13: Criteria for Airport

Protected area

The protected area in this study includes churches, mosques and parks. The landfill should not be located in close proximity to in such sensitive areas since these areas are used for meeting, praying and others. In this study area a minimum distance of 750m was used for site selection process. For this study the distance used to prepare a buffer zone 3000m buffer was used as best distance for selecting the suitable landfill site. The most suitable solid waste disposal sites should be selected from >3000m distance from protected area [9].

Factor	Criteria value	Classification	Assign value
Protected Area	0-750m	Unsuitable	1
	750-1500m	Less suitable	2
	1500-3000m	Medium suitable	3
	>3000m	Highly suitable	4

Source: (From Minalu Ambachew, 2016)

Table 3.14: Criteria setting for protect area

Ground water

The ground water circulation and downward flow of pollutants is depending on the lithology and hydraulic condition of materials more specifically soil type, soil texture, soil depth and buffer zone of drainage and surface water [9]. Suitable lands for solid waste disposal in soil type, soil texture, soil depth, geological formation and buffer zone of surface water and its drainage line areas are suitable for ground water table.

In this study, the suitability analysis of the above parameters used as groundwater impacts in the study area with the limitation of finding groundwater shape file. Therefore, ground water impact can be minimized by determining soil type, soil texture, soil depth, slope of the land, surface water and its drainage line.

Identification of constraints/restrictions

Constraint maps are limitations or restrictions which prohibit certain elements to be taken into account for disposal sites. Constraint maps are used to distinguish lands that are suitable for landfill siting and those lands that are restricted. The constraint maps are produced by overlaying each individual theme or raster map by using the raster calculator in the analysis tools. This procedure created a constraint map for each theme containing only two classes represented by 1`s for suitable land and 0`s for unsuitable land.

Spatial analysis

Solid waste disposal site selection is the complex, tedious and costly process that needs to consider many conflicting criteria. To make analysis, ArcGIS Spatial Analysis is a powerful tool used to generate slope, land use, soil condition, geology, buffering of different criteria and conversion from their sources within the GIS environment through its special analysis tools. This special analysis can convert solid waste site selection criteria into a buffer and criteria map which is suitable for analyzing in the GIS environment.

Overlay analysis

The weight is given through empirical methods and subjective judgments by the decision maker. For this study, the overlays can use different input features to the base map (structural plan of the study area), such as slope, soil, buffer and land use data from different sources.

The final map was prepared by using overlay operation in the arc tool box using overlay analysis of each input layer or factors such as surface water/river, land use/land cover, road network, and slope, built up area, soil types and suitable site in the attributes assign the suitability. In this process, Weight was assigned to different thematic layers based on their significance in deciding the site suitability. Moreover, weighted overlay analysis was employed in deciding the potential location of waste disposal site of the study area. This is obtained by AHP online calculating the matrix product of the pairwise comparison matrix and the weight vectors and then adding all elements of the resulting vector.

Multi-criteria decision-making

Multi-criteria evaluation (MCE) technique is used to deal with the difficulties that decision makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into more understandable parts, analyze each part separately, and then integrate the parts in a logical manner [10]. Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives, according to many criteria, often conflicting, to guide the decision maker towards a judicious choice [11].

MCDA consists of a series of techniques such as a weighted summation or concordance analysis that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/sitting a particular facility/service [12]. Analytic hierarchy process (AHP) in which pair wise comparisons will also be used to determine the relative importance of each alternative in terms of each criterion is one of the most commonly used MCDM tools [13].

A measure of how far a matrix is from consistency is determined by computing the consistency ratio (C.R.). This is obtained by AHP online calculating the matrix product of the pairwise comparison matrix and the weight vectors and then adding all elements of the resulting vector. Also a Consistency Index (C.I.) is computed using the following formula:

$$CI = \frac{\lambda max - n}{n-1} \quad \text{.................................. (1)}$$

Where n is the number of criteria and λmax is the biggest eigenvalue [14]. To determine if the comparisons are consistent or not, the consistency ratio (*C.R.*) is calculated using the formula:

$$CR = \frac{CI}{RI} \quad \text{.................................. (2)}$$

Where *R.I.* is the random inconsistency index

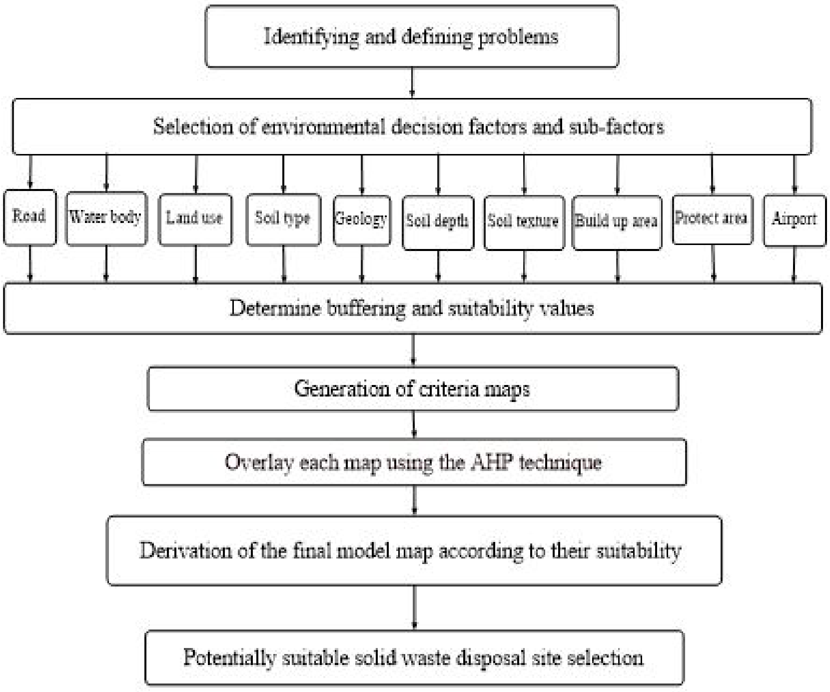
A reasonable level of consistency in the pair-wise comparisons is assumed if the results of the value of *C.R.* < 0.10, while the results of *C.R.* ≥ 0.10 indicates inconsistent judgments(Malczewski, 2000).

N	1	2	3	4	5	6	7	8	9	10	11
R.I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Table 3.15: Random consistency index (Malczewski, 2000)

Conceptual framework of the study

The general workflow of this study includes six major steps. The detail of the conceptual framework is shown in figure 3.4.



Source: own developed using NCH software

Figure 3.4: General methodological flowchart of the study

Results and Discussion

This chapter discussed different data sets that were used to determine suitable solid waste disposal site. In this study, suitable site for solid waste was determined for Bahir Dar city by using the GIS, its analysis tools and remote sensing. For this study eleven/11/ suitability criteria (built up area, main road, surface water, protect an area, airport, slope, geology, soil type, soil depth, land use/land cover and soil texture) were used based on the relevant literatures, standards of urban development and construction, in addition to international practices. Maps were created for each suitability criteria and the final composite map was finally produced by overlaying of the individual maps through AHP techniques.

Existing solid waste disposal site analysis

In the study area, there were individuals organized to collect solid wastes from door to door by individual collectors, transport carts and stored it in containers for a long period of time and transport to the opened disposal site located on the right side of Bahir Dar to Addet and Tiss Abay main road. Solid waste collectors collect from individual house, hotels, restaurants, and others with transport car and manpower. In hotels and restaurants, they collect waste twice a day whereas in individual houses they collect twice a week. For example, Drim Light PLC collect and transport 70 m^3 solid waste by 5m^3 transporting cars and 80 m^3 by16 m^3 transporting car. The total amount of waste collected and transported by Drim Light PLC accounts 150m^3 solid waste per day and disposing in an open disposal site.

Only 104980 piece of solid wastes converted into coal and 560500kg solid wastes prepared compost still new. Drim Light PLC covers 50% of the total solid waste collected and transported in the city. Other organized collectors cover sub city in Belay zeleke, Shumabo, Ginbot20, Shinbit, and Hidar11 only collect and transport to the open disposal site. This shows that all solid wastes generated from the city transported to the disposal site without reuse within an open disposal site which is not fenced in its surroundings due to these children and animals entered into the waste site freely and becoming exposed.

Most of the solid wastes generated from different sources were dumped in the city open disposal site. The residents nearer to the existing open dump site are suffering from odor, pollution of air and pollution of water bodies as such they cannot use it for home consumption. Solid waste disposed in the open field close to the drainage contaminates the river highly because of runoff since the slope towards the water body. People living around the disposal site always comply about the effect of disposing waste since the present landfill site did not fulfill / consider waste disposal site selection criteria. This leads to high potential of environmental problems, human health risk, lower the beautifulness of the city, risk to animals and plants and the disruption of wealth.

According to observation, informal interview and the analysis, the existing solid waste disposal site having different problems, because it did not consider major environmental, social and health factors like distance from water bodies, topography, soil type, distance from protect area, distance from road and settlement/built up area. It was not selected based on waste disposal site selection criteria. If one of the criteria fall under unsuitable/restriction for a solid waste disposal site, that site is recommended as unsuitable for solid waste disposal.

As a result, distance from road, distance from built up area and surface water are the main problems in the city disposal area. The disposal site is not fenced in its surroundings due to these children and animals entered into the waste site freely and becoming exposed. Considering all criteria, the suitability of current solid waste disposal site determines in Table 4.1 and figure 4.2 the following ways.

Figure 4.1: present solid waste disposal site looks like

Sn	Type of Criteria	Suitability class	Suitability condition
1	Land use/land cover	Open land	High suitable
2	Distance from buildup area	300-600m	Less suitable
3	Protect area	750m-1500m	Less suitable
4	Airport	>8000m	High suitable
5	Distance from water body	300m-600m	Less suitable
6	Distance from main road	0-500m	Unsuitable
7	Slope	0-10%	High suitable
8	Soil type	Chromic luvisols	Highly suitable
9	Soil texture	Clay	High suitable
10	Soil depth	>100cm	High suitable
11	Geology	Basalts related to volcanic center	High suitable

Source: (From the analysis of disposal site)

Table 4.1: Existing solid waste disposal site suitability analysis

From the above table, we can be concluded that the current solid waste disposal site is restricted /unsuitable due to distance from main road.

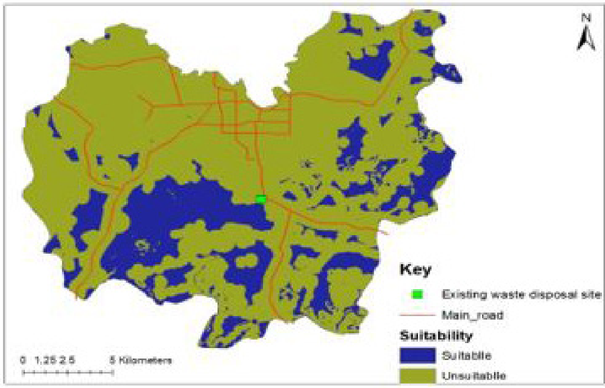


Figure 4.2: Existing waste disposal site suitability location

Evaluating and mapping the suitability of criteria

Slope suitability analysis

The majority of the study area falls under the slope class of 0-10%, which covers 30560.97/82.87% of the total study area. All the rest of the study area which accounts 2532.6/6.87%, 1020.22/2.77% and 2763.7/7.49% were covered by slope classes 10-15, 15-20 and 20% respectively. This shows that the slope is less significant criteria for solid waste disposal site selection for Bahir Dar city (Table 4.2 and Figure 4.3). This means that the study area is more or less flat in its topography and suitable for solid waste disposal site.

Based on above explanation suitability map of slope prepared as shown figure 4.3.

Sn	Slope class	Suitability class	Suitability rank	Area/ha	Share %
1	0-10	High suitable	4	30560.97	82.87
2	10-15	Medium suitable	3	2532.6	6.87
3	15-20	Less suitable	2	1020.22	2.77
4	>20	Unsuitable	1	2763.89	7.49

Table 4.2: Area coverage and slope suitability analysis

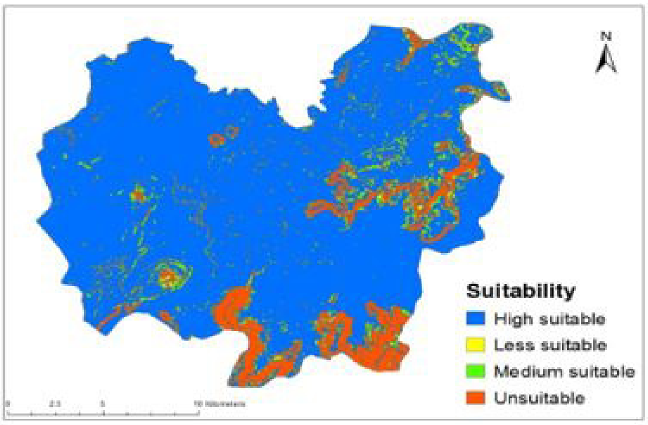


Figure 4.3: Slope suitability map of the study area

Surface Water Suitability analysis

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 higher discharge and greater downstream influence, no solid waste disposal should be sited within the floodplains of major rivers. The hydrology class and suitability level are given in Table 4.3 and Figure 4.4 respectively.

Therefore, as the distance between the solid waste disposal and water body's decreases, the probability of polluting the water becomes high.

Sn	Buffer distance	Suitability class	Suitability rank	Area/ha	Share %
1	0-300	Unsuitable	1	6406.31	17.37
2	300-600	Less suitable	2	5320.54	14.43
3	600-1000	Medium suitable	3	6376.32	17.29
4	>1000	Highly suitable	4	18777.22	50.91

Table 4.3: Surface water suitability and area coverage

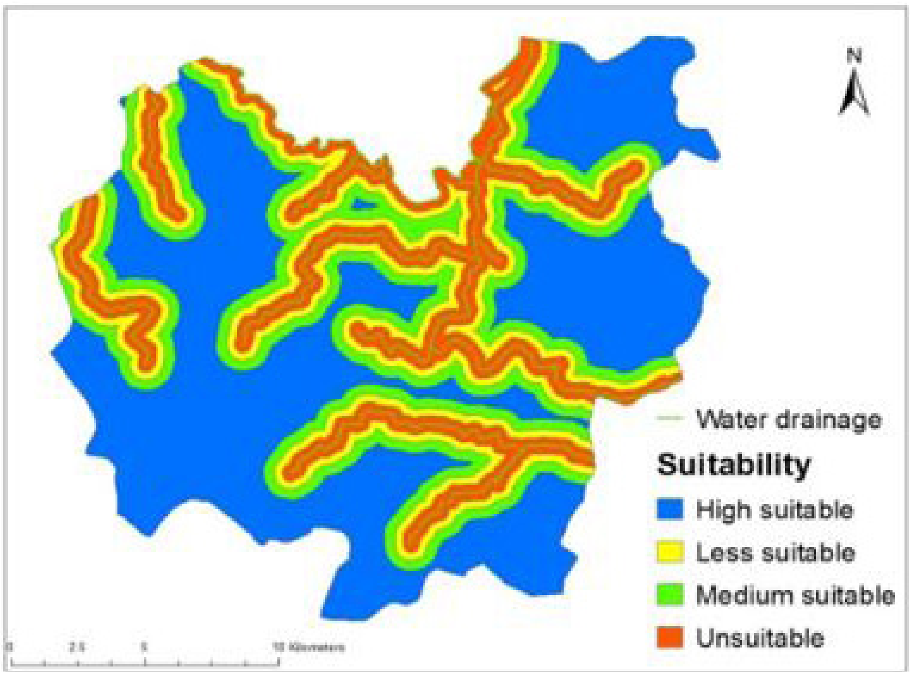


Figure 4.4: Surface water suitability map of the study area

Land use/land Cover suitability analysis

The LU/LC of the study area, large part covered by farmland which accounts about 21461.04/58.11%, open area, built up area, forest area, wetland, road net and an airport account for 5163.65ha/13.98%, 4930.15ha /13.35%, 3845.84ha/10.41%, 816.12ha/2.21%, 624.44ha/1.69% and 88.28ha/0.24% of the total study area respectively.

Land use/land cover of the study area is shown in figure 4.5.

Sn	Land Use type	Suitability class	Suitability rank	Area/ha	Share %
1	Airport	Unsuitable	1	88.28	0.24
6	Road net	Unsuitable	1	624.44	1.69
7	Wetland	Unsuitable	1	816.12	2.21
2	Built up area	Unsuitable	1	4930.15	13.35
3	Farm land	Less suitable	2	21461.04	58.11
4	Forest/bush	Medium suitable	3	3845.84	10.41
5	Open area	High suitable	4	5163.65	13.98

Table 4.4: Area coverage and land use/land cover suitability

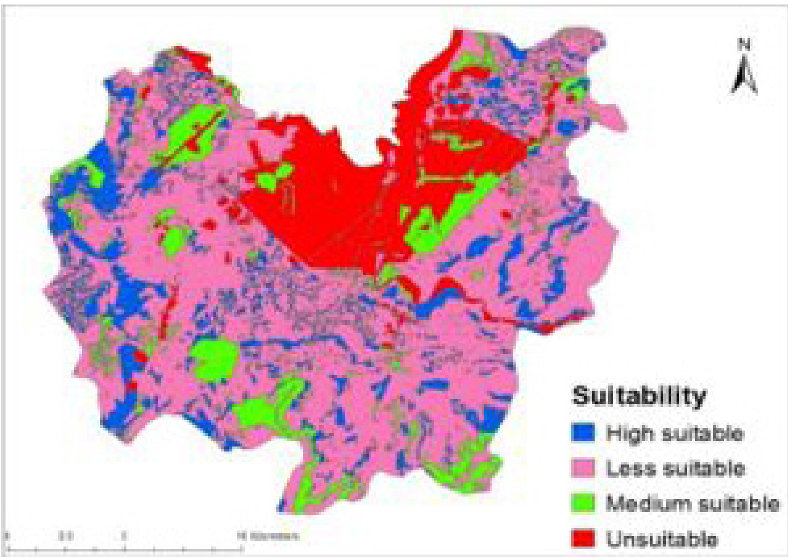


Figure 4.5: Land use/land cover suitability map of the study area

Main road network suitability analysis

The solid waste dumping site must be located at the suitable distance from the road network. The existing SWD site in the city is accessible, but very close to Bahir Dar to Addet main road which is located within the restriction zone that means the disposal site did not fulfill the required minimum distance. As the general concept, the solid waste disposals shall not be located within 500 meters of the main city streets or other main transportation routes but it failed under this region.

The main road network proximity suitability map of the study area is clearly indicated in the figure 4.6.

Sn	Distance	Suitability class	Suitability rank	Area/ha	Share %
1	0-500	Unsuitable	1	8579.48	23.36
2	500-1000	Less suitable	2	6371.62	17.35
3	1000-2000	Medium suitable	3	9318.1	25.37
5	>2000	Highly suitable	4	12461.11	33.93

Table 4.5: Area coverage and road network suitability

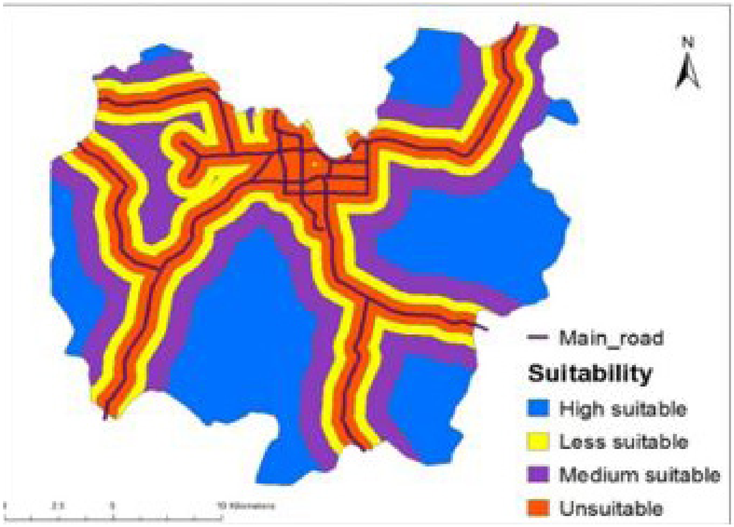


Figure 4.6: Road suitability map of the study area

Soil type suitability analysis

The study area of the soil type is largely dominated by chromic luvisols soil, which is covered by 17835.43ha/48.33% and found in most parts of the study areas. The second type of soil is eutric leptosols soil covers the area of 9188.4/24.9 %. The remaining eutric vertisols, haplic luvisols, lithic leptosols, and rock and waterbody which is covered by 5269.12ha/14.28%, 372.61ha/1.01%, 1725.39ha/4.68%, and 2513.07/7.32% respectively.

Sn	Soil type	Suitability class	Suitability rank	Area/ha	Share%
1	Rock and waterbody	Unsuitable	1	2513.07	6.81
2	Eutric vertisols	Less suitable	2	5269.12	14.28
3	Haplic luvisols	Medium suitable	3	372.61	1.01
4	Lithic leptosols	Medium suitable	3	1725.39	4.68
5	Chromic luvisols	Highly suitable	4	17835.43	48.33
6	Eutric leptosols	Highly suitable	4	9188.4	24.90

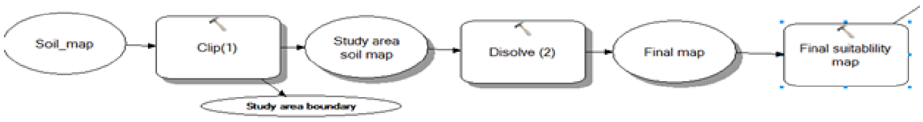


Table 4.6: Area coverage and soil suitability

Geological suitability analysis

The geology of an area will directly control the soil types created from the parent material loading bearing capacity of the solid waste disposal's foundation and the migration of leachate. Rock and its structure type will determine the nature of soils and the permeability of the bedrock. Geologic structure will influence the movement of leachate and potential rock-slope failure along joints and tilted bedding planes. The suitability level when considering the geological type is given in Table 4.7 and Figure 4.8.

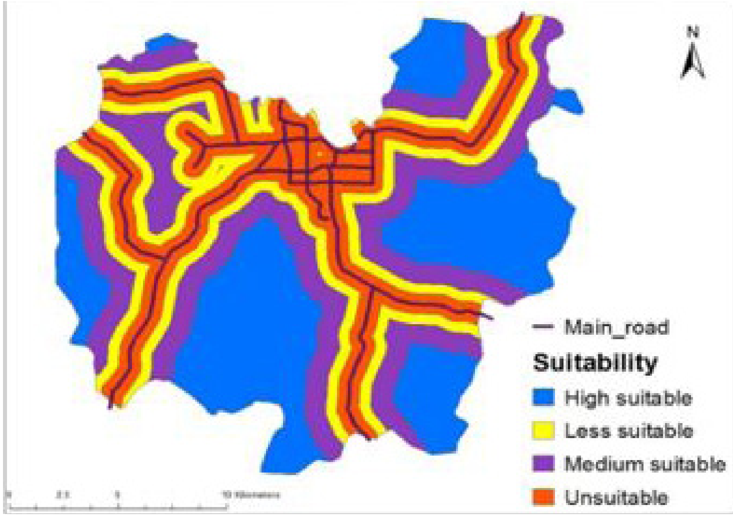


Figure 4.7: Soil type suitability map of the study area

Sn	Geological features	Suitability class	Rank	Area/ha	Share %
1	Alluvium	Unsuitable	1	1384.81	3.75
2	Lake	Unsuitable	1	256.28	0.69
4	Ashangi basalts	Less suitable	2	3903.04	10.58
3	Termaber basalts (2)	Medium suitable	3	5203.74	14.10
5	Basalts related to volcanic center (2)	Highly suitable	4	24428.04	66.19
6	Baselts related to volcanic center (3)	Highly suitable	4	1727.43	4.68

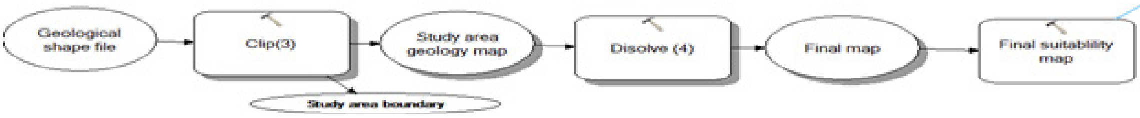


Table 4.7: Area Coverage and suitability of geological feature

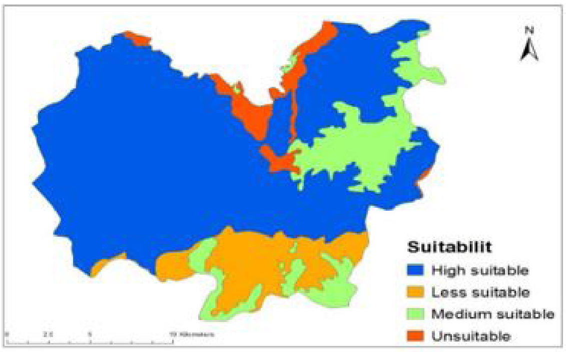


Figure 4.8: Geological feature suitability map of the study area

Distance from built up area suitable analysis

Any type of waste disposal should be at a safe distance from built up area in order to avoid bad odors and health risks. Hence, solid waste disposal should be placed away from built-up areas. Different researchers set different built-up criteria for solid waste disposal site selection. In this paper, built-up suitability distance with a minimum of less than 300m considered as unsuitable for solid waste disposal site. Built-up buffer suitability map of the study area is shown as in table 4.8 and figure 4.9

Sn	Distance/m	Suitability class	Suitability rank	Area/ha	Area in%
1	0-300	Unsuitable	1	18598.22	50.41
2	300-600	Less suitable	2	8666.76	23.49
3	600-1000	Medium suitable	3	5744.89	15.57
4	>1000	High suitable	4	3886.14	10.53

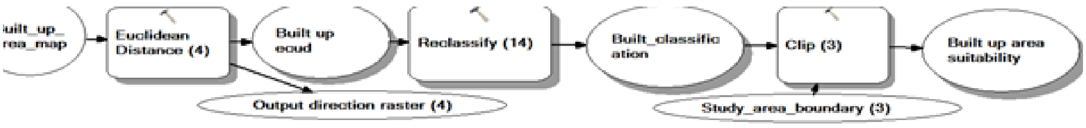


Table 4.8: Area coverage and built up suitability analysis

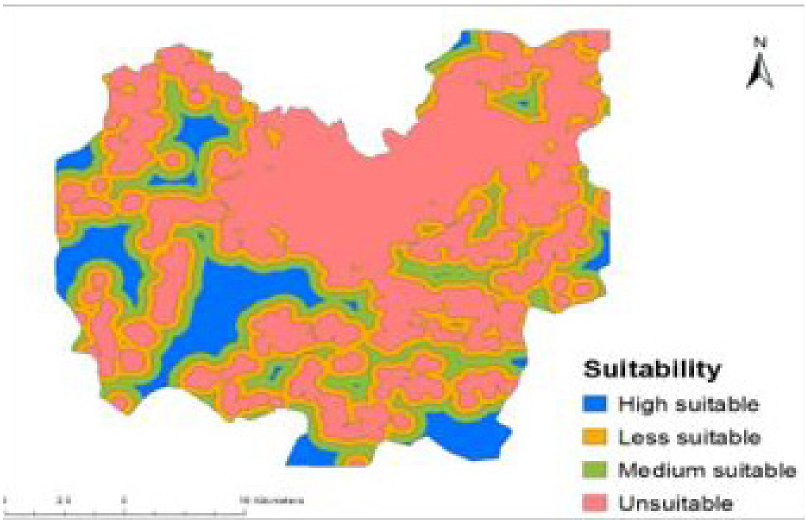


Figure 4.9: Suitability map of built-up area

Soil depth suitability analysis

The suitability classification is based on the depth of the soil and its drainage into waterbody and ground water. Low soil depth with high infiltration that lead drained of erosion towards the water body and pollute the water will risk on human beings and other water users.

Sn	Soil depth in cm	Suitability class	Area/ha	Share %	Suitability rank
1	0-25	Unsuitable	4234.61	11.48	1
2	25-50	Less suitable	9169.23	24.86	2
3	50-100	Medium suitable	372.46	1.01	3
4	>100	High suitable	23109.7	62.65	4

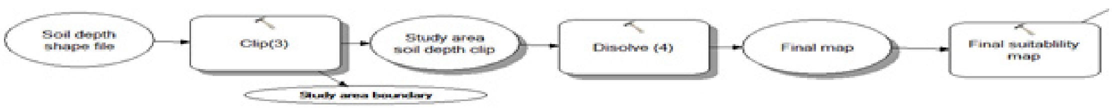


Table 4.9: Area coverage, suitability and ranking of soil depth

Soil texture suitability analysis

The suitability classification is based on the permeability of the soil and its structure. This clay soil is one of the best sites for landfill sitting because clay can prevent leachate problems. Leachate refers liquid that has percolated through solid waste or another medium.

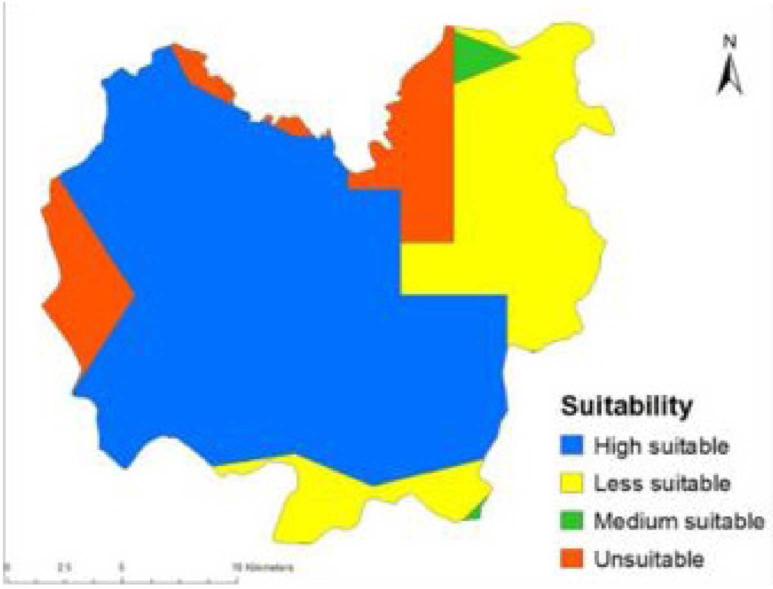


Figure 4.10: Soil depth suitability map of the study area

Sn	Texture	Suitability class	Area/ha	Share %	Suitability rank
1	Water body and Rock	Unsuitable	2511.13	6.81	1
2	Sandy loam	Less suitable	1723.48	4.67	2
3	Clay to clay loam	Medium suitable	9169.23	24.86	3
4	Clay	High suitable	23482.16	63.66	4

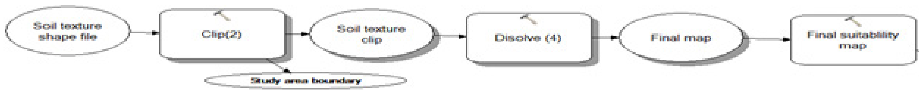


Table 4.10: Soil texture area coverage, ranking and suitability analysis

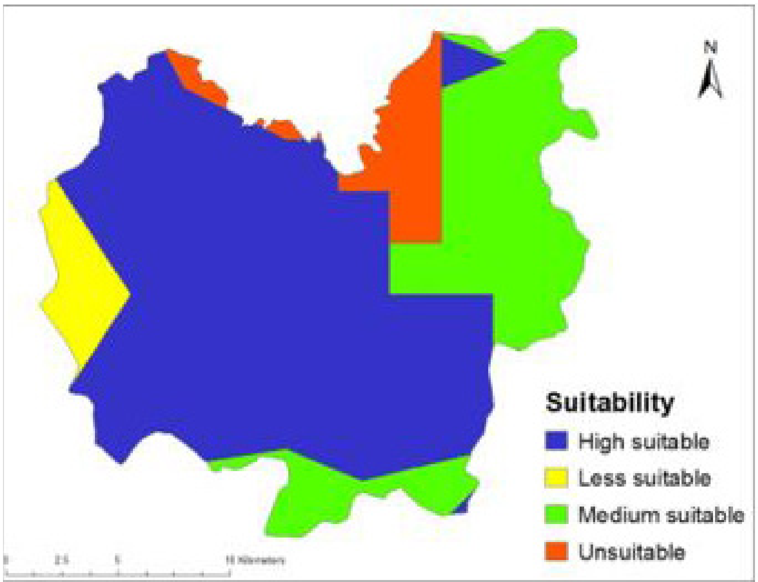


Figure 4.11: Soil texture suitability map of the study area

Airport suitability analysis

Waste disposal sites attract a variety of birds to be accumulated around. This issue may interfere with the operation of airplanes. A landfill should not be situated around the regulatory zone of an airport authority. In this study area a minimum distance of 3000 m was used for site selection process to protect different birds for the flight of airplane obstacle when they existing around the waste disposal site.

Sn	Buffer distance	Suitability class	Area/ha	Share %	Suitability rank
1	0-3000	Unsuitable	4812.69	13.04	1
2	3000-5000	Less suitable	3507.86	9.50	2
3	5000-8000	Medium suitable	5187.85	14.06	3
4	>8000	High suitable	23399.5	63.40	4

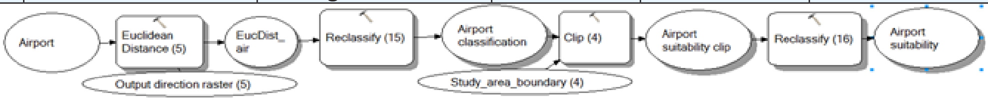


Table 4.11: Airport area coverage, ranking and suitability analysis

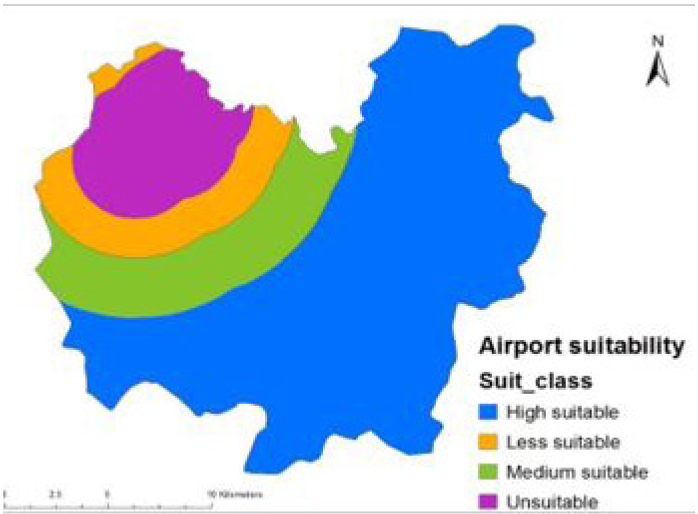


Figure 4.12: Airport suitability map of the study area

Suitability analysis for protected area

The landfill should not be located in close proximity to in such sensitive areas since these areas are the meeting, praying and other purposive. In this study area a minimum distance of 750m was used for waste disposal site selection process to protect human and social sensitivity of the protected area from waste disposal effects.

Sn	Buffer zone	Suitability class	Suitability rank	Area/ha	% share
1	0-750	Unsuitable	1	4480.3	12.14
2	750-1500	Less suitable	2	10451.4	28.32
3	1500-2000	Medium suitable	3	17678.1	47.90
4	>2000	High suitable	4	4293.86	11.64

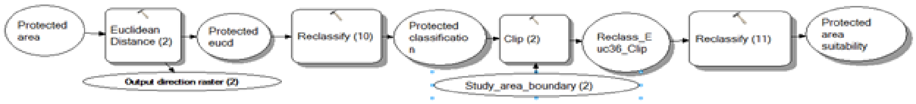


Table 4.12: Protect area coverage, ranking and suitability analysis

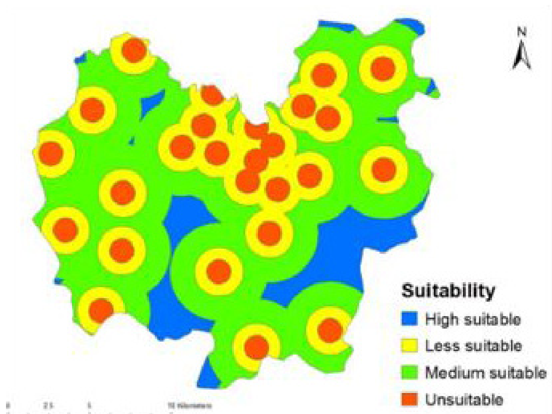


Figure 4.13: Suitability map of protected area in the study area

Result of final constraint/restriction map

This procedure created a constraint map for each theme containing only two classes represented by 1`s (suitable site) and 0`s (for unsuitable site). The constraint maps (surface water, road, airport, slope, different soil condition, geology, protected area, land use/land cover and built up area) are performed by converting all criteria maps to raster map and use a raster calculator and create the final constraint and suitability maps. Finally, from the total of study area constraint or unsuitable or restriction area is covered 28300.61ha or 76.95% and the remaining study area covered 8474.96ha or 23.05% is suitable for solid waste disposal that the restriction condition is clearly shown below table 4.13 and figure 4.14 and 4.15.

Criteria	Unsuitable condition
Distance from water body	300 around water body
Distance from road	500 around main roads
Distance from airport	3000 around airport
Distance from built up Area	300 around built up area
Distance from protect area	750 around protect the area
Land use, land cover	Settlement, road, wetland and built up area
Soil condition	Depth <25cm, water body and rock
Geology	Alluvium and lake

Table 4.13: Constraint/restriction conditions in the study area

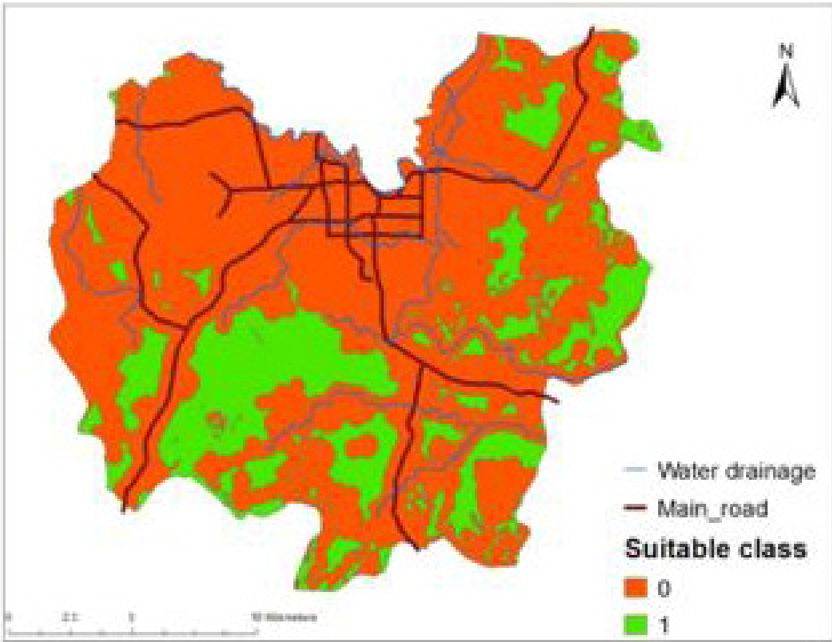


Figure 4.15: Constraint map of the study area in polygon and raster form

Result of weighting the criteria

According to (Malczewski, 2000) if the consistency ratio is less than or equal to 0.1, it signifies acceptable. The consistency ratio of this study indicated that 0.027<0.1 was acceptable. In order to combine all the layers to process overlay analysis, standardization of each data set to a common scale of 1, 2, 3, 4 (value 1 = unsuitable, value 2 = less suitable, value 3 = medium suitable, value 4 = highly suitable) was performed. In this study such steps are done within the AHP calculator on online calculation and start pairwise comparisons to calculate priorities using the analytic hierarchy process. Finally overlying each factor weight into one system for the production of final suitable disposal sites. According to various factors, there were the main aspects to be considered for evaluation of the criteria with online AHP techniques determination as shown below in Table 4.14.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Built up area	24.4%	1
2	Water body	19.6%	2
3	protected area	15.0%	3
4	Land use	11.1%	4
5	Main road	10.0%	5
6	Airport	6.4%	6
7	Slope	4.4%	7
8	Geology	3.3%	8
9	Soil type	2.5%	9
10	Soil depth	1.7%	10
11	Soil texture	1.6%	11

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5	6	7	8	9	10	11
1	1	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	9.00
2	1.00	1	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
3	0.50	1.00	1	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
4	0.33	0.50	1.00	1	1.00	2.00	3.00	4.00	5.00	6.00	7.00
5	0.25	0.33	0.50	1.00	1	2.00	3.00	4.00	5.00	6.00	7.00
6	0.20	0.25	0.33	0.50	0.50	1	2.00	3.00	4.00	4.00	4.00
7	0.17	0.20	0.25	0.33	0.33	0.50	1	2.00	3.00	3.00	3.00
8	0.14	0.17	0.20	0.25	0.25	0.33	0.50	1	2.00	3.00	3.00
9	0.12	0.14	0.17	0.20	0.20	0.25	0.33	0.50	1	3.00	2.00
10	0.11	0.12	0.14	0.17	0.17	0.25	0.33	0.33	0.33	1	1.00
11	0.11	0.11	0.12	0.14	0.14	0.25	0.33	0.33	0.50	1.00	1

Number of comparisons = 55
Consistency Ratio CR = 2.7%

Principal eigen value = 11.407
Eigenvector solution: 5 iterations, delta = 2.6E-8

CR=0.027 which is <0.1 was reasonable acceptable

Source: (from online AHP-OS author: Klaus D. Goepel, BPMSG AHP Priority Calculator) AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Table 4.14: Weighting of the criteria using pair wise comparison matrices

Solid waste disposal site suitability analysis of the result

The final map was overlaid by using overlay operation in the arc tool box in spatial analysis tool and input each layer or factors such as surface water/river, land use/land cover, road network, slope, built up area, soil types, soil texture geological condition and soil depth and arrange the weighted overlay in the overlay operation and then assign the value of each suitability within the GIS environment [16-18].

Final suitability = 24.4%built up area+19.6% water body+ 15%protcted area+11.1% land use + 10%main road+6.4% airport+4.4%slope +3.3% geology+2.5%soil type +1.7% soil depth +1.6% soil texture with in GIS weighted overlay analysis.

This overlaying process was assigned to different thematic layers based on their site suitability values and then overlay analysis was employed in deciding the potential location of waste disposal sites of the study area and then finally intersected with constraint map for finding of the final suitable area according to lands suitable for solid waste disposal. By using the stated criteria, the suitable area for solid waste dumping may facilitate different environmental, social, economic and health cost in all the people living in and around the city. Moreover, the study in criteria analysis had shown that about 2.46 % are more suitable in order to minimize environmental impacts and the suitable area was far away from the protected area, road, river, settlement and urban center. Highly suitable area of landfill site is located in the western part of the city (figure 4. 16).

Sn	Final land suitability	Suitability rank	Area (ha)	Area (%)
1	Unsuitable	1	28300.61	76.95
2	Less suitable	2	5567.22	15.14
3	Medium suitable	3	2001.4	5.44
5	High suitable	4	906.34	2.46

Table 4.15: Final area coverage, ranking and landfill suitability

Out of the total area of the study site, about 2.46% (906.34ha) fall under highly suitable categories due to the region satisfies the criteria set such as different soil, built up area, surface water, land use/land cover, slope and road network. The medium suitable area covers an area of 5.44% (2001.22ha), the less suitable area covers 15.14% (5567.22ha) and the remaining 76.95% (28300.61ha) falls under unsuitable condition for solid waste disposal sites indicate figure 4.14.

Considering the effect of solid waste on human health, economy and other aspects, the selected sites are most preferable and acceptable from solid waste disposal site selection criteria suitability analysis in the study area.

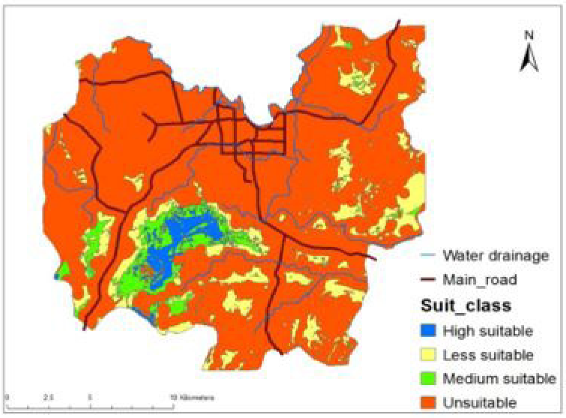


Figure 4.16: Final potential suitability map of the study area

Results of solid waste disposal site by study area kebeles

The study area contains eight (8) different Kebeles and Bahir Dar city with regard to distance to the city for waste disposal site. The solid waste disposal site suitability of each kebele shown in the table 4.16 below.

Kebele name in the study area	Unit	Suitability level for solid waste disposal				
		Unsuitable	Less suitable	Medium suitable	High suitable	Total
Zenzelima	Ha	3549.43	638.03	118.35	0	4305.81
Werib kola stiwen	Ha	3368.42	1413.45	120.87	0	4902.74
Dishet abaraji	Ha	3543.49	735.63	461.48	231.36	4971.96
Sebatamit	Ha	1656.01	832.19	6.23	0.05	2494.48
Wondata	Ha	1650.38	713.63	54.82	0.06	2418.89
Yinesa sositu	Ha	2898.59	874.46	1186.6	660.48	5620.13
Yibab	Ha	3060.65	321.74	46.87	14.38	3443.64
Woramit	Ha	5206.7	35.4	5.56	0	5247.66
Bahir Dar town	Ha	3304.4	0	0	0	3304.4

Source: (Developed from the analysis selected criteria in the study area kebeles)

Table 4.16: Study area waste disposal site suitability by kebele

Conclusions

Solid waste disposal site selection is an environmentally acceptable disposal of solid waste on the ground. The main purpose of establishing a solid waste disposal site is to protect the safety of the environment by minimizing the effects on resources and community health. This study has examined the problems of the solid waste disposal sites for Bahir Dar city and its implications on the residents of the population in the city for the final suitability site selection. The study revealed that the city has grown in population, industrialization as well as the spatial extent over the years. The findings have shown environmentally sustainable, socially acceptable and economically viable solid waste disposal site selected with the help of GIS, its analysis tools and remote sensing. The criteria for waste disposal site selection used are slope, geological feature, soil conditions, distance from the water body, distance from built-up areas, distance from airport, distance from protected area and distance from main roads. GIS software, its environment tools, the satellite image and different shape files are used for solid waste disposal site selection and analysis. Integrating AHP with GIS for spatial decision making process is a worthwhile technique to handle large and conflicting criteria in landfill site selection processes. The results have shown that one site was selected as most suitable. The sites are easy to access and manage for disposal of solid wastes finding in the research. This place is far away from any water sources, settlements, protected area and other variables put into the analysis.

The final selected solid waste disposal site is grouped as high suitable, medium suitable, less suitable and unsuitable. The result of the final suitability map indicates that 2.46% of the study area have highly suitable, 5.44 % medium suitable, 15.14 % less suitable and 76.95 % unsuitable from the total study area. Most areas are located in south-west part along Bahir Dar to Addis Ababa main road to the left side. Based on the results, the most potential areas for solid waste disposal sites are available on Yinsa sositu, Dishet abaraji, Werib kola stiwen and Sebatamit kebeles where there are least environmental and health risks. Hence, the findings of the study will serve as a working document for the Bahir Dar city municipality of management officials in the identification and selection of suitable solid waste disposal site for the future.

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