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The Problem of Solid Waste Site Selection in Woldia Town

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Abstract

Solid waste management system is a serious problem in many countries. However, this problem is most acute in developing countries such as Ethiopia. The aims of this article are to investigate the solid waste disposal management system in the town, produce suitable waste disposal site and mapping, and evaluating final candidate landfill sites. The article demonstrates that factors such as geology, soil, slope, land use land cover, proximity from road, distance from the center of the town and hydrogeology are important in selecting a suitable solid waste disposal site. In this article it is argued that Geographic Information System (GIS) methodologies such as, buffering, overlay, spatial analysis 3D analysis and sit suitability modeling are effective to analyze the above data. For the purpose of this article four sites which are located in the western side of the town are identified as a suitable landfill site. These sites are finally evaluated with other many criterion to put them in hierarchical order of significance.

Keywords: Landfill; GIS; Suitability modeling; Solid waste management; Ethiopia

Introduction

Background of the problem

Solid waste management has long been a global environmental problem. This is because of rapid growth of population, urbanization and lack of appropriate waste disposal management system. As a result of this problem major environmental issues poses stress to the survival of human beings [1]. The most common problems associated with poor management of solid waste includes; transmission diseases, fire hazards, foul odor, atmospheric and water pollution, aesthetic pain and economic victims [2]. The improper solid waste management and the combined effects of inadequate sanitation, unsafe water supply and poor personal hygiene are responsible for 1.5 million (88%) of childhood deaths from diarrhea related to such wastes. These scholars did not show how to minimize the problem rather than indicating the severity of the problem.

In Ethiopia most of the diseases are related to poor environmental sanitation and water contamination, lack of suitable waste disposal site, public latrine and poor waste disposal management system in the vicinity which can affect the community's daily activity [3]. This view argues that there is a need for waste disposal management system.

Habtamu and Alelign suggested that suitable waste disposal site is the best method to solve this problem. In addition, they argued that suitable waste disposal site selection process must be conducted by setting different valuable criteria based on the nature of the area concerned. The Criteria can be physical, socio–economic and land use which can be processed, analyzed and interpreted through melt-criteria analysis of GIS technology [4]. Building on the findings of Mujibor et al. [4] this article suggests that the solution to selecting suitable waste disposal site can be conducted by using suitable modeling of GIS technology. GIS special suitability modeling have the power of management, analysis and store large amount of data used as criterion and also saves time and money.

Objective of the Study

The major objective of this article is to select suitable solid waste disposal site in Woldia town by applying Geographic Information System. The specific objectives are;

- Investigate the solid waste disposal management system of the town.
- Identify suitable waste disposal site and prepare its map.
- Evaluating final candidate landfill sites.

Materials and Methods

Certain materials and methods can be applied to explain and understand the problem of waste management. The purposes of the materials and methods are discussed below.

Nature and sources of data

The nature of the data used in this article are secondary and primary data. The secondary data are; water well points and lithology from Ethiopian Ministry of water and energy, geology and soil map from geological survey of Ethiopia, mater plan of the town from the municipality office and digital elevation model from Ethiopian mapping agency. Primary data like global positioning system point and pictures are collected through field survey. To organize, manipulate, interpret and analyzed these data Arc GIS 10.1 and ERDAS imagine 2010 softwares ware used.

Methods of data analysis

Different GIS spatial operation methodologies ware used to analyze the data such as;

Digitizing to convert the base map into digital form. It also used to digitize roads and streams for compatibility.

Buffering is used to generate areas of a given distance around the specified criterion used for waste disposal site selection. Features that buffering is applied ware roads, streams and ground water wells with different values.

Overlay is used to integrate different input features with the master plan, such as; digital elevation model geology, soil and hydrogeology. It also used to intersect the factor map with the constraint map to produce final suitable map.

Special analyses is used to generate slope, hill shed, contour and aspect data from the digital elevation model. It also used to perform special suitability modeling to select the suitable waste disposal sites.

Description of the study area

Woldia Town is found in North Wollo Zone, Amhara Regional State of Ethiopia. The absolute location is 11°50' N altitude and 39°36' E longitude. The relative location of the town is 520 Km north of Addis Ababa and bordered by Habru Woreda in the South, Gubalafto Woreda in the West and East, and Raya Kobo Woreda in the North and Northeast as shown in Figure 1 below.

Woldia is characterized by rugged topography that governs the drainage pattern and makes the flow of the surface water down to Shele stream. But in the area there is no perennial rivers and lakes. The area is also characterized by Woyena Dega (subtropical) and Dega, climatic zone with the altitudinal value between 1500-1700 m and 2300-2400 m above mean sea level having an average annual rainfall of 850 mm and 22°C average daily temperature.

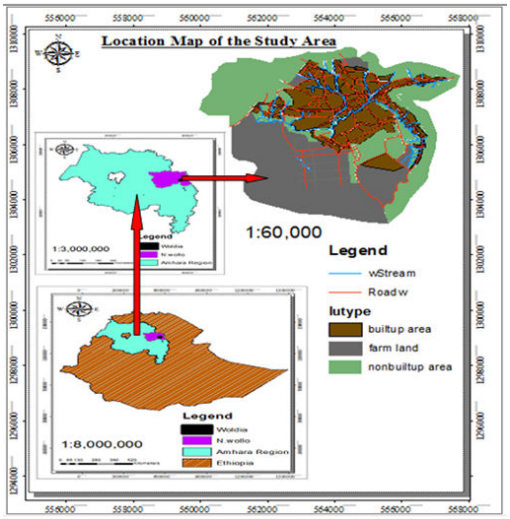

Figure 1: Study area map.

Results and Discussion

Solid waste disposal management system of woldia town

The first, finding of this study illustrates that waste disposal system of the town is not as such satisfactory. This is due to the absence of transportation machines, carts, waste collection machines and other forms of facilities. The second, result of the study indicates that solid wastes found in the area are a mixture of different plastics, ash, construction remains, market wastes and chat wastes. The main sources of these wastes are; residents, commercial centers, municipality services, construction centers and enterprises. The third, finding is that the wastes are disposed along the roads, sewage canals, and streams and on open spaces. About 48.7% of the users dispose the waste along streams and sewage canals, while 36.2% wastes are disposed along roads and on open spaces. The remaining 15.1% is disposed properly.

Suitable waste disposal site selection and mapping

To select a suitable waste disposal site that will minimize the current problem of solid waste management in the tow different criteria ware used and discussed as follows.

Geological criterion for suitable waste disposal site selection

The geological formation of the area is grouped into three main formations. These are Asheng, Aiba basalt and Alajea formations having different characteristics. The most important characteristics which ware evaluated in this study for the purpose of suitable waste disposal site selection are; degree of porosity, thickness of the rocks, and the presence of fractures. These factors or criteria ware used to select the suitable rock type for waste disposal site. Spatial analysis operation of GIS was used to select the suitable rock type. The result shows that, Alajea formation is very suitable for waste disposal site, because it has on porosity and fracture. Ashang and Aiba basalt formations are not suitable because of high porosity and less in depth. The difference is shown in Figures 2 and 3 below.

Soil criterion for suitable waste disposal site selection: The difference in the nature of soil results in the difference in water infiltration and holding capacity. The permeability and porosity of a given soil controls the vertical as well as horizontal movement of contamination from waste leachate [3]. There are five soil types on the study area with different characteristics. This soil types are; eutric cambisols, verti cambisols, leptosoils, phaezems and haplic xerosoils [5].

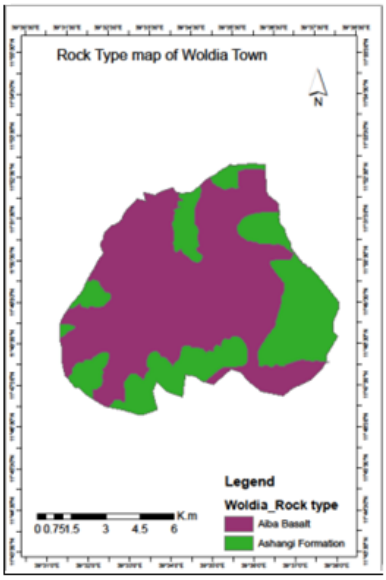

Figure 2: Geological map.

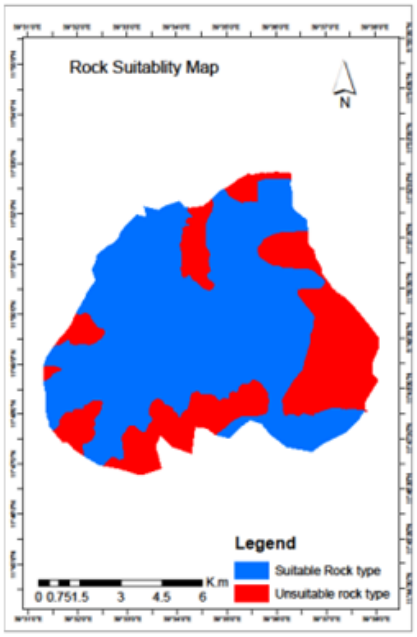

Figure 3: Suitable Geology map.

From the general soil map of the study area (Figure 4), suitable soil map (Figure 5) was prepared. This is based on the criteria the site must be on a suitable soil with greater than 140 cm depth and cannot be easily penetrate by water. Selection operation of GIS was used to perform this task.

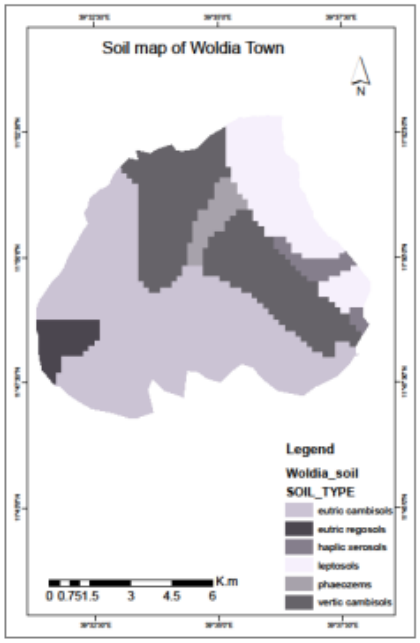

Figure 4: Soil map of the study area.

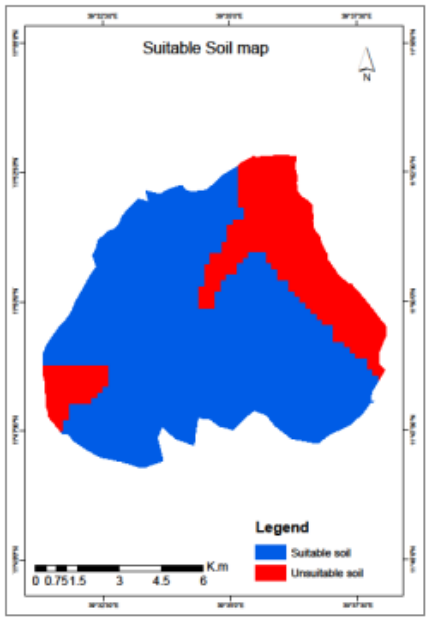

Figure 5: Suitable soil map.

Hydrological criteria for suitable waste disposal site selection: Even though, there are a number of hydrological criteria that can be affected by solid waste disposal site, in this study ground water table and surface water are used due to the absence of data.

Ground water table: It is an important environmental criterion for landfill site selection process. Therefore, solid waste disposal should be placed away from ground water wells. Otherwise, solid waste disposal can have irreversible human and environmental impacts. As a result, proximity from ground water well was considered as one criterion for this study.

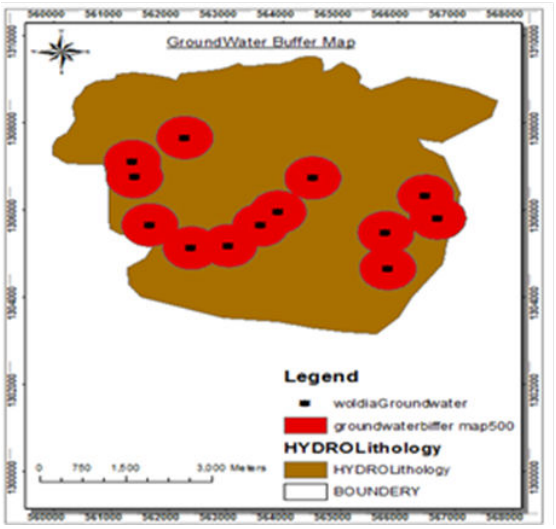

Figure 6: Groundwater buffer map.

A 500 m multiple ring buffer operation of GIS was applied to mite this purpose. Finally, Figure 6 is generated from Figure 7 as a suitable area for waste disposal site.

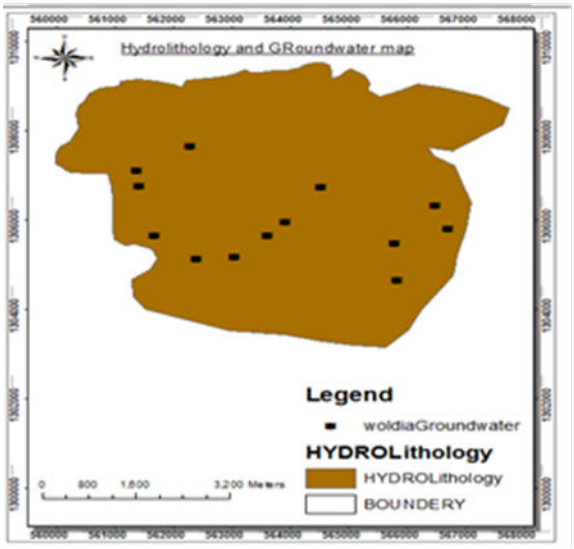

Figure 7: Groundwater map.

Surface water: The types of surface water exist in the study area are seasonal and permanent streams. These water bodies are used for drinking purpose in the peripheral parts of the town. To protect these water bodies from contamination of waste disposal site 500 m buffer zone is used. To mite this objective multiple ring buffer analysis of GIS was applied. Finally, Figure 8 is generated as a suitable waste disposal area from Figure 9 of input data.

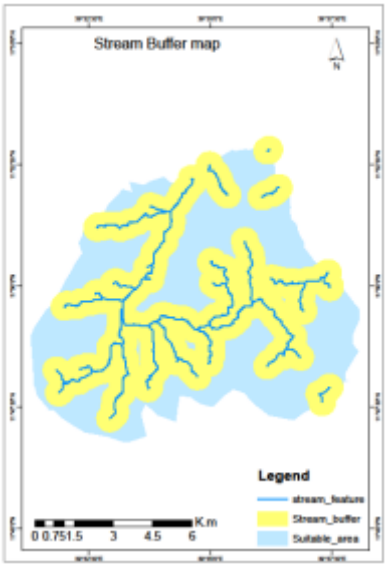

Figure 8: Stream buffer map.

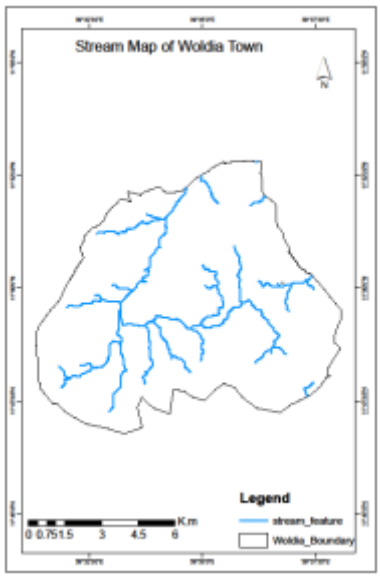

Figure 9: Stream map.

Slope criteria for suitable waste disposal site selection: The slope of an area is an important factor for waste disposal site selection. Slope determines; structure, integrity, and the flow of floods surrounding a landfills site. Slope also have an implication for drainage and ultimate land operations that are directly related to the topography of a site. Flat and gently rolling hills that are not subjected to flooding are the best sites for landfill [6].

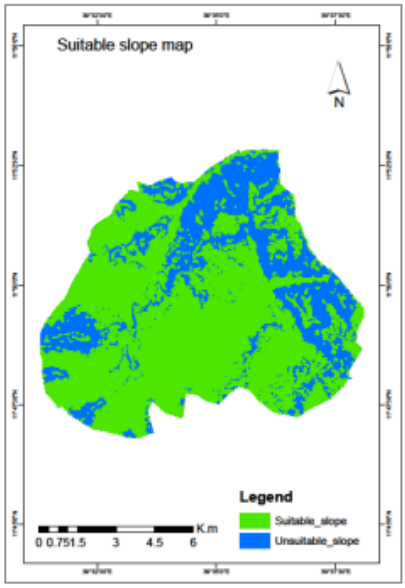

Figure 10: Suitable slope map.

Slope failure below or adjacent to landfills, will result in waste containment, accumulation and release of debris into the surrounding area. Therefore, land with slopes less than 15% should be considered as

suitable for waste disposal sites [6]. In addition, suitable slope less than 11% was used in this study. This was done by raster calculator spatial analysis operation of GIS. Finally, Figure 10 is generated as a suitable waste disposal area from Figure 11 of input data. Figure 10 below shows that blue color is unsuitable slope and green color is suitable slope.

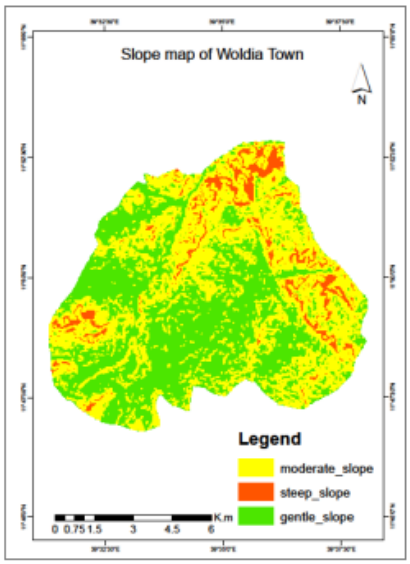

Figure 11: Slope map of the study area.

Land use land cover criteria for suitable waste disposal site selection: Most the land use is covered by settlements, commercial areas, governmental and private institutions, and other social services. The second largest area is covered by bush lands, wet lands, bare lands and some reserved free lands. The third type of land use is farmland in the peripheral part of the town. The area has also a number of streams with a wide nature, as gorges. With regard to land use land cover, this study uses the following points as criteria.

No major lines of electrical transmission or other infrastructure (i.e., gas, sewer, water lines) cross the landfill cell development area. To minimize the risks a buffer of 500 meter should be applied in these criteria.

The landfill site must be 1 kilometer far from settlements, religious areas, educational areas and other social services.

No environmentally significant Wetlands of important biodiversity or reproductive value are presented within the potential area of the landfill. In addition, the site should be constructed in areas that do not have an important economic or ecological value. To meet this specification, 0.5 kilometer buffer zone was applied.

However, to identify the required areas that are out of the specified distance from the above criteria spatial analysis of GIS operation was applied. Finally, Figure 12 is selected as a suitable area from a total land use land cover map of Figure 13 as follows. In this Figure 12 the red color is unsuitable land use while the blue color is suitable land use.

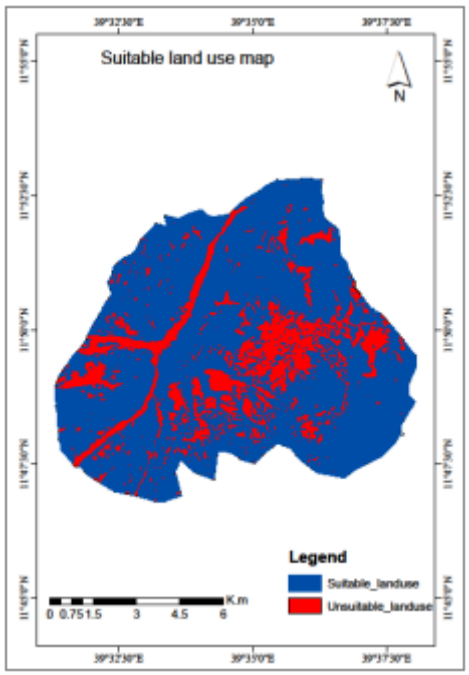

Figure 12: Suitable land use land cover map.

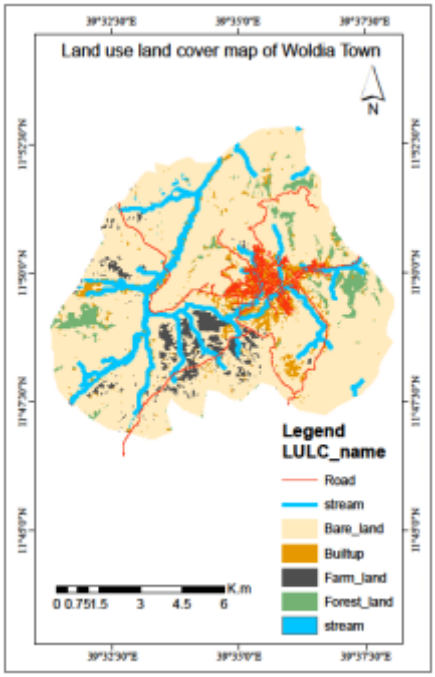

Figure 13: Land Use Land Cover Map.

Road criteria for suitable waste disposal site selection: A road was one of the criterion that should be considered from an economic and social point of view during solid waste disposal site selection processes. This is because sitting landfill too close to roads may have public health

problems as landfill pose hazardous effect to human health. Moreover, a landfill site too far from road network is also not recommended due to high transportation cost. Therefore, to minimize such problems, landfill must not be sited too close to or far from roads.

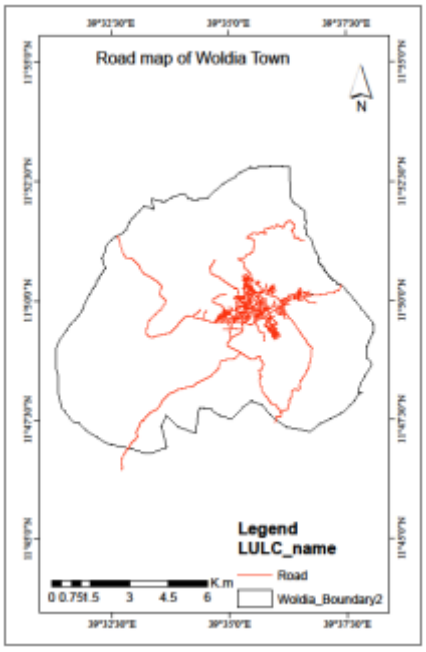

Figure 14: Road map of the study area.

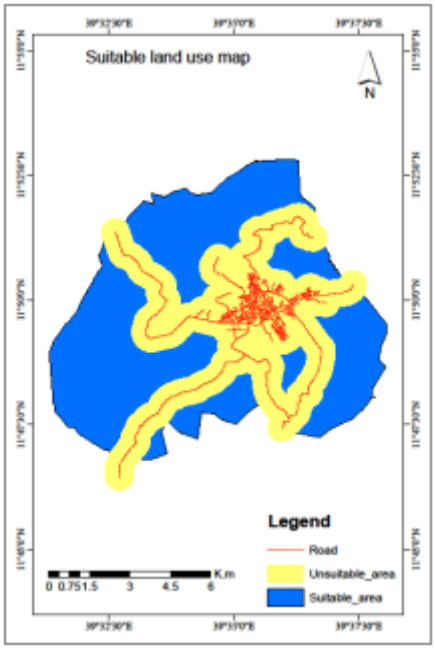

Figure 15: Road buffer.

For this study, areas within 500 m and 1000 m were used as a best site for landfill [7]. Therefore, multiple ring buffering was used to select these areas from the total road map (Figure 14) of the study area and Figure 15 was produced as a road buffer map. Figure 15 below shows that the blue color is suitable are and yellow color shows that unsuitable area.

Spatial suitability modeling of waste disposal site

The above analysis of different criterion revealed the complex intersection of factors that can determine suitable solid waste disposal site. This section prepare a model for criteria like geology, soil, ground water hole, surface water and socio-economic factors such as slope distance from settlement, are not the same in their spatial location. Due to this difference, the overall criteria are grouped into factor and constrain criteria models.

Factors suitability modeling

For factors model geology, soil, stream buffer and groundwater criteria have nearly similar. This is because these criteria are highly influenced by the selected landfill leachate. This means that when these criteria are poor in nature they will result in contamination of the ground water that the people uses for their daily life. A model for the combination of the factor criteria is shown as below. This is done by applying analysis tool of selection and intersection operations of GIS (Figure 16).

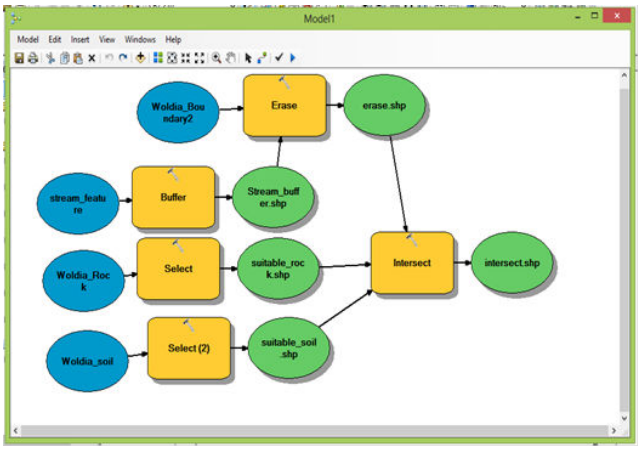

Figure 16: Landfill suitability factors model.

From this factors model above the suitable landfill map (Figure 17) was generated by the intersection of geological suitable area, suitable soil, areas out of the road buffer, and areas out of groundwater buffer. The factor maps indicate the relative suitability of the area for sitting landfill. This map shows that there are different suitable landfill sites that differ from each other by their size and location as indicated in Figure 17 below.

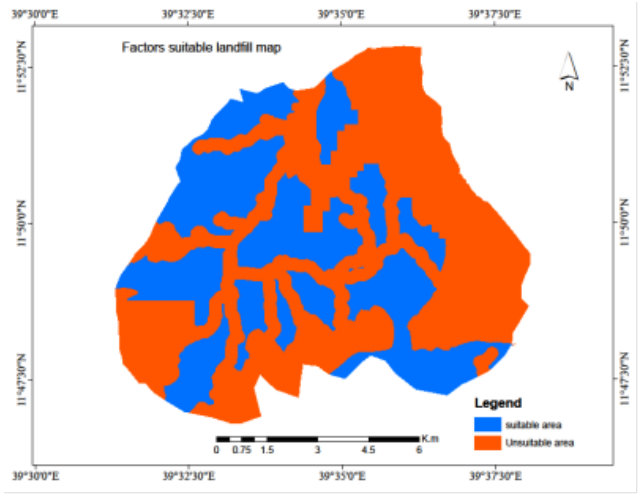

Figure 17: Factors suitable map.

Constraint suitability modeling

Constraints includes land use land cover suitable map, road buffer map, and suitable slope map. Specific value was given for each criterion and suitable site was selected according to each. The suitability modeling organizing these data layers which are identified as constraint and combine all the constraint maps to prepare the overall constraint map. The model shows the process of combining the constraint maps by applying a series of overlay procedures (the intersection command). The overall effect of the constraint map below indicates the extent of the study area, which is designated as suitable and not suitable for sitting the landfill (Figure 18).

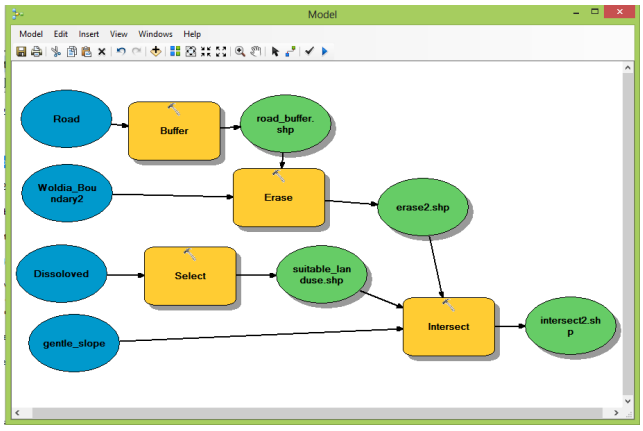

Figure 18: Factors suitable map.

The above model shows that the process of combining the constraint maps by applying a series of overlay procedures (that is the intersection command). The overall effect of the constraint maps indicates the extent of the study area, which is designated as suitable and not suitable for sitting the landfill as shown below (Figure 19).

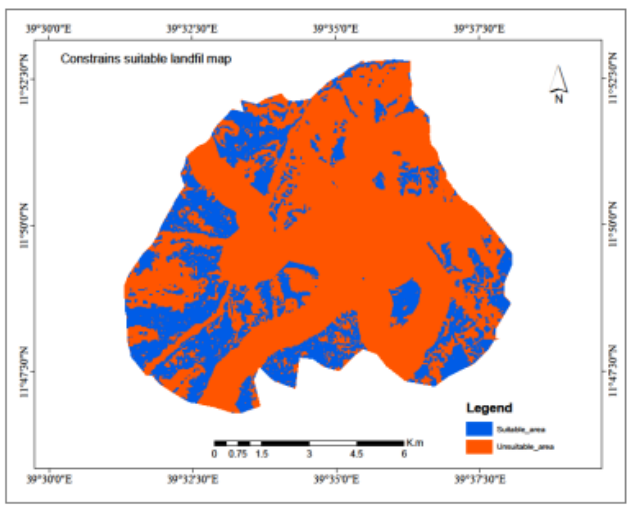

Figure 19: Factors suitable map.

Final suitability modeling

Final suitability modeling is a combination of factor suitability modeling and constraint suitability modeling by applying suitability modeling of GIS. To do, this model overlay operation of intersection was implemented in addition to selection operation of extraction (Figure 20).

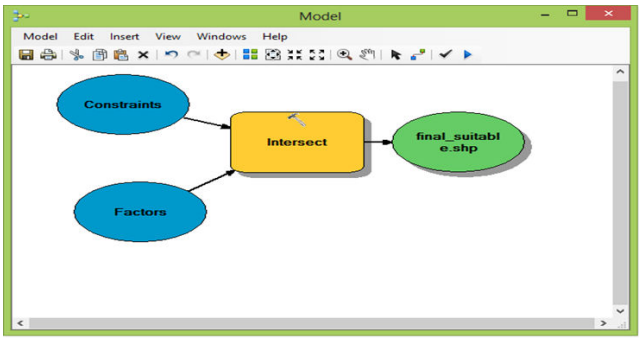

Figure 20: Suitability Modeling.

The above model shows the composite suitability of the constraint map and the factor maps. The resulting sites selected can be labeled as Site 1, Site 2, Site 3 and site 4. But it is still possible to make further suitability differentiation among these candidate sites. To arrange these sites based on their importance, a good landfill site evaluation of candidate site activity was conducted using additional criteria in the next section of this paper. The next figure shows the final candidate site for landfill in the area (Figure 21).

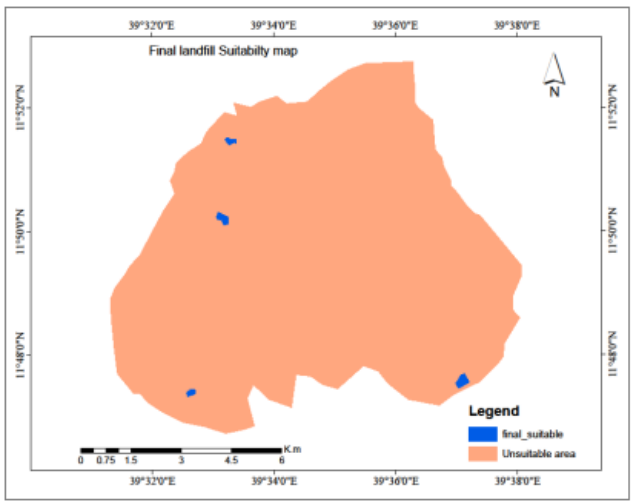

Figure 21: Final candidate landfill site.

Evaluating candidate landfill sites

Evaluating the selected candidate landfill site is one of the last but not the list objective of this project. Socio-economic criteria like size of the site, distance from nearby settlements and distance from the center of the city are the determinant criteria used to evaluate potential landfill site so as to choose the best suitable site. Size of landfill is one of the determinant criteria for sustainable solid waste management as size of land selected for landfill determines the number of years for which the landfill will be used as waste disposal site. From sustainability and economic point of views, larger size of land that will serve for at least ten years is more preferable than a small size. This is because selecting large sized landfill site can minimize the cost of site selection, design, and closure that will be performed at the end of its lifespan [7].

Accordingly, the area is calculated in GIS environment and shows that, site 1=7 ha, site 2=5 ha, site 3=4 ha and site 4=4 ha. From this value, one can understand that the value of site two is very high relatively than the rest.

For evaluating landfill site, distance from the center of the city is also another very important criterion from an economic point of view. Landfill far from the center of the town is not preferable due to high transportation cost that will be incurred during its lifetime. Therefore, a site close to the center of the city is more preferable than far sites. We take Adago square as the center of the town. The measurement of all the candidate landfill sites showed that, landfill site one=6.5 km, landfill site two=7 km, landfill site three=8 km and landfill site four=8.2 km. From this result we can understand that landfill site one is very close and more suitable and site four is very far and not suitable due to transportation cost. This measurement shows that there is a contradiction of the criteria to the site. To alleviate such a contradiction, another criteria such as distance must be added, from the nearby settlements.

However, landfill should not be located to near settlement area as it have negative impact on human health. Evaluation of candidate landfill sites with the distance from the nearby settlement area can minimize such effects. Accordingly, the measurement of the sites with distance from the nearby settlements in GIS environment shows that landfill site one=1.6 km, landfill site two=0.8 km, landfill site three=2 km and landfill site four=2.2 km. From this measurement, the suitability rank is landfill 4, landfill 3, landfill 1 and landfill 2, considered from highly suitable to less suitable respectively. As described above, the criteria are conflicting with each other (Distance from city center and Distance from nearby settlement area). To minimize such a problem, the researcher selected the site that covers the largest area to make the landfill used for a long period. The site that fulfills this criterion is landfill site one and its distance from the nearby settlement is about 1.6 km (Figure 22). According to the criteria set by the Municipality, "the site must be used for ten years and it is one km far from the nearby settlement. The candidate sites are arranged from the highly suitable to the fairly suitable as follows (Table 1).

Site name	Suitability rank
Site one	Highly suitable
Site two	Moderately Suitable
Site three	Suitable
Site four	Fairly suitable

Table 1: Candidate sites.

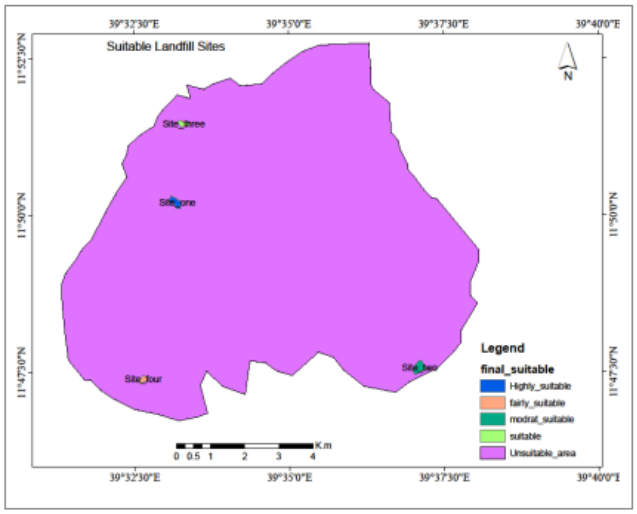

Figure 22: Final evaluated landfill site.

Conclusion and Recommendation

Solid waste management in Woldia Town was not satisfactory. This is mainly because of the absence of suitable waste disposal site. Therefore, selecting suitable waste disposal site selection may solves this problem. GIS was used to conduct this site selection process by using different criteria. To select a suitable site it is important to consider the condition of the locality in addition to the standardized guidelines.

To overcome this problem the researcher establish different criteria. The criteria were grouped into seven as geological criteria, soil criteria,

hydrology/hydro geological criteria, road criteria, land use land cover criteria, and slope criteria with a specific value for each.

By using such criteria, the researcher produces landfill suitability area/map for each criterion in GIS environment by applying analysis tool like buffering, overlay, and extraction of selection operations by screening and identification of each criterion, final landfill site selection was conducted by using suitability modeling technique. To apply the suitability modeling the criteria are grouped into factors and constrains. Finally, this factor model and constrain model were integrated into one model to produce the final landfill sites. As a result, four-candidate sites were selected with different values of areal coverage, distance from the center of the city, and distance from the nearby settlement. By comparing this socio-economic criterion difference the sites were arranged from highly suitable to less suitable as, site one=highly suitable, site three=moderately suitable, site two=fairly suitable and site four=less suitable.

To make the selected landfill site most appropriate and to protect the environment and human health the following recommendations were given.

- Factors such as cost of construction and community preferences also influence landfill site selection and therefore, they should be included as evaluating criteria.
- Drainage system should be constructed around the landfill.
- Criteria like major lines of electrical transition or other infrastructure (i.e., gas, sewer, water lines) cross the landfill cell development area and wind direction are not included in this study. Therefore, the selected landfill must be evaluated according to these criteria.
- The selected landfill site was only for non-hazardous solid waste. Therefore, hazardous wastes should not be deposited in this site.

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