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Suitable Solid Waste Disposal Site Selection Using Geographical Information System (GIS): A Case of Debre Berhan Town, Ethiopia

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Abstract Siting solid waste disposal is an extremely difficult task mainly due to the fact that the selection process involves many factors and strict regulations. Nevertheless, if not systematically and scientifically sited and managed properly, it will result in environmental and socio-economic problems. The town of Debre Berhan is currently using dumping site that has not been selected by scientific study which is environmentally sound and socio-economically acceptable. The main aim of this study is to find the suitable solid waste disposal site by using the GIS-based Multi Criteria Evaluation techniques in Debre Berhan town. Factors such as slope, depth to ground water table, permeability of soil, land use/ land cover, proximity from roads, proximity from ground water wells, proximity from water bodies were used for selecting suitable solid waste disposal site within the study area. The factor maps were reclassified and standardized in GIS environment followed by preparation of their suitability maps. The relative weights of factors were estimated using Analytical Hierarchy Process and factors maps were developed by using GIS spatial operations. Weighted Linear Combination was also used to integrate the factor maps and produce overall solid waste disposal suitability map. The final solid waste disposal site suitability map prepared in four suitability rank such as highly suitable, moderately suitable, low suitable and unsuitable. The result shows that around 3.81% area is under highly suitable for solid waste disposal site, 47.91% is moderate suitable and 15.91% area is unsuitable for suitable for solid waste disposal site. The results indicates that the method is capable of identifying locations highly suited for suitable for solid waste disposal site.

Keywords: *solid waste, disposal, multi-criteria evaluation, analytical hierarchy process, GIS*

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1. Introduction

Solid wastes could be defined as non-liquid and non-gaseous products of human activities, regarded as being useless [1]. Its origin is mainly from households, municipal and construction [2]. Solid waste management has long been a worldwide environmental problem. This is because of the rapid growth of population and urbanization that decreases the non-renewable resources and disposal of waste and toxic waste arbitrarily, as a result of this major environmental issues posing stress to the arrival of human being [3]. Solid waste management is referred to as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and recovery, and final disposal of solid wastes in a manner that is in accordance with the best principles of public health, economics, engineering, urban and regional planning, conservation, aesthetics, and other environmental considerations which are also responsive to public attitudes [4].

In most of the developing countries solid waste management techniques like waste reduction, recycling and waste reuse are being widely used to manage solid wastes. However, there are usually residual matters left, to remove the presence of these residual matters, the most economical and, if systematically and scientifically implemented, environmentally friendly approach is using landfilling [5]. Urban solid waste management is considered as one of the most urgent and serious environmental problems facing municipality authorities in developing countries particularly in Africa. General awareness of our environmental problems has led to the development of pollution control technologies, more rigorous legislation, strategies on waste handling and disposal to minimize the environmental impact associated with solid waste. Waste disposal is an important part of waste management system, which requires much attention to avoid environmental pollution [6]. Poor management of municipal solid waste may result to in consequences such as pollution, low aesthetic values and economic losses due to failures in recycling and composting valuable components of the municipal solid waste. Improper

management of municipal solid waste may result in serious urban, sanitary and environmental problems such as unpleasant odor, risk of explosion in landfill areas, as well as groundwater contamination because of leachate percolation [7].

Nowadays due to a rapid population growth rate and increasing per capita income the generation of Municipal Solid Waste (MSW) is dramatically increasing in a way that results serious health and environmental problems. These problems and effects are exaggerated in most developing nations of the world where the solid wastes dumping is being carried out in unplanned way causing problems especially to the poor people who have direct exposure to it [8,9]. The most common problems occurring with the result of unplanned disposal MSW are transmission of diseases, fire hazards, unpleasant odors, atmospheric and water pollution problems, urban aesthetic problems as well as huge economic loses [10,11]. The problem of waste management is widely seen in economically developing countries because of their only intension of industrial development and it is causing them effects on environmental and public health problems in the later times [12].

A suitable disposal site must have environmental safety criteria and attributes that will enable the waste to be isolated so that there is no unacceptable risk to people or the environment while it is operating. Criteria for site selection will include natural physical characteristics as well as socioeconomic, ecological and land-use factors. Preferable selection of suitable site for waste disposal has been normally carried by traditional approaches i.e. throwing it at all types of free land in or around the town [13]. Ethiopia has Environmental policies. The policies address different environmental issues including Solid Waste Management (SWM). The bases for the Environmental Policies of Ethiopia (EPE) are articles 92.1 and 92.2 of the constitution of the Federal Democratic Republic of Ethiopia [14]. In the current times, the selection of suitable landfill sites that combine social, economic and environmental factors for locating solid waste dump sites has been recognized as a major problem in planning and construction of the urban areas located especially in developing countries. Over the last decades, many developing urban areas in Ethiopia are suffering with the challenge of managing its solid waste as a result of increase in waste generation, rapid population growth and improper disposal sites [15].

GIS (geographic information systems) are ideal for preliminary site selection studies because it can manage large volumes of spatially distributed data from a variety of sources and efficiently store, retrieve, analyze and display information [6]. Local governments generally lack sufficient funds and experts to implement a complete siting process that causes significant damage to the environment [16]. GISs and environmental models function with a board spectrum of geospatial data are used for divers applications and spatial analyses at different scales. The examination and organization of data into a useful form produce information, which then enables appropriate analysis and modeling [17]. Numerous criteria must be taken into consideration in the landfill sitting and weights must be assigned to each of them [18,19]. Many factors must be incorporated into landfill siting decisions and GIS is ideal for these preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources [16]. Multi Criteria Decision Analysis techniques can be used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities [20]. The integration of GIS and Multi Criteria Decision Analysis is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data while Multi Criteria Decision Analysis supplies consistent ranking of the potential landfill areas based on a variety of criteria [21]

As the population of Debre Berhan Town is dramatically increasing due to expansion of industry, both natural birth and immigration of people mostly from the nearby rural areas, and in parallel as the living standard of the dwellers of the Town is growing, the generation of household, industrial and construction waste is increasing significantly. The increasing rate of the waste generation has created disposal problems leading to the pollution of the land, water and air.

In Debre Berhan town solid wastes from hospitals, industries, households and commercial areas are collected and dumped, which may contain leachable and toxic compounds that are harmful to the environment and human health. The disposal system of solid waste in the town is open dumping, which is commonly carried out on areas which are not been selected following any scientific way for suitability.

Majority of 75% population of Debre Berhan disposed waste illegally into public places, river and ditches. Fewer households (2.7%) reported that they practiced burning of the waste in some parts of the town to get exonerate the collected waste. Such practice poses high risk on the local environment [22].

The main aim of this study is to identify and map the most suitable solid waste disposal site in Debre Berhan town using GIS techniques. Specifically identifying factors for selecting suitable solid waste disposal sites; determining the relative importance of the factors for solid waste disposal site using the Analytical Hierarchy Process method and mapping the most suitable site for wind farm in the study area.

2. Materials and Methods

2.1. Materials

ArcGIS desktop is well known in the world and the most widely used category of GIS software. It has been developed by Environmental System Research Institute Inc. (ESRI), Redlands, USA. In this study the components of ArcGIS desktop like Arc Map, Arc Catalog, and Arc Toolbox have been used to create the geo database, editing, data management and storage, geo referencing data from different sources, performing spatial multi criteria analysis, generating criteria maps and assigning weightage for each criterion, overlaying, analysis and visualization of output data, and etc. It is ArcGIS software and its extensions mainly used in addition to some others that are rarely projected for minor purposes such as DNR Garmin for

uploading spatial information and conversion purposes, Google Earth, Notepad (MS excel) for further viewing, editing and rearranging the spatial data of GPS and secondary sources whenever needed etc. IDRISI is a comprehensive geographic analysis and image processing system that has been developed by Clark Labs for Cartographic Technology and Geographic Analysis at Clark University, South Carolina, USA. The software has been used to perform multi criteria decision analysis using the built-in decision support module.

Both primary and secondary data were used in the study. The primary data were collected from field surveys and observation. Whereas, the secondary data for the study was acquired from internet, reports, books, journals, governmental institutions and other documents. Two identified sources of data were Primary data sources and Secondary data sources. Primary data sources were Debre Berhan Town naturally existing and manmade features, inhabiting community, Aerial Photograph of the Town. Published literatures from the web and unpublished documents both qualitative and quantitative were secondary data sources in addition to different organizations. Data gathering procedure includes different techniques that are applied formally and informally in order to achieve all documents for the study. There are two major data collection methods used: Instrumental Survey was made to get primary data of desired locations through the entire area of the town by means of the researchers with instruments and assisting experts with labor forces and formal contact with relevant organizations simple unstructured questionnaire comprising of both close and open ended questions was prepared to make contact and conversations with relevant workers in organizations to identify and collect valuable secondary data and materials.

2.2. Methods

solid waste disposal should be located a certain distance from the features such as lakes, ponds, rivers, wetlands, flood plain, highway, critical habitat areas, water supply, well and airports [23]. Debre Berhan town solid waste disposal site selection was done using Multi Criteria Decision Evaluation and creating layers to yield a single output map. The weights were developed by providing a series of pair wise comparisons of relative importance. Based on experience and likely impact on surrounding environment, different weights were assigned to all the parameters. Analytical Hierarchy Process was used to produce the weights. These methods were developed as Figure 1 by referring to different sources from various literatures.

Table 1. Data and their sources

No.	Types of Datasets	Format	Sources
1	Land use land cover	Raster	Interpretation of Landsat 8 image (2016) from EMA, Addis Ababa
2	Slope	Raster	Interpretation of ASTER GDEM image(2016), Addis Ababa, Ethiopia
3	Soil texture	Shape file	Ministry of Water and Energy, Addis Ababa, Ethiopia
4	Surface water (river/streams)	Vector, Shape file	Ethiopian water resource office, Addis Ababa, Ethiopia
5	Groundwater wells	Vector, Shape file	Debre Berhan Water Supply and Sanitation Office, Debre Berhan
6	Groundwater tables	Vector, Shape file	Debre Berhan Water Supply and Sanitation Office, Debre Berhan
7	Road network	Vector, Shape file	Ethiopian Road authority, Addis Ababa

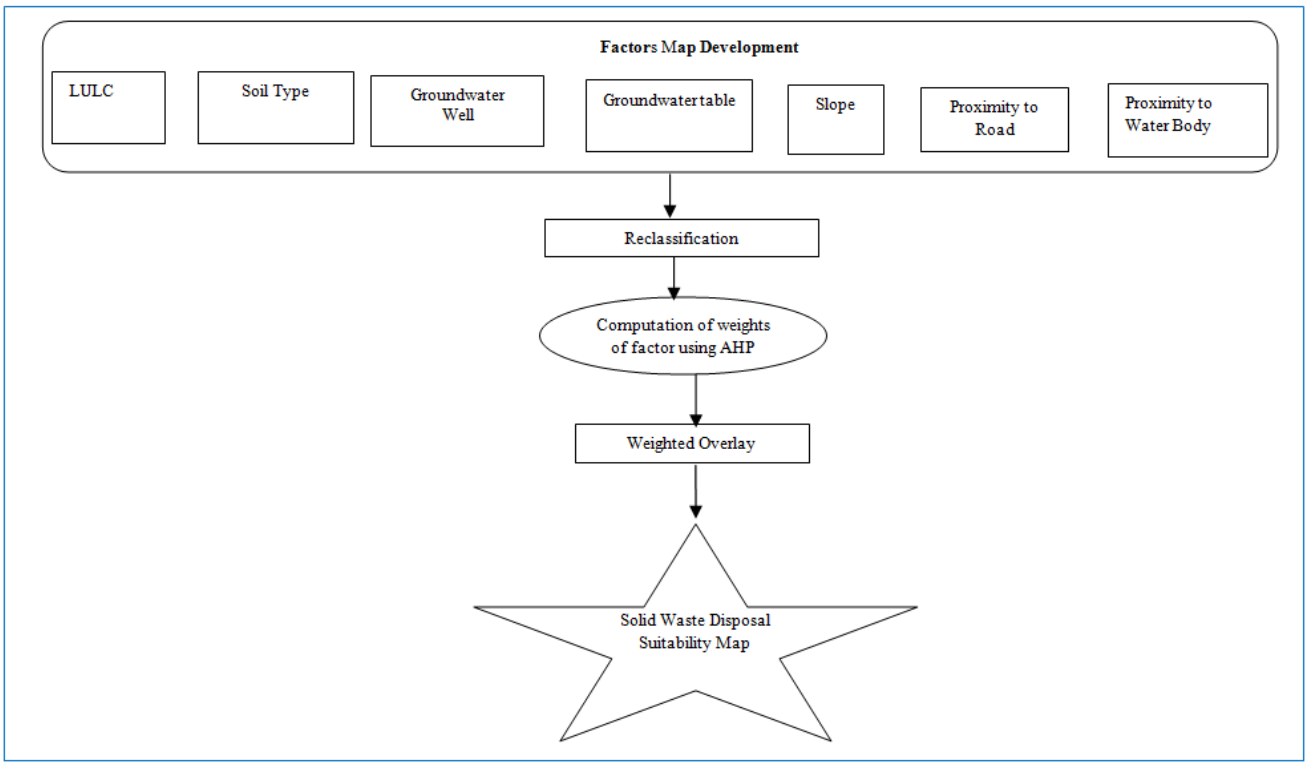

Figure 1. Technological scheme of the study

3. Results and Discussion

3.1. Factors Development

For a particular decision making problem, the set of evaluation criteria may be developed through an examination of the relevant literature, analytical study and opinions. Each pixel has a value range from 0 to 255 which represents the suitability of each pixel to be the optimal site. Higher value represents higher suitability of the area for the solid waste disposal sites selection. [24]. The factors affecting the selection of solid waste disposal sites in this study area are Slope, distance from surface water, distance from main road, land use land cover, groundwater wells, groundwater tables and soil texture. Factor maps represent the criteria that will affect the optimal site selection. The relative comparisons between the seven data layers were performed by asking experts comprising of hydrologists, engineers, end-users and reviewing of literature to give the assessments and judgments regarding the variables related to solid waste disposal sitting and their significances in terms of weights. The comparison conducted indicated that highest weighting for the elevation data layer followed by the groundwater well, groundwater table, surface water, land use, road, and soil data and slope.

Table 2. Factors and their eigenvectors weights for solid waste disposal siting

	LU	Soil	PWP	GWD	S	PR	PWB	Weight	Weight (%)
LU	1							0.15	15
Soil	2	1						0.10	10
PWP	7	6	1					0.25	25
GWD	7	6	1	1				0.20	20
S	3	1/2	1/4	1/4	1			0.05	5
PR	2	1/2	1/5	1/5	1/2	1		0.10	10
PWB	7	2	1/2	1/2	3	5	1	0.15	15
1.00									**100.0**

(Note: LU = Land Use, PWP = Proximity to Well Points, GWD = Ground Water Depth, S = Slope, PR = Proximity to Road, and PWB = Proximity to Water Bodies.)

Slope: slope is an important factor in suitable site selection process, because slope determines the amount of runoff in the site. Steep slopes are not suitable for solid waste disposal establishment where the construction costs of excavation increases in higher slopes. Also, the suitable slope of land surface is important in preventing the leach ate flowing. In this study, slope of the study area was generated from DEM using Arc-GIS spatial analyst extension of surface tool. Then the slope raster was reclassified into four classes of slope percent. The reclassified slope was ranked from 1 to 4, as 4 is highly suitable and 1 is for the least suitable for site selection [26].

Table 3. Classes and rankings of slope for solid waste disposal analysis of study area

Factors	Weight	Classes	Ranking	Suitability
Slope (Percent)	0.05	0 - 2	5	Very high
		2 – 9	4	High
		9 – 15	3	Moderate
		15 – 30	2	Low
		> 30	1	Unsuitable

Road: is one of the criteria that should be considered in suitability analysis. Solid waste disposal sites should not be very close to roads, this is because as solid waste disposal close to roads may result public health problem. As the general concept, the solid waste disposal shall not be located within 400 meter of any major highways, town streets or other transportation routes. Solid waste dumping site must be located at suitable distance from roads network in order to facilitate transportation and it is preferred to locate landfills away 400 meter distance from roads [25].

Table 4. Classes and rankings of proximity to road for solid waste disposal analysis of study area

Factors	Weight	Classes	Ranking	Suitability
Main Road (Proximity)	0.10	0 - 300	1	Unsuitable
		300 – 1000	5	Very High
		1000 – 2000	4	High
		2000 – 3000	3	Moderate
		3000 - 4000	2	Low

Surface water: Most of the surface waters in the study area are streams. The landfill site must not be close to surface water bodies like streams, rivers and lakes. This is because as the distance between the landfill and water bodies narrows, the probability of polluting the water becomes high. The pollution in water resources causes savior problems in environment, public health as well as economy. Areas located within distances less than 300m from permanent and seasonal rivers are excluded due to the possible interaction between the solid waste disposals [26].

Table 5. Classes and rankings of proximity to surface water for solid waste disposal analysis

Factors	Weight	Classes	Ranking	Suitability
Surface Water (Proximity)	0.15	0 - 300	1	Unsuitable
		300 –500	2	Low
		500 - 1000	4	High
		1000 – 5500	5	Very high

Soil Type: These are important to agriculture with very high dark-colored clay minerals having high water storage capacity. The most important characteristics of vertisols are their water holding capacity. This clayey soil is one of the best sites for solid waste disposal sitting because clay can prevent leachate problems. This is because leachate migration from the landfill could be a potential source of surface and groundwater contaminations. Leachate refers liquid that has percolated through solid waste or another medium. Leachate from solid waste disposal usually contains extracted, dissolved and suspended materials, most of which may be harmful.

Table 6. Classes and rankings of soil type for solid waste disposal analysis of study area

Factors	Weight	Classes	Ranking	Suitability
Soil type (Related to water absorption)	0.05	Eutric Cambisols	1	Low
		Eutric Leptosols	2	Moderate
		Eutric Vertisols	4	High
		Urban Area	5	Unsuitable

Ground water: The ground water circulation and downward flow of pollutants through rocks and soils is depending on the hydro geological condition of materials more specifically hydraulic properties such as porosity and permeability. Then due to its negative effects the areas, 500m distance from well are omitted from the potential areas [26].

Table 7. Classes and rankings of ground table and well for solid waste disposal analysis of study area

Factors	Weight	Classes	Ranking	Suitability
Ground Water Table (Proximity)	0.20	0 - 500	1	Unsuitable
		500 – 800	2	Low
		800 – 1200	3	Moderate
		1200 – 2000	4	High
		> 2000	5	Very high
Ground Water Well (Related to depth)	0.25	22.789 – 67.174	1	Very Low
		67.174 – 76.673	2	Low
		76.673 – 83.779	3	Moderate
		83.779 – 92.287	4	High
		92.287 – 120.181	5	Very High

Urban land use: From the main criteria that should be give serious consideration in solid waste disposal site selection land use / land cover is one. This is because of the fact that, solid waste disposal has very serious adverse effects related to societal health on the neighborhood land use / land cover as well as economic effects by reducing economic values of the land. Hence, land use of the study rea should be studied and high value land must be excluded from landfill siting [27].

Table 8. Classes and rankings of landuse for solid waste disposal analysis of study area

Factors	Weight	Classes	Ranking	Suitability
Land use (based on their sensitivity)	0.15	Water bodies	1	Unsuitable
		Built up	2	Low
		Open space	4	Very High

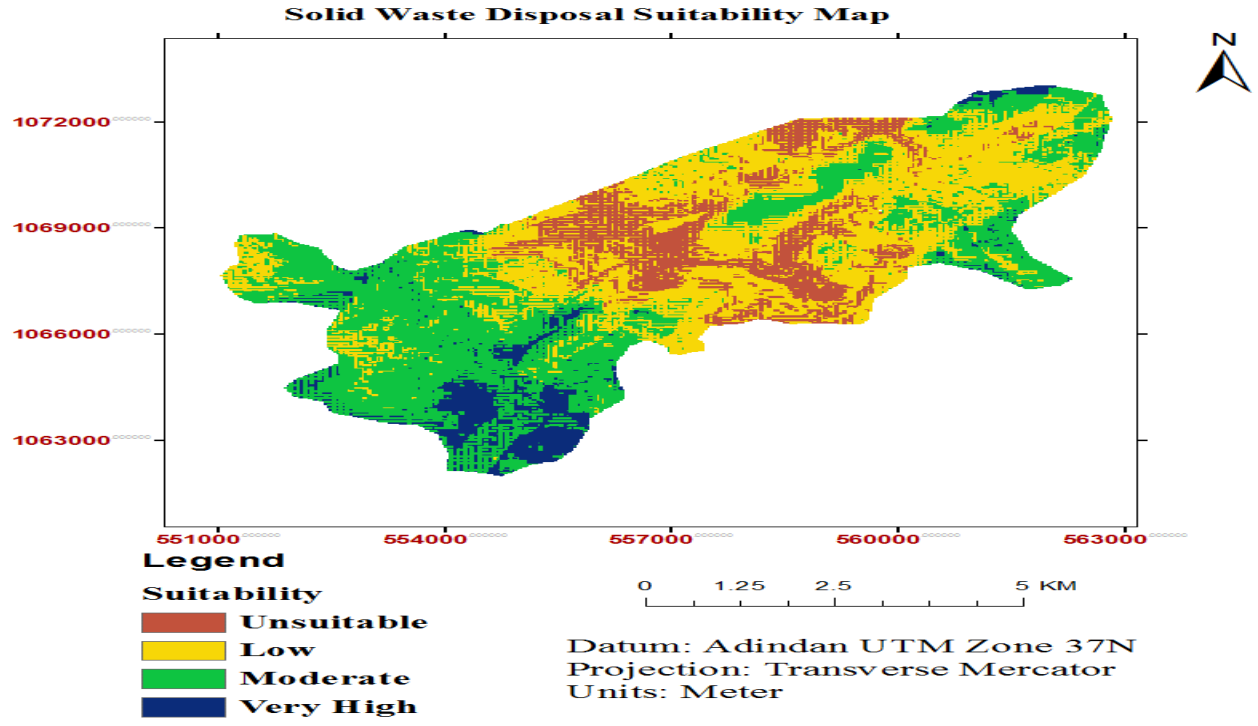

Figure 2. Solid waste disposal suitability map of the study area

3.2. Solid Waste Disposal Suitability Results

The area coverage of each suitability index of the sites was calculated in ArcGIS environment showed that 10.90 km^2 (15.91%) of the study area is unsuitable (restricted) for solid waste disposal site as the areas are environmentally unfavorable and economically. This unsuitable (restricted) area include close to surface water (river, streams, lake)

(area with a 300m buffer zone), groundwater wells (area with a 22m depth), groundwater table (area with a 500m buffer zone), areas with steep slope (>30%), areas with close to road networks and far from road networks with a 300m buffer zone. The main advantage of these areas restriction was to minimize their negative effects of on environment and public health as well as to minimize the cost of construction and maintenance of the solid waste disposal site. However, 0.91km^2 (3.81%) of the area was low suitable for solid waste disposal site and the area of 27.21km^2 (32.37%) moderately suitable. Out of the remaining area, 0.41 km^2 (0.72%) of the area was very high suitable these areas are preferable for solid waste disposal, because of their minimum effect on environment, public health and cost effective than other parts of the study area, shown in (Table 9), with different suitability indices.

Table 9. Area Coverage and identification of suitable areas

NO.	Suitability	Area(km^2)	Area (%)
1	Very High	0.51	3.81
2	Moderate	27.21	47.91
3	Low	18.35	32.37
4	Unsuitable	10.9	15.91
Total		57.11	100.00

4. Conclusion

The selected sites as a result of these analyses are therefore found best and reliable information for any government and non-government bodies to introduce the solid waste disposal based on the research result either as a reference Benchmark partially or use as it is pre proposed. Researchers, starting from their series of data gathering, preparation, factor development and Analysis stages have found that solid waste disposal sites must be reserved and construction project of the solid waste disposal site must be implemented at least at one point among the selected areas for Debre Berhan Town. This study considered seven factors namely: slope, permeability of soil, ground water table depth, land use/land cover, proximity from roads, proximity from ground water well and proximity from water bodies for selecting the most suitable solid waste disposal site. The Multi Criteria Evaluation (MCE) technique integrated with GIS application for spatial decision making process is an advisable method to execute multiple criteria in solid waste disposal site selection processes. The importance weight of each criterion was determined using the pair-wise comparison technique in the Analytic Hierarchy Process (AHP). Consequently, thematic map of solid waste disposal suitability for each of the factors were prepared in GIS environment. Each factor maps were evaluated using Weighted Linear Comparison (WLC) technique with their respective importance, environmental and health related factors were given more importance for the selection of the suitable areas. The study indicated that, out of total area, 0.41 km^2 (3.81%) and 27.21 km^2 (47.91%) of the area was very high suitable and moderate suitable, respectively, these areas are preferable for solid waste disposal site, because of their minimum effect on environment, public health and cost effective than other parts of the study area, with different suitability indices.

5. Recommendations

Out of their entire of research experience and the living resolvable problems of solid waste disposal site selection in the research area Debre Berhan, the researchers would like to strongly that, the relevant Town Administrative bodies and other stakeholders without any preconditions shall take the ideas of this research of solid waste disposal sites and effectively use for the improvement and welfare of all the industrial, commercial and residential society and above all the Town's environmental health as a general. Scholars with research ideas have positive impact for the support of either the surrounding communities or government scientific ground developmental activities and as result need assistance and collaboration. Therefore the Town Administration by any means shall offer itself and work together with the experts to either safe guard government properties or effectively develop the Town which is exemplary in all aspects of appearance. The present study more factors were considered for a suitable solid waste disposal site selection. However, other factors such as drainage pipe networks, wind direction, geology and transmission lines are not included criteria determination. Because the limitation of data source. Therefore, further study should fill this research gap by including these factors.

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