



RESEARCH ARTICLE

MULTI-CRITERIA ASSESSMENT (MCA) AND SELECTION OF A SOLID WASTE DISPOSAL SITE WITHIN WA MUNICIPALITY, UPPER WEST REGION, GHANA

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ABSTRACT

Municipal solid waste management is a problem in most developing countries of the world. This is because of its nature, quantity generated, cost of transportation and the selection of final storage sites, which together presents a huge challenge for most municipalities. Improper solid waste disposal has serious environmental consequences which ultimately affects human health. The most common problems associated with improper selection and management of final waste disposal sites for solid waste include disease transmission, fire hazards, odour nuisance, air and water pollution, aesthetic nuisance. Economic cost arising from transportation due to long distances of travel to deposit solid waste also discourage the use of waste disposal sites. Municipal solid waste management is considered one of the most serious environmental and social problems faced by municipal authorities in developing countries. This work considered the selection of a suitable site for the disposal of municipal solid waste generated within the Wa Municipality of the Upper West Region of Ghana, using Multi-Criteria Evaluation technique in G.I.S. To determine the most suitable waste disposal sites in the municipality, the study integrated environmental and socio-economic criteria including proximity to road networks, distance to residential and important built-up areas, water bodies to select the most optimal location for waste disposal. The results showed a total of three (3) proposed suitable sites, out of which a site with reasonably optimal distance as well as easily accessible to roads was preferred as the most suitable site for the municipal solid waste disposal (landfill) in the Wa Municipality.

KEYWORDS

Landfill, Site selection, G.I.S., Solid waste, Multi-Criteria Evaluation, Ghana

1. INTRODUCTION

Solid waste management is one of the basic key services rendered by almost all municipal authorities to maintain good sanitary conditions in cities (Bosompem et al., 2016). However, solid waste management is a major global problem most especially in highly urbanized cities particularly in developing countries including Ghana. This is because the processes applied in managing the wastes are mostly unscientific, outdated and/or inefficient (Minghua et al., 2009). The inefficiency of solid waste management is not only based on lack of policy but also, lack of education, and infrastructure, as well as social awareness of problems arising from solid waste. As a developing country, Ghana is faced with serious problems of handling its solid waste generated (Naa, 2012). The poor management of solid wastes has negatively impacted human health and the environment. The situation is even more critical with an increasing population growth in urban areas, since increase in population, with little to no management plan leads to increase in solid waste generated (Ampofo et al., 2015; Bosompem et al., 2016). The effective management of solid waste generated in municipalities including its storage, transportation and disposal is a key factor in preventing and/or reducing poor human health and environmental problems.

This Municipal solid waste can be grouped according to its origin (domestic, industrial, commercial, construction or institutional), according to its content (plastic, organic, glass, metal, paper, etc.) or according to its hazardous potential (toxic, nontoxic, radioactive,

infectious or flammable) (Centre for Environment and Development, 2003). These materials, after usage, are dumped anywhere in our communities (Puopiel, 2010). In Wa municipality, solid waste is dumped in the centre of most towns and nearby villages. These heaps of solid waste located in the centres of towns, produce very offensive odour which negatively affect the health of humans and the environment. The problems associated with solid waste management is as enormous as the diversity in the content of the waste as well as the quantity of wastes generated and the financial limitations imposed on public services in towns and cities (Ampofo et al., 2015; Haq et al., 2015). When proper management is given to solid waste, it helps reduce or eliminate the harmful impacts on the environment and human health, thereby improving economic development which brings about improved standard of living (Environmental Protection Agency, 2006). There are series of methods employed in effectively managing the solid waste of a municipality. These include monitoring, storage, collection, transfer and transport, recycling and disposal of the generated waste (Puopiel, 2010).

Locating an appropriate site for the final disposal of solid waste is a major problem facing most emerging and fast urbanising towns and cities, with the Wa municipality not being an exception (Douti et al., 2017; Olaide, 2018; Olanibi and Emmanuel, 2022). Selecting a suitable site for landfill should therefore be done with much scrutiny and knowledge, considering all necessary factors including environmental and socio-economic factors (Bosompem et al., 2016; Ismael, 2021). The absence of these causes negative impact on the ecology, economy, environment and human health.

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Geographical Information System (G.I.S) analysis offers the suite of tools to handle large amount of spatial data and provides the privilege to create map layers, using multi-criteria analysis involving factors like soil types, residential settlements, surface water, geology, forest reserves, etc. (Rikalovic, 2014; Kumar et al., 2016; Kilicoglu, 2020). G.I.S. is considered an accurate and reliable tool in selecting a suitable site for disposal of solid waste. This is because, they are designed to massively reduce or eliminate the negative effects associated with solid wastes (Bilintoh and Stemm, 2015). The landfills are usually situated such that they are buffered away from various environmentally sensitive areas (Mahamid and Thawab, 2010).

Extreme protective measures are often put in place in the construction of Landfills. The bottom is lined with either clay or plastic to prevent leaching of the liquids from the waste which may pollute underground water bodies. The leachates are pumped out after treatment. Also, bore holes or monitoring wells are dug near landfills to constantly check the quality of ground water. Sanitary landfills are sometimes used to generate energy. Anaerobic decomposition of the wastes generates some useful gases including methane (CH₄), carbon dioxide (CO₂), and traces of other biogases, which can be trapped and used as energy source in generating heat and electricity (Aguilar-Virgen et al., 2014).

G.I.S. based Multi-Criteria Evaluation (G.I.S.-MCE) deals with the allocation of portion of the earth surface suitable for a specific objective on the basis of selected features. It is a process that combines geographical data in the form of map criteria and value judgements (decision-makers' preferences) to obtain relevant information for decision making (Wang et al., 2009; Kilicoglu, et al., 2020). Site selection is one of the most important decisions one has to make in the set-up, expansion or relocation of a solid waste disposal site. This goes to say that, the location of a dumping site plays a critical role in an effort to reduce or mitigate the effects associated with wastes (Bosmans et al., 2013). Primarily, the objective of site selection for waste disposal is to identify the most appropriate site with well-defined conditions by way of analysing criteria or factors (Cobos-Mora et al., 2020). Waste disposal sites are believed to be a problem of spatial decision, hence, the use of geographic methods by most researchers now. With the advent of Geographic Information System (G.I.S.) such studies have become much more common and easy (Eskandari et al., 2012; Bilintoh and Stemm, 2014).

1.1 Solid Waste Disposal in WA Municipality

Solid wastes management within the study area involves three (3) major processes including collection, transportation and final disposal. Collection of solid waste is performed by the three (3) collection systems namely: municipal containers (skips), collection from institutions, and door-to-door collection. This is carried out by the municipal assembly and assisted by Zoomlion Ghana, a private waste management firm. In the

municipal containers system, large open steel containers are located in open spaces near public schools and other commercial areas. Households and other waste producers then dispose their wastes into the containers. Door-to-door collection system service is made available to households located far from major roads. In this system, solid waste is collected from the households to the container stations by labourers and made ready for transportation. Solid waste collection from institutions is however, done by way of payment per container. The solid wastes collected from the various systems are then transported to the final dumping site (called 'siri-yirii' in local terms) located 5km away from the town, in the Wa-west district.

There are several problems associated with the management of solid waste in the municipality. These include; dumping of solid wastes in open spaces at the centre of localities, making people vulnerable to diseases; damage of containers by people living around; dumping of hot substances into plastic containers thereby burning them; indiscriminate dumping on streets, bushes and abandoned buildings; and wrongful siting of the only available solid waste disposal site in the municipality. The current site is very close to human settlement, about 36.576 m away from settlements. Public dumping (open space) accounts for about 49.7% of the waste disposal methods, with public dumping (container) representing 38.4%, 4.2 % for indiscriminate dumping, and less than 10% for other means of waste disposal including burning and burying (Ghana Statistical Service, 2013 population and housing census). The location of the only available disposal site however, poses several dangers to human health and the environment. The scenery is ugly and a nuisance. Also, the area is vulnerable to ground and surface water pollution since the landfill is not properly engineered. Additionally, all types of solid wastes from domestic, market, industry, commercial and hospitals containing leachable toxic compounds have been left not-separated and untreated. Moreover, the solid wastes are left uncovered after disposal, thereby increasing the risk to environmental and public health related problems.

2. MATERIALS AND METHODS

2.1 Study Area

Wa Municipality is one of the eleven Districts/Municipalities that make up the Upper West Region (UWR) of Ghana. The Municipality was upgraded from district level into a municipality in 2004 following Legislative Instrument (L.I.) 1800, in pursuant of the policy of decentralization which started in 1988. Wa Municipal shares administrative boundaries with Nadowli district to the north, Wa East district to the east and Wa West district to the west and south respectively. Wa, the capital of the Municipality, also serves as the Regional capital for the Upper West Region. It has a land area of approximately 579.86 square kilometers, which forms about 6.4% of the Region size. Figure 1 represents a map of the Wa Municipality (GSS, 2013).

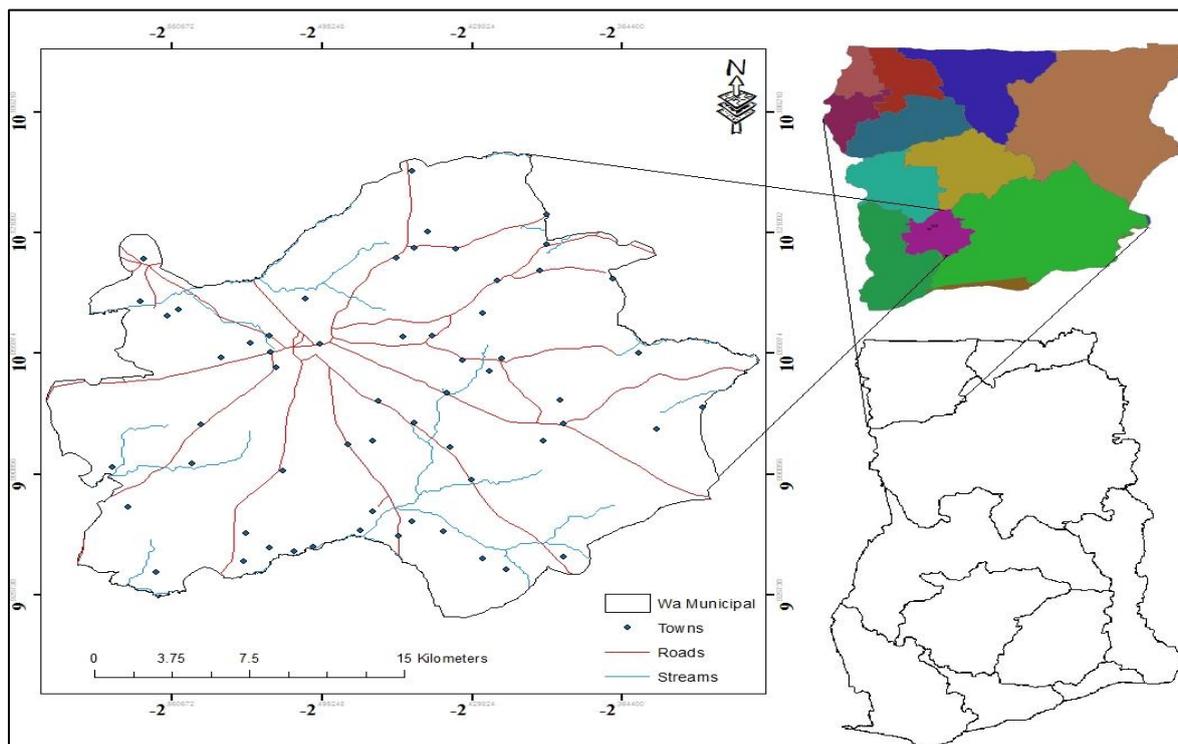


Figure 1: A map of Ghana showing the study area boundary

2.2 Methodology

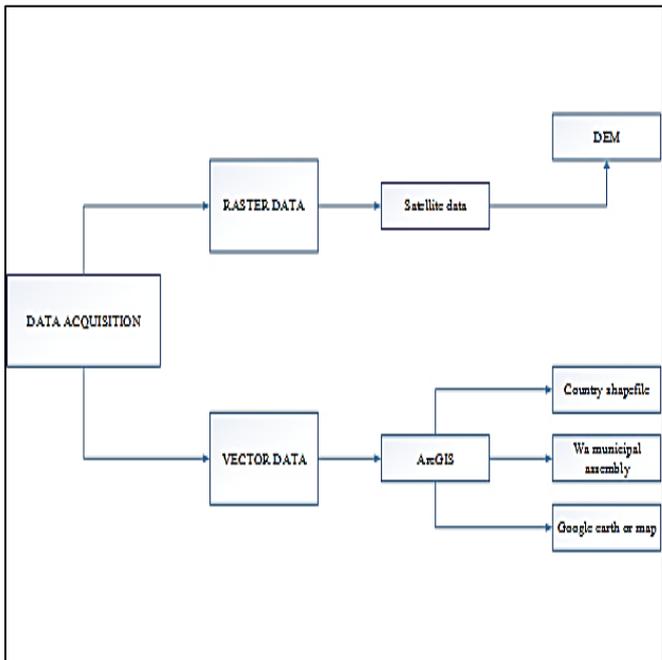


Figure 2: Source of Data

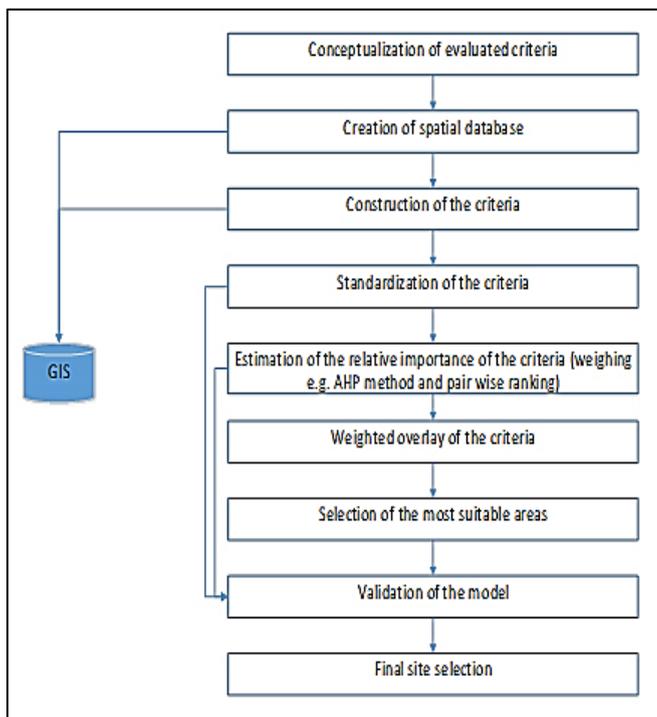


Figure 3: Conceptual Framework of GIS-Based Multi-criteria Evaluation

The study used a site selection assessment model within the G.I.S.-Based Multi-Criteria Assessment (MCA) tool. Scientific research has showed that several factors including slope, landuse/landcover (LULC), roads, settlements, etc. should be taken into consideration in site suitability analysis and selection (Mahamid and Thawab, 2010; Javaheri et al., 2006; Aderoju et al., 2018). Seven (7) socio-economic and bio-physical factors from various sources including roads, soil types, slope, landuse/landcover (LULC), settlements, geology and water bodies (table 1) were considered in the study. Roads, rivers and settlements were then buffered using appropriate recommendations. Using the G.I.S. software (ArcG.I.S. 10.4.1®), maps of all the factors considered were created. Figure 2 shows the data types used in the study while figure 3 shows a conceptual framework of the procedure adopted in arriving at the final suitable site identified.

2.3 Euclidean Distance Analysis/Buffering

Euclidean distance is the ordinary straight-line distance between two points in Euclidean space. This element incorporates buffering of various

features like roads, streams/rivers, towns or settlement into various standard requirements (Table 2) (Wilson et al., 2012).

Table 1: Dataset/ input data	
DATA TYPE	SOURCE
Roads Maps	Digitized Google Road Maps
Landuse/Landcover	Country shapefile
Settlement	Digitized images from Google maps
Soils data	Country shapefile
Geology	Country shapefile
Slopes	DEM (Digital Elevation Model)
Drainage system	DEM (Digital Elevation Model)

Table 2: Standard buffering distances	
Criteria	Unsuitability Area (m)
Road Networks	100
Surface Water	200
Residential Areas	300

Source: Adapted from Wilson et al., 2012

Table 2 above, shows distances used as zones of exclusion in the selection of a suitable site. This buffered zone was used to protect the environment and people from the effects of contamination of the operation of the site.

2.4 Overlay Analysis

The Analytical Hierarchy Process (AHP) by means of pair-wise comparison was employed to assign weights to the criteria considered in the study so as to select the most suitable site (Adewumi et al., 2019; Sehnaz et al., 2011, Wang et al., 2009). The relative weight of each criteria was determined by using pair-wise comparison method of AHP which involve creating a ratio matrix. Pair-wise comparison was the input while weight was the output with a percentage ranking used (Ghoseiri and Lessan, 2014). Using previous study as a reference for comparative assessment of landfill site selection, an analysis was carried out (Wilson et al., 2012). Criteria of more importance were given the highest ranks. Table 3 shows each criterion and their respective rankings.

2.5 Model Builder

The overall process for determining suitable sites for solid waste disposal was performed through the spatial analysis tool in G.I.S. using the ArcG.I.S®. Model Builder. The model builder is a tool used for generating and managing automated and self-documenting spatial models. Using a model builder makes the creation of process flow diagrams and scenarios to automate the modelling process. In using model builder, the themes created were converted to grid themes using the vector conversion tool. Models are represented as sets of spatial processes, including buffer, classification, and reclassification and overlay techniques.

A weight of influence was assigned to each of the themes based on its importance. The result then successively multiplied by each of the constraints. This process is often used in site suitability studies where several factors affect the suitability of a site (Cobos-Mora et al., 2020). The weighted overlay process in G.I.S. was further used to combine the factors and constraints in the form of a weighting sum process.

Table 3: Criteria with respective rankings	
Criteria	Percentage ranking (%)
Towns	30
Water Bodies	25
Soil	20
Road	15
Slope	10

3. RESULTS AND DISCUSSIONS

3.1 Selection of Suitable Site

G.I.S. (ArcG.I.S.®) was used to generate thematic map layers of geology, soil types, stream networks, road networks, as well as other buffered features which were used as the main themes for selecting the most appropriate site.

3.2 Soil Types

Landfill sites should not be sited and/or constructed on highly permeable soils but on soils with low permeability. Figure 4 shows the three soil types identified in the study area, namely lithic and dystric Leptosols, Vertisols and Lixisols. The Food and Agricultural Organization (FAO) defines Leptosol as the type of soil with very low and shallow soil profile depth, often containing large amount of gravel (indicating little soil forming process). Leptosols are susceptible to erosion and desiccation, and are not waterlogging. Lithic leptosols, the most extensive Leptosols on earth are less than 10 cm deep found around mountain areas. On the other hand, Lixisol has subsurface accumulation of kaolinitic clay and are identified by the absence of an extensively leached layer below the uppermost layer. Clay has the ability to retain water, thereby not allowing water or any other liquid to percolate into groundwater system. Also, Vertisol is described as a type of soil with high content of expansive clay minerals, many of which are known as montmorillonite. They usually form deep cracks in dried seasons or years (FAO, 2015). A research identified lixisol and acrisol as the best soil type for soil waste disposal or landfill construction. This is because they are rich in clay, and clay has the strongest ability to retain water, not allowing it to percolate into the ground water system (Olaide et al., 2018). Figure 4 shows the soil map of the study area. Among the soil types identified in the study, lixisol has more clay and covers more than half the total size of the study area.

3.3 Landuse/Land Cover (LULC)

Bio-physical materials found on the surface of the earth are referred to as land cover. They include bare land, asphalt, grass land, water bodies, agricultural, etc. Landuse/Landcover (LULC) map of the study area was generated using ArcG.I.S.® and was further converted into raster format (Figure 5). The study identified the landcover types as open cultivated savanna woodland, widely open cultivated woodland, and urban areas. According to Kumar et al., 2016, grasses or herbs, with or without scattered trees from 0 to 5m (referred to as scrub lands) is the preferred landuse/land cover for solid waste disposal. Figure 5 shows the LULC map of the study area. It was observed that widely open cultivated savanna woodland covered most parts of the study area.

3.4 Geology of the Study Area

Waste disposal sites are to be located on impermeable or strong geologic formations so as to prevent the downward movement of leachates from the wastes into the underground water. The geology of the study area was determined to be Birimian volcanic, Birimian sediment and Dahomeyan (Figure 6). The Dahomeyan is made up mainly of sandstones while Birimian volcanic and sediments consist of interlayered sedimentary and volcanic flow rocks metamorphosed to low green schist facies.

3.5 Slope

Another important factor considered was the slope of the study area. The slope of an area is referred to as the degree to which the area surface tends upward or downward. Literature reveals that areas with high slopes have a high risk of pollution. As such, a suitable solid waste site cannot be located on hilly or highly steep slopes (Sehnaz et al., 2011). The Slope map was derived from the Digital Elevation Model (DEM) of the study area, and reclassified on a scale of 1 to 10 in raster format. Figure 7 shows the slope map derived from DEM of the study area while figure 8 shows slope map after reclassification, where steep slopes are identified in red and less steep slopes in green.

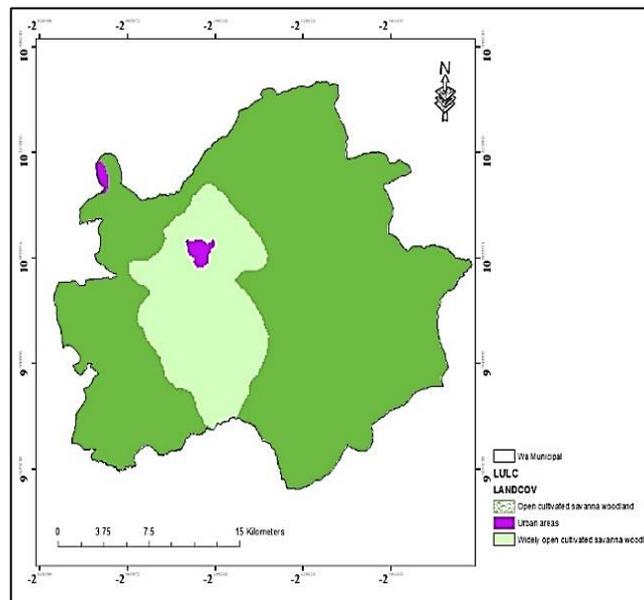


Figure 5: Landuse/Landcover map

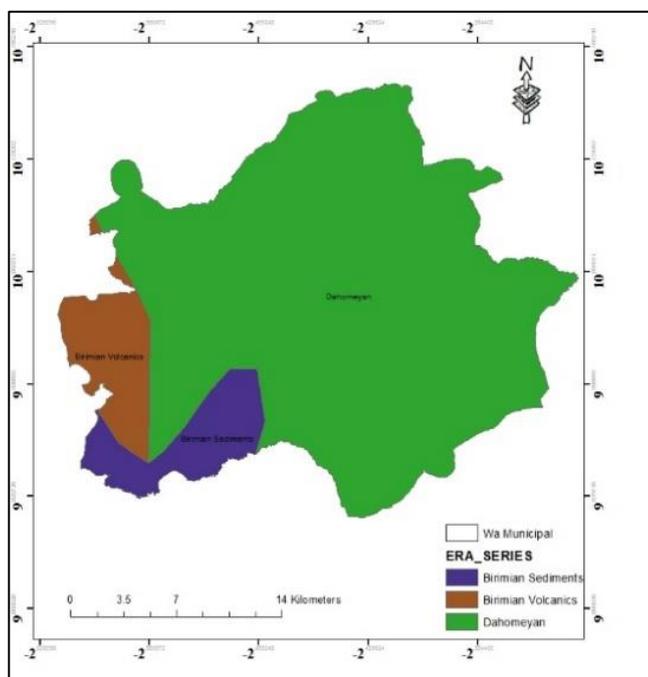


Figure 6: Map Showing Geology of Study Area

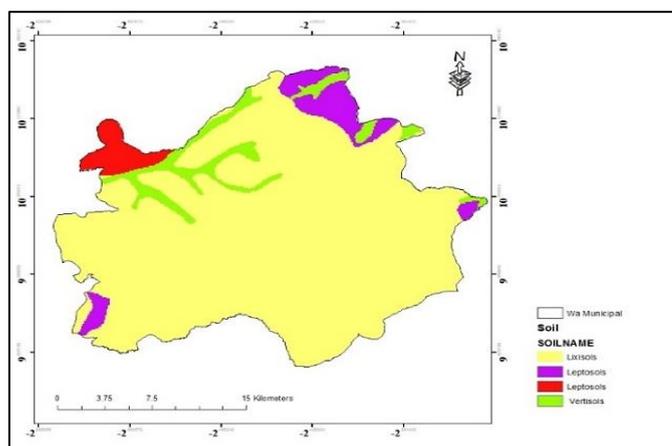


Figure 4: Soil map of Study area

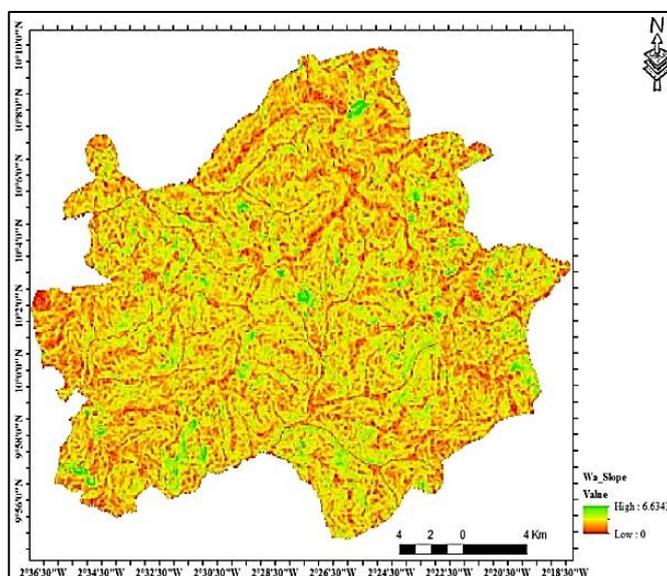


Figure 7: Slope Map

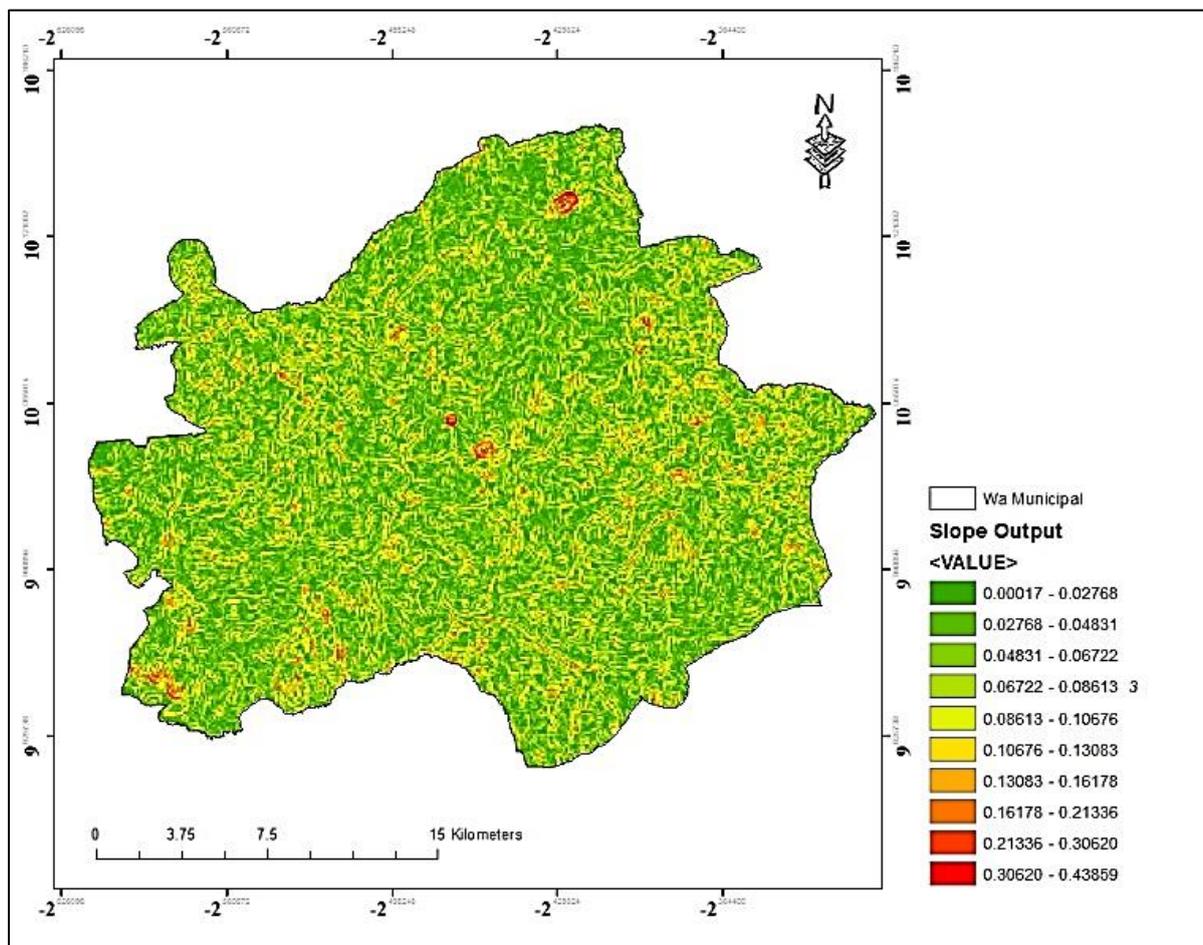


Figure 8: Map Showing Reclassified slope of Study area

3.6 Euclidean Distance Analysis/Buffering

The roads, streams, and towns within the study area were buffered. This element incorporates buffering of various features like roads, streams/ rivers, towns or settlement into their various standard.

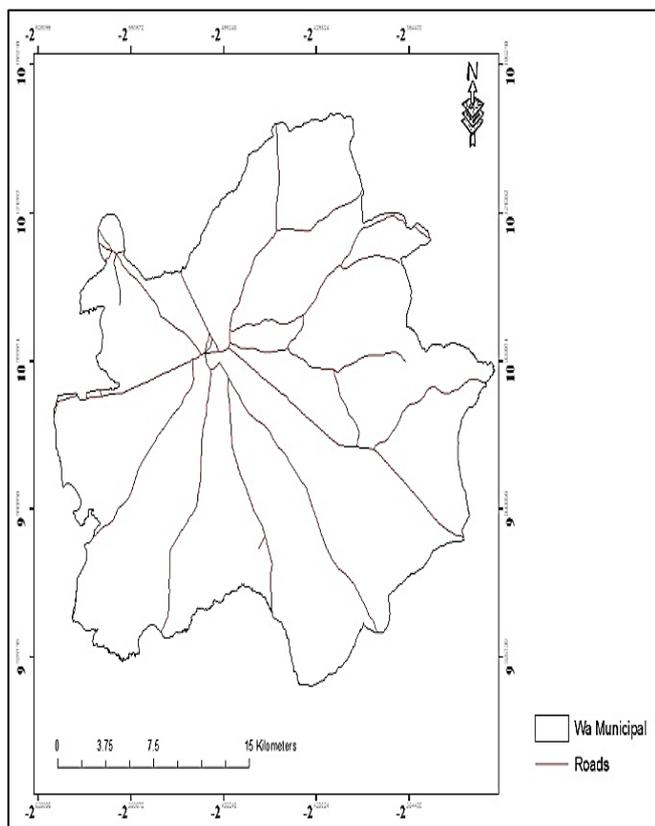


Figure 9: Map showing Road networks

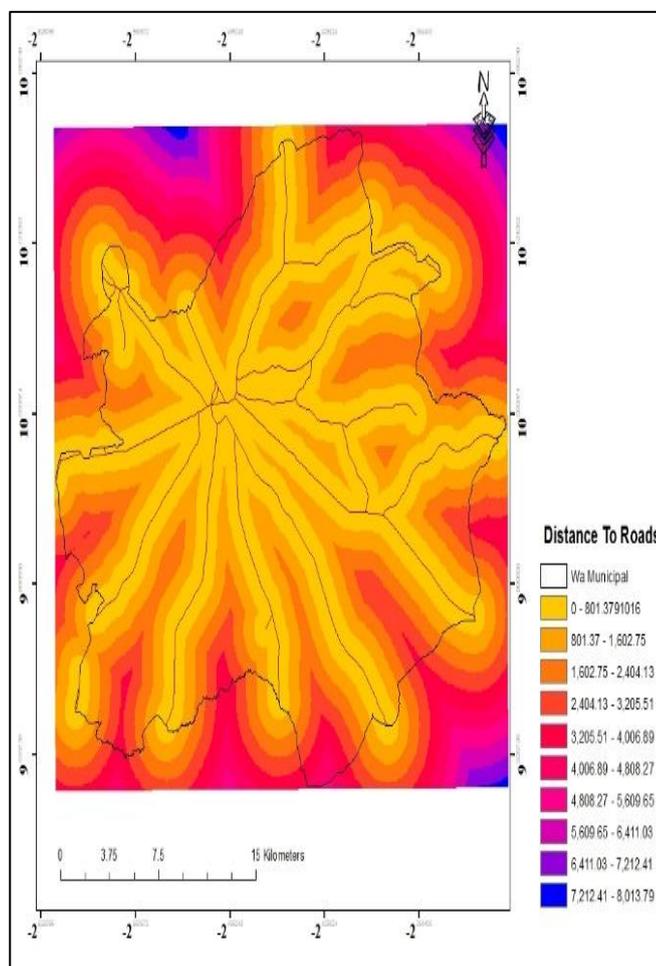


Figure 10: Map showing Buffered Roads

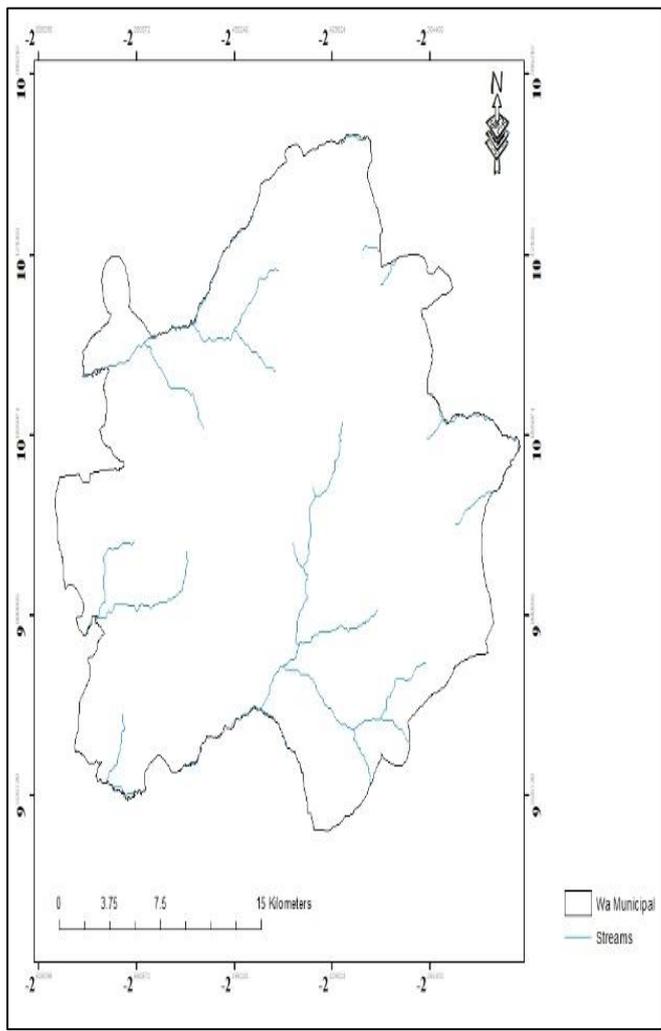


Figure 11: Stream networks within study area

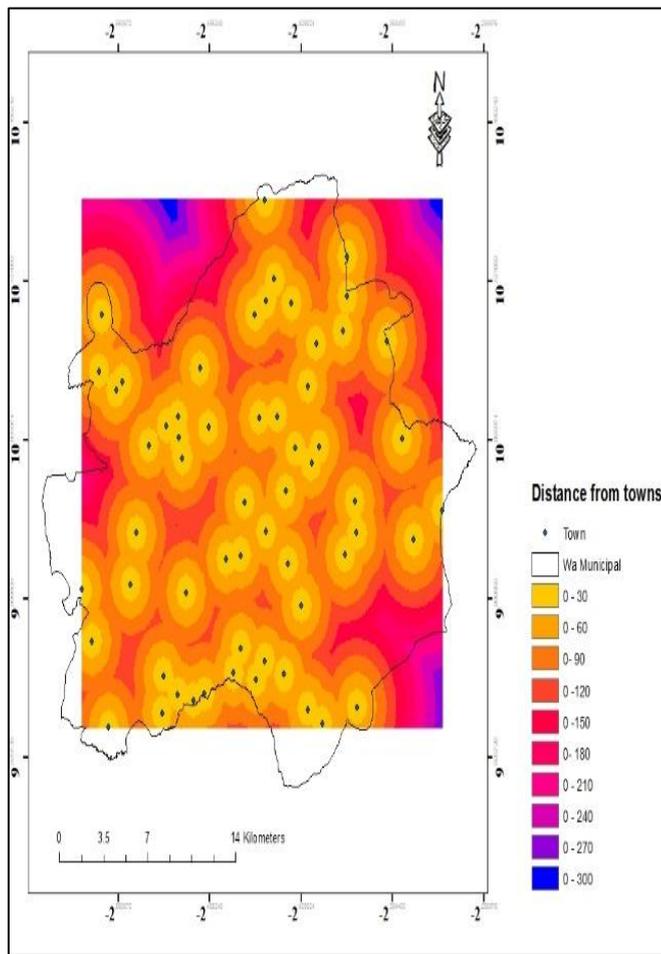


Figure 13: Map showing the location of towns/settlements in study area

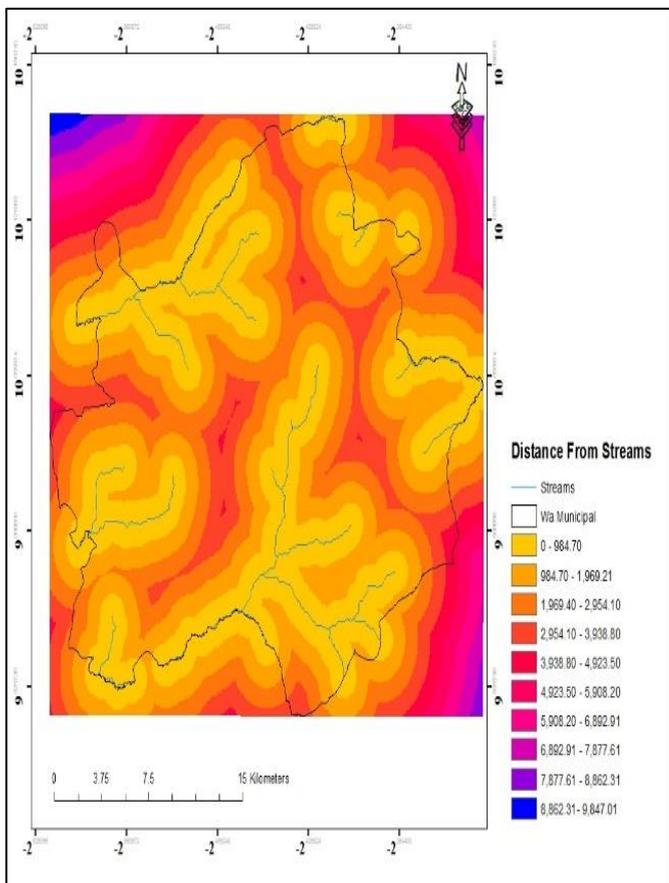


Figure 12: Map showing Buffered streams

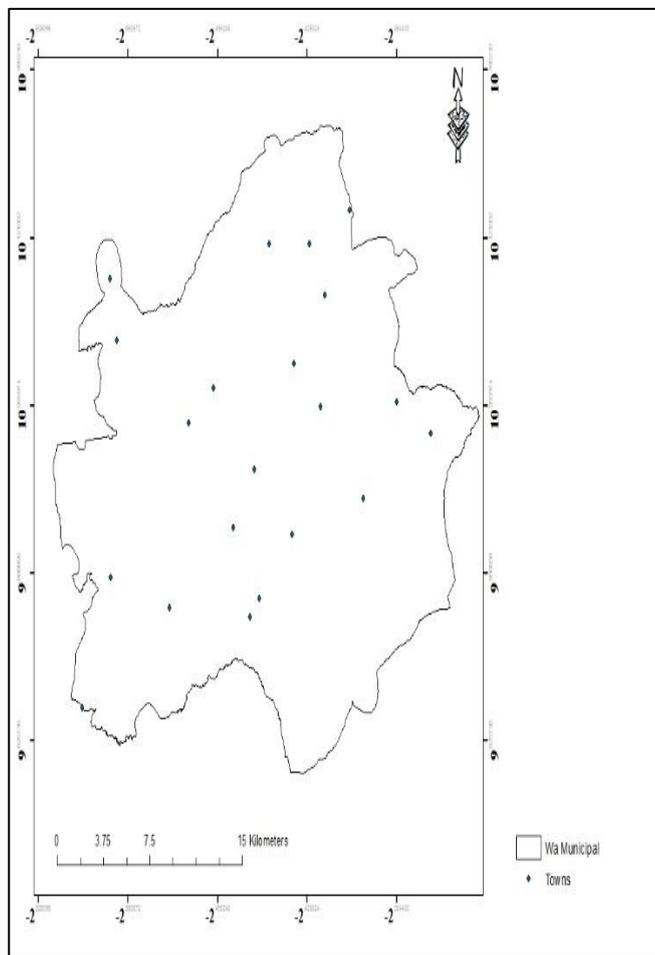


Figure 14:

3.7 Model Builder Process for Suitable Site Selection

The spatial analyst tool in ArcG.I.S.® was used to first create a model. The environmental settings for the model were further specified for the process. Each feature or data inserted into the model was executed to derive an output map referred to as layer. The map layers derived included

slope, distance to road, distance to towns, and distance to rivers or streams. The output layers derived were each grouped into different classes through the process of reclassification. Generally, a completed model was attained using the weighted overlay, Con, Majority filter, and Raster to polygon tools. Figure 16 shows a framework of the model generated.

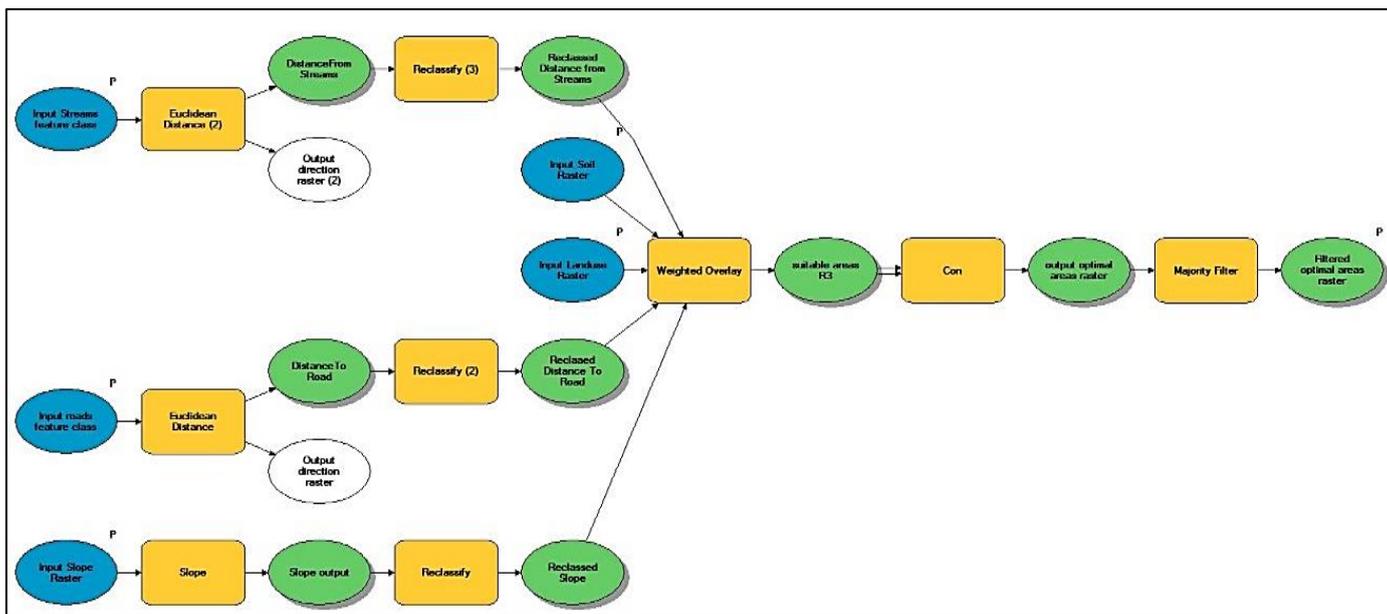


Figure 15: Model builder framework

3.8 Suitable Sites

Site/Area	Latitude	Longitude
Site 1	10.038	-2.575
Site 2	10.091	-2.380
Site 3	9.983	-2.330

During the model building process, three (3) suitable sites were selected before a final more suitable site was selected. Figure 17 is a map showing the location of all three (3) identified suitable sites, labeled site 1, site 2, and site 3. Buffering of the various features was done using 200m for water bodies, 100m for roads, and 300m for towns. Streams, towns and roads

were taken into consideration so as to make the final site selected environmentally and economically acceptable. Table 4 shows the coordinates of the three suitable sites identified in Figure 17.

3.9 Final Site Selection Considering All Criteria in the Study Area

In order to successfully determine a final single site considered most appropriate for solid waste disposal, the conditional tool in G.I.S. was used. The following conditions were set: The site should be considerably large in size; it should not be too far from road networks; and lastly, it should be farther away from rivers/streams, settlements and populated areas. Figure 18 shows the final site selected for Solid Waste disposal in the study area. The site is located to the east of the study area and about 200 acres in size.

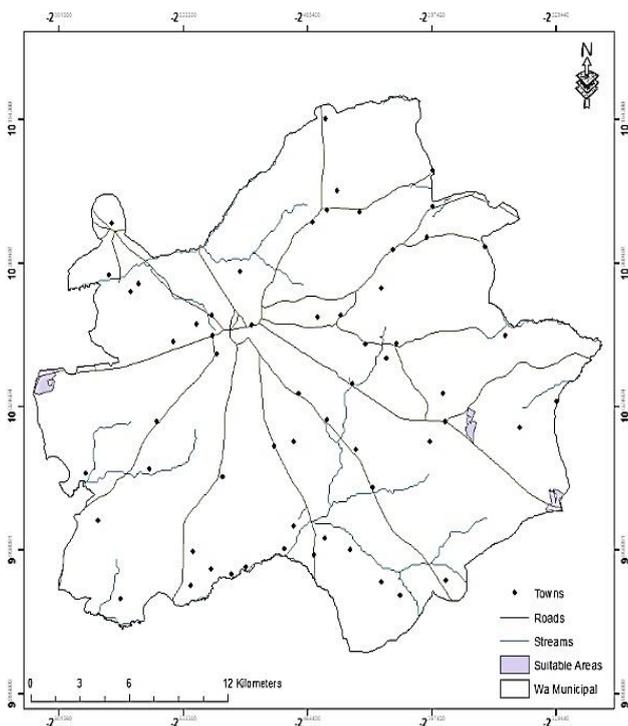


Figure 16: Map showing Suitable sites

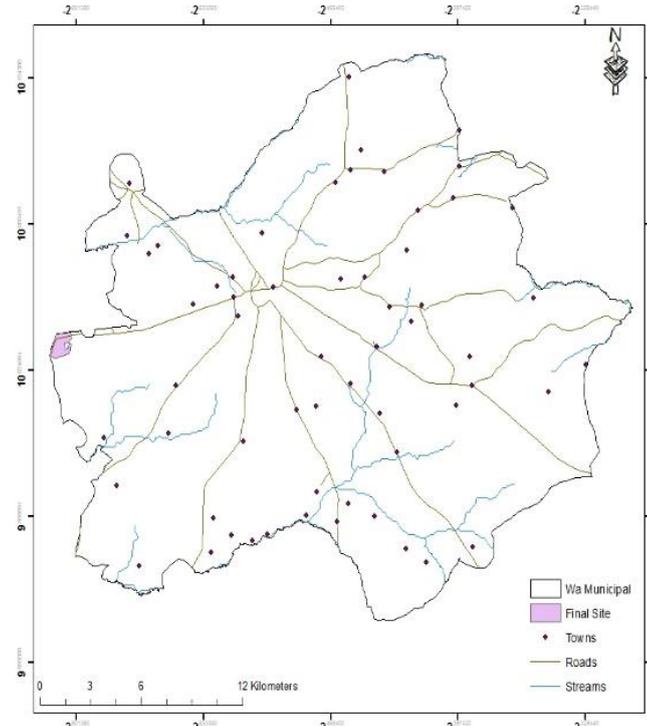


Figure 17: Map showing Final Suitable Site

3.10 Alternate Access Route to The Final Solid Waste Disposal Site

An alternative access route was further required to minimize traffic, as well as avoid delayed or hindered transportation of solid waste to the final site. These are situations likely to occur through unforeseen circumstances like collapsing culvert (Bridge), accidents or road construction activities.

Using the model builder approach, the study successfully selected an alternative route, considering slope, destination point, existing roads, and landuse, and using Wa Township as the central point (Figure 19). The model building process was executed using the cost distance analysis tool in ArcG.I.S. Figure 19 is a framework of the model builder process followed to identify the alternative route.

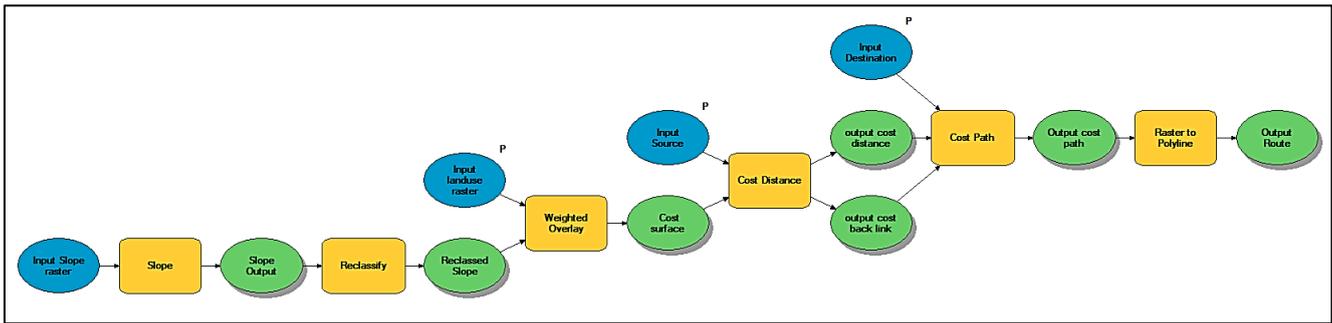


Figure 18: Model builder process for an alternative route

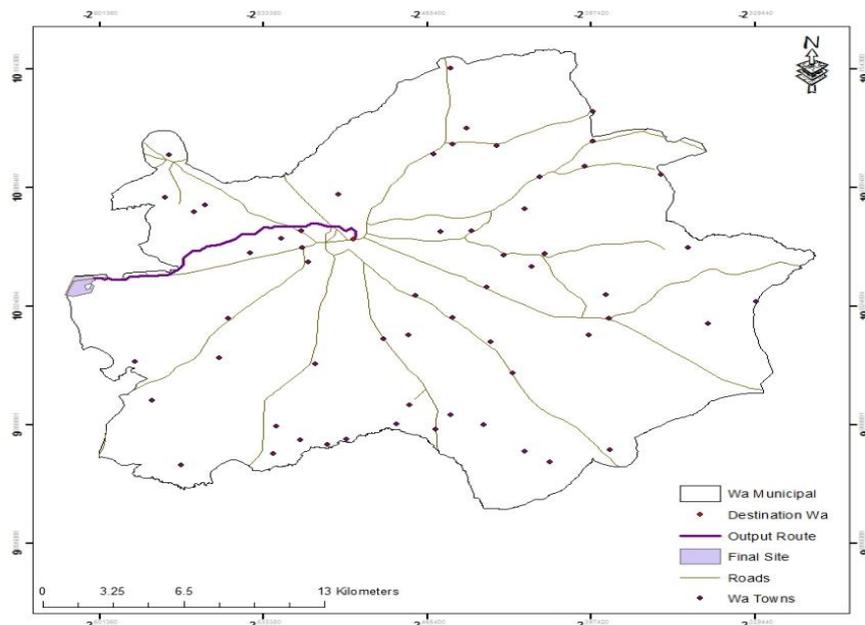


Figure 19: Map showing the best alternative route

4. CONCLUSION

The Analytic Hierarchy Process (AHP) and Multi-Criteria Decision Making (MCDM) techniques with the integration of Geographic Information System (G.I.S.) were used to perform analysis for solid waste disposal site selection, and the appropriate, most suitable site as well as a cost-effective alternative access route was identified in the study area. The alternative route could help to minimize traffic, and avoid delayed or hindered transportation of waste to final site due to unforeseen circumstances like collapsing culvert (Bridge), accident or road construction activities, etc.

Solid waste management is the most difficult challenge facing most municipalities around the globe, both developed and developing countries. Landfill is one of the simplest and cost-effective management systems employed in many parts of the world to safely dispose-off solid waste. The open dumping system practiced by many cities has for several years not been environmentally sound and socially acceptable mainly because of its wrongful siting.

Geology, soil type, landuse/land cover, slope, drainage pattern (water bodies), and roads were the criteria analyzed in selecting a suitable landfill within the study area. G.I.S.-based multi-criteria evaluation approach was employed to perform a spatial decision making process. The only available landfill designated for solid waste disposal in the study area was sited in a highly unsuitable location. G.I.S. based multi-criteria evaluation techniques was successfully able to identify first, second, and third suitable sites with less or no negative effects on the environment as well as on human health, for solid waste disposal. A final optimal site, considerably large in size, not too far from road networks and farther away from rivers/streams, settlements and populated areas was selected from the three suitable sites identified using the conditional and filter tools in model builder.

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