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# MCDM-GIS Based land suitability evaluation for Abattoir site: the case of Addis Ababa, capital city of Ethiopia

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***Abstract***

Abattoir is one of the important urban functions that need a suitable site to be compatible with the surrounding geographic features. Cities that have increasing population size having one abattoir is difficult to be accessible for all; especially in the city of Addis Ababa. In Ethiopia, there are limited research efforts that address the land evaluation for Abattoir through the AHP-GIS approach in Ethiopia particularly in Addis Ababa. In this study, MCDM-GIS-based approach was used to map suitable sites for Abattoir in Addis Ababa, the capital city of Ethiopia. To select and evaluate the site; ten physical and social criteria were used. All factor maps were geo-referenced and reclassified according to their suitability based on norms and standards of abattoir site selection. Weights for each criterion were assigned based on the Analytical Hierarchy Process using a pairwise comparison matrix. After assigning weights, all criteria were combined (WLC) to get the most suitable sites for the abattoir, and based on the overlay result a thematic map of the selected potential sites was produced. From the total study area, about 17.7% were found as the most suitable potential sites and they were grumped as 10; and 1.7% was unsuitable for abattoir sites. Thus, decision-makers should give due attention to social, economic, and environmental norms and standards to select abattoir potential sites to improve the environmental sanitation, abattoir service delivery, and wellbeing of the society at large.

**Key words**: Abattoir, Potential site, GIS, AHP, Ethiopia.

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## Introduction

Abattoirs are one of the important urban functions that need a suitable site to be compatible with the surrounding geographic features. However, they are observed being located at inappropriate sites posing environmental hazards to their surroundings and are also affected by some nearby activities. Abattoirs are livestock processing industries, located near the population and services (for Ethiopian case, usually within the municipal boundary of the corresponding cities and towns). The slaughterhouses as highly polluting as industries and seriously affect the environment so assigning important criteria for finding the appropriate location is a critical issue (Habibi, 2005). The activities involved in abattoirs pose environmental hazards to the neighboring areas. These are manifested in the form of liquid wastes, storm water contamination, solid wastes, airborne wastes, diseases, and noise (Environmental Protection Authority/EPA, 2002; World Health Organization /WHO, 1984). In some other situations such as in Gimbi town, abattoirs are built very close to water supply dams that the liquid waste disposed of joins the water, representing a serious hygienic hazard (NUPI, 1999). Conversely, abattoirs could be affected by certain nearby incompatible activities. Examples are industrial activities that emit smoke and dust. The most notable ones include; encroaching by other urban land uses (housing and commercial activities) through time dimension, being nearer to waste disposal site, and exposed to pollution (a typical example is Teppi town (NUPI, 1999), constructing within the central business center indicating serious incompatibility problems. Hence, the establishment of abattoirs at an appropriate site considers the identification of a large number of factors to make spatial decisions and the extent of the interrelationship among these factors and difficulties in decision making (Malczewiski, 1999). Many researchers had carried out studies on municipal abattoirs operation, the suitability of meat and byproducts, and the prevalence of cattle diseases in Ethiopia and the world at large. In addition to those researches, the Ethiopian Ministry of Urban Development and Construction (2010) conducted their own research at different small towns of Ethiopia and at Addis Ababa without a GIS tool application. Basically, geographic information technology is a means to make many types of work more efficient and works more effectively; it enables better decisions, based on better information (Antennuci, et al, 1990). Again Ethiopian Ministry of Urban Development, Housing and Construction (MUDHCO, 2013) conducted their own project at Addis Ababa by considering a few criteria such as accessibility of road, electric power, and water supply without considering other significant criteria like proximity to residence, fault line, reserved area, slope and other factors. They selected a site at Furi Hanna located in the southwestern part of the city in Nifas Silk lafto sub-city, particularly at South-West of the Hanna Mariam Church, but in this area there is faulting; so it reduces the life span of the abattoir service delivering activities. Another researcher, Aysheshim (2002) conducted his research on the application of GIS for urban planning in Ethiopia with particular reference to abattoir site suitability analysis for kulito town. In Addis Ababa city the demand and level of coverage of meat production in the city is increasing from time to time but the existing abattoir inaccessible for all butchers and users, hence illegal slaughtering is taking place in different parts of the cities. However, the city is suffers from inadequate infrastructure and deficient services to guarantee abattoir and with related problems like sanitation for the level of development expected by its status of country’s political and economic center. Furthermore, its establishment very near to city’s major settlement areas since it did not consider all the necessary criteria that modern abattoirs require during its establishment.  Moreover, it is associated with many other problems such as due to the effect of expansion, the existing abattoir engulfed particularly by new residential areas and become at the center; the waste products released from abattoir areas may pollute the environment and reduce the aesthetic value of the city so it makes the life of residences to be difficult as a result of high emission of bad odor.  Having in mind, all those associated challenges with the existing abattoir the city need other abattoir sites. Therefore the current study considered both the experience of NUPI and MCDM techniques supported by the GIS tool to select suitable sites abattoirs.

## MATERIALS AND METHODS

### Description of the Study Area

Addis Ababa was founded in1886, which is located in the central part of Ethiopia covering an area extent of about 540km$^2$ (54000ha.), with an average elevation of 2600m above sea level. Its geographic location is between $8^0 54' 00''$ and $9^0 6' 00''$ N, $38^0 42' 00''$ and $38^0 54' 00''$ E or 465000m and 485000m East; and 980000m and 1005000m North between latitude and longitude respectively figure 1.

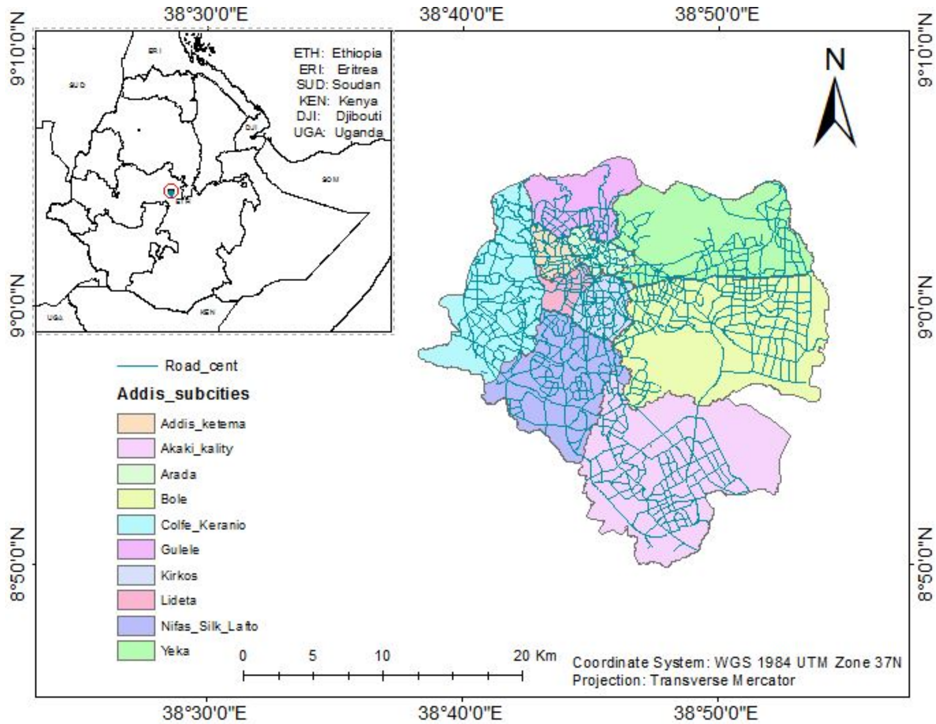

Figure 1: Location map of the study area.

The altitude of Addis Ababa varies between 2000 m at Akaki to 3200 m at Entoto. The prominent landforms around and in Addis Ababa are the Entoto ridge on the northern side, the flat and undulating landform inside the city, and the young volcanic mountains of Wechacha (3350 m asl), Furi (2850m asl) and Yerer (3099m asl) lying in the west, southwest, and southeast respectively. (Tsegaye, 1995). The two major rivers flowing in the city are Kebena (Big Akakai) on the east and Small Akaki on the west. These two rivers drain to the south and join Lake Abasamueal which is out of Addis Ababa (Tsegaye, 1995).

**Methodology**

**Data used and source.**

- Digital Soil map obtained from Ministry of Agriculture.
- Geological map of the area was collected from Ethiopian Geological Survey Agency (EGSA) in the form of hard copy.
- Land use/ cover obtained from Municipal Land Management Office.
- Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), 30m resolutions. were downloaded from United States geological survey (USGS) via FTP (http://glovis.usgs.gov) to delineate and characterize the watershed.
- Wind direction collected from National Metrological Agency.
- Protected areas (Gulele botanic garden, hospitals, schools areas etc. obtained by Digitized/extracted from the existing land use/land cover map of the study area.
- Airport map obtained from Ethiopian Civil Aviation

**Method**

Arc GIS Version 10.3 was used for developing the prototype database for the study area. The data were geo-referenced and the projection type was re-defined accordingly in the Arc GIS environment for further processing. Therefore, the geo-referenced data was manipulated and analyzed in Arc GIS to select the appropriate abattoir potential sites. Finally, the information was compiled from literature about the safe distances to an abattoir site to be used to determine the buffer zones for each layer. After creating the classes for each layer by using buffer zones, each layer was converted into individual raster maps and then reclassified. After the preparation of all input data layers, the method Analytical Hierarchy Process (AHP) was selected among the decision rules to analyze the data for abattoir site selection by using GIS, figure 2.

**Spatial Multi-Criteria Analysis Approach**

GIS-based Spatial Multi-Criteria Approaches (SMCA) was employed to identify the most suitable abattoir potential sites in the study area. There are several methods for deriving weights, among many; In this study, the weights were developed based on Analytical Hierarchy (AHP) method which developed by (Saaty, 1980) using a pairwise comparison matrix. A matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9, and the higher the weight, the more important is the criterion. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons, If CR > 0.10, then some pairwise values need to be reconsidered and the process is repeated till the desired value of CR < 0.10 is reached. The main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting conflicting objectives and its ability to detect inconsistent judgments using consistency ratio (CR). The factors and their resulting weights were used as input for the spatial multi-criteria evaluation (SMCE) technique for the weighted linear combination of overlay analysis (Malczewski, 1999).

**Weighted Linear Combination (WLC) in the GIS Environment**

Weighted Linear Combination (WLC) was used to evaluate the suitability of abattoir sites. The approach allows the decision-maker to assign weights according to the relative importance of each suitability map and combines the reclassified maps to obtain an overall suitability score. WLC implemented via the following four steps. The first step is the determination of data, the second step is the development of attributes of criteria and their standardization, the third step is the determination of the relative importance weights, and at final step is overlay analysis/combining of all criteria used in this study to find the most suitable sites for abattoir potential sites (Malczewski, 2004).

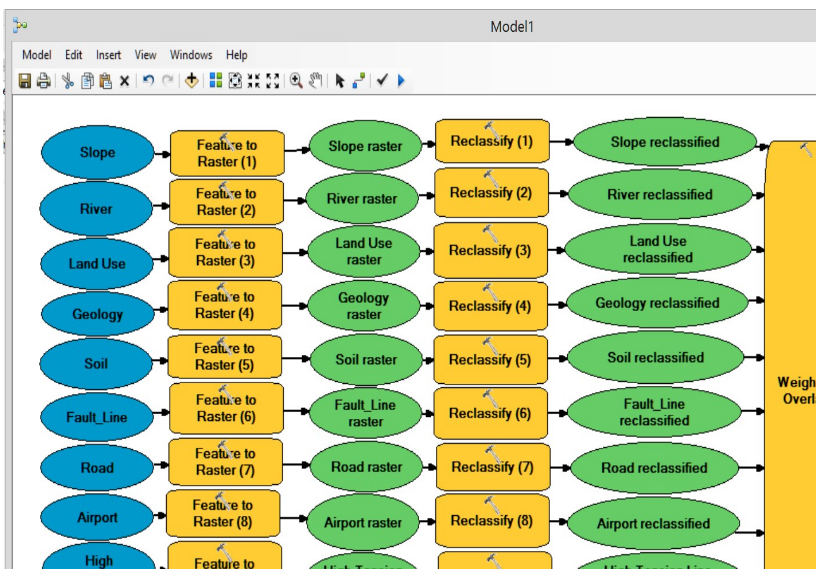


**Figure 2: Procedures to select abattoir potential sites.**

**Evaluated Criteria**

Abattoir site selection studies depend on the natural and legal conditions of an area. In this regard the criteria and principles considered in this study were divided into three broad classes namely, physical (slope, geology, soil, drainage, borehole, etc.), environmental (protected areas), and socio-economic criteria (road network, residential and land use land cover).

**Slope of the Study Area**

In this study, slope factor was generated from DEM using the ArcGIS spatial analyst extension of the surface module, which enabled to classify of the area according to the steepness and the gentleness of the terrain. The Slope function could calculate the maximum rate of change between each cell and its neighbors. Every cell in the output raster had a slope value. The lower the slope value, the flatter the terrain was, and the higher the slope value the steeper was the terrain. Then the slope raster was reclassified into four classes of slope percent by examining the value and the frequency of slope percent in the study area. The reclassified slope was given a rank value 1 to 4 with a higher value of 4 showing highly suitable, while the lower value of 1 showing unsuitable, Table 1. Thus, as recommended by (LMA, 2000) the desired slope for the abattoir site is suggested to be near to the gently sloping area, which ranges from 4 to 12 percent.

Table 1: Slope suitability and area coverage

| S.n | Slope class (%) | Suitability | Rank | Area (ha.) | Area (%) |
|---|---|---|---|---|---|
| 1 | 0-4 &>25 | UNSUITABLE | 1 | 7950 | 14.7 |
| 2 | 4-12 | HIGHLY SUITABLE | 4 | 20650 | 38.2 |
| 3 | 12-25 | SUITABLE | 3 | 21850 | 40.5 |
| 4 | 25-30 | MODERATELY SUITABLE | 2 | 3550 | 6.6 |
| Total | | | | 54,000 | 100 |

From the table 38.2%, 40.5% and 6.6% of the total area are highly suitable, suitable and moderately suitable for abattoir site respectively. The remaining part of the area (14.7%) is unsuitable for abattoir; this shows that the area is steep and very flat.

**Hydrology of the Study Area**

The abattoir site must not be located in close proximity to surface water. The criterion is important from the point of view of both environment and economic concerns because, in addition to causing pollution problems, it may require an efficient drainage system with high expenses. The streams/river factor was generated from the digital elevation model (DEM) using the ArcGIS spatial analyst extension of the hydrology module. Then it was buffered based on the 100m distance standard criteria set by EPA, 2002, to locate abattoirs from critical environmental resources such as streams/rivers. Thus, four buffer zones have been drawn around streams and rivers, and relative suitability rank was assigned; buffers far to rivers are more suitable, while buffers near to streams are unsuitable. A rank value of 4 was given to a distance of > 150 m, while a rank value of 1 was given to distances of < 100 m (table 2).

 

Table 2: Rivers/ Streams suitability and area coverage

| SUITABILITY CLASS | RANK | DEGREE OF SUITABILITY | AREA (HA.) | AREA (%) |
|---|---|---|---|---|
| **< 100M** | 1 | Unsuitable | 11830.5 | 21.9 |
| **100M – 150M** | 2 | Moderately suitable | 7102.5 | 13.2 |
| **150M – 200M** | 3 | Suitable | 7343.5 | 13.6 |
| **> 200M** | 4 | Highly suitable | 27723.5 | 51.3 |
| **TOTAL** | | | 54,000 | 100 |

From table 2, 11830.5 hectare (21.9%) of the study area was excluded from the siting processes due to the vicinity to the streams and rivers and hence unsuitable for the abattoir and given a 1 value, the area covers 7102.5 hectare (13.2%) of the study area is moderately suitable and given 2 value, the area of 7343.5 hectare (13.6%) of the study area is suitable and given 3 value. An extent of 27723.5 hectares (51.3%) of the area is highly suitable for abattoir siting because of the minimum effect on surface water due to the area is far from the river.

**Land use /Land Cover of the Study Area**

From the land use map of the study area use map 23 land are identified then the land use vector map is then converted to a raster map, and then land-use types are grouped and ranked according to their suitability for abattoir site according to user-defined membership.

**Land use Suitability Analysis**

The classification of urban land use/land cover involves the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. Then each of the land use/cover types was reclassified into 4 classes based on their importance to evaluate suitable sites to locate abattoir for overlay analysis. According to UNEP (2005), low economic value lands ( i.e. open space and agricultural lands are more preferable for the location of abattoirs than residential, commercial, industrial and other related high economic value land this is mainly due to the low cost of acquisitions. Thus, open spaces are ranked as most suitable; agriculture is ranked as moderately suitable; forest lands, are ranked as suitable; urban services and built-up lands, are ranked as least suitable. The following (Table 4) shows the land use suitability classes and area coverage in hectares and percentages respectively.

Table 3 : Land use suitability classes and area coverage

| No | Suitability classes | Suitability rank | Area in (ha.) | Area in (%) |
|---|---|---|---|---|
| 1 | Highly suitable | 4 | 5,023.5 | 9.3 |
| 2 | Suitable | 3 | 14,966.7 | 27.7 |
| 3 | Moderately suitable | 2 | 5,793.8 | 10.7 |
| 4 | Unsuitable | 1 | 28,216 | 52.3 |
| **Total** | | | **54,000** | **100** |

Source: Reclassified land use map attribute table.

Based on the above land-use suitability, from the land-use suitability point of view, the largest part of the study area (52.3%) was found as unsuitable for abattoir sites whereas, 9.3% and 27.7% of the areas were highly suitable and suitable respectively. The remaining 10.7% of the study area was found moderately suitable for Abattoir sites. The data displayed on the above land-use suitability table was extracted from the land use reclassified map of the attribute table and the data was converted into the respective units of measurements.

**Geology of the Study Area**

Addis Ababa is located in the western margin of the rift valley and consists of different volcanic rocks that range from basic to acidic composition. According to the geological survey the largest part of the study area is covered by Ti3- Wchecha–Yerer- Furi Ignimbrite (25.6%) which is found in the Eastern, central, and southwestern parts. The second most available geological unit which is found in the southern and northern parts of the study area is Qb-Quaternary Basalt (18%), and the third dominant geological unit is Repi Basalt (15.4%) that covers western, northern, and central parts of the study area. The least geological units of the study area are found in the southern parts namely Qsc-Quaternary Scoria (0.3%), Qs -Quaternary eluvial sediments in the south (0.5%), and Ts-Tertiary Sediments (1.4%).

**Geology Suitability of the Study Area**

Geology is one of the important environmental factors that should be considered during abattoir site selection processes. Geological suitability helps to identify permeability, faults, consolidation of the rocks, and other related factors of the geological units of the study area. The geological units of the study area were reclassified into four suitability classes in the Arc GIS environment using spatial analyst tools (reclassify tool). During the reclassification phase, the required weights were assigned based on (Erosoy and Bulut,2009), geological unit's suitability standard. The suitability of the geological units of the study area ranges from highly suitable to unsuitable and the highest weight (4) was assigned to highly suitable and the lowest value (1) was assigned to unsuitable geological units for abattoir sites selection (Table 6).

Table 4: Geological suitability ranges and area coverage of the study area.

| GEOLOGICAL SUITABILITY RANGES | SUITABILITY RANK | AREA IN (HA) | AREA (%) |
|---|---|---|---|
| HIGHLY SUITABLE | 4 | 34560 | 64 |
| SUITABLE | 3 | 13500 | 25 |
| MODERATELY SUITABLE | 2 | 1242 | 2.3 |
| UNSUITABLE | 1 | 4698 | 8.7 |
| | | 54,000 | 100 |

Source: Extracted from reclassified geology map of attribute table.

From the above geological units suitability (Table 6), the largest part of the study area (64%) was covered by consolidated geological units and was considered as highly suitable for abattoir sites, 25% was suitable, and 2.3% of the area was moderately suitable, and the remaining area of 8.7% from the total study area was unsuitable for abattoir sites.

**Soil type of the study area**

According to the Ministry of Agriculture (2007), the soil of Addis Ababa is classified into seven categories namely chromic vertisols, pellic vertisols, calcic xerosols, chromic luvisols, eutric nitisols, leptosols, and ortic solonchaks. Each soil type and its areal coverage are clearly shown in the following soil map of the study area. Each of the soil type area coverage was extracted from the respective attribute table in the Arc GIS environment. The soil types and area coverage of the study area are clearly presented in the following (Table 7) below:

Table 5: Soil types and area coverage of the study area:

| No. | Soil types | Area in (ha.) | Area in (%) |
|---|---|---|---|
| 1 | Pellic Vertisols | 27,914.5 | 51.7 |
| 2 | Chromic Vertisols | 4,626.4 | 8.6 |
| 3 | Calcic Xerosols | 4,176.9 | 7.7 |
| 4 | Chromic Luvisols | 1,365.9 | 2.5 |
| 5 | Eutric Nitisol | 11340.5 | 21.0 |
| 6 | Leptosols | 469.9 | 0.9 |
| 7 | Ortic Solonchaks | 4105.9 | 7.6 |
| Total | | 54,000 | 100 |

**Soil Suitability**

The physical characteristic of the soil of the study area is one of the main criteria to select abattoir sites. The physical properties of Vertisols in Ethiopia generally contain more than 40% clay in the surface horizons and close to 75% in the middle part of the profiles. The sand fraction is low, often less than 20%, and is found in the bottom and the surface (plough layer) horizons (Berhanu, 1985). Leptosols of the study area characterized by very thin soils over continuous rock and soils that is extremely rich in coarse fragments (FAO, 2013). On the other hand, Luvisols has higher clay content in the subsoil than in the topsoil, as a result of pedogenetic processes (clay migration) leading to an argic subsoil horizon in the 50 – 100 cm depth (FAO, 2013). Nitisols are deep, well-drained, and contains 30% of clay contents as well as high aggregate stability. The deep and porous solum and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion and good internal drainage and fair water-holding properties. Solonchaks have a high concentration of soluble salts and a clay poorer surface soil over a clay richer nitric horizon that has mostly a columnar structure (FAO, 2013).

**Table 6: Soil suitability classes and area coverage**

| No. | Soil suitability classes | Suitability rank | Area (ha.) | Area (%) |
|---|---|---|---|---|
| 1 | Highly suitable | 4 | 32,520 | 60.2 |
| 2 | Suitable | 3 | 12,632.4 | 23.4 |
| 3 | Moderately suitable | 2 | 4,235.1 | 7.8 |
| 4 | Unsuitable | 1 | 4,612.5 | 8.6 |
| Total | | | 54,000 | 100 |

Source: Reclassified soil map attribute table.

According to the different researchers, for example, Abdoli, 1993, as the amount of soil permeability increase, the suitability site will decrease because the very high permeable soils are vulnerable to erosion it reduces the life span of the abattoir and the most probable the movement of liquid waste which is produced from this industry to pollute the environment, so the highest value (4) was assigned to Vertisols because of their high clay content properties and low permeability of water and other liquid pollutants like leachates down to the ground. Therefore, based on the above soil suitability (Table 8) shows, areas covered by Vertisols (60.2%) were considered as highly suitable for abattoir sites. The second highest soil suitability value (3) was assigned to Eutric Nitisols and Chromic Luvisols because physically these types of soils are characterized by high stability but less clay contents than Vertisols. Areas covered by these types of soils (23.4%) were taken as suitable areas for abattoir while, the lowest soil suitability value (1) was assigned to Leptosols and Calcic Xerosols because physically they are characterized by very thin soils over continuous rock and extremely rich in coarse fragments. The coarse texture of soil has high permeability of water and aggravates groundwater contamination by liquid wastes. Therefore, areas covered by these types of soil (8.6%) were found to be unsuitable for abattoir sites. The remaining areas covered by Orthic Solonckaks soils (7.8%) were found to be moderately suitable for abattoir sites.

**Fault Lines**

There are a number of faults most of which have a sub-parallel trends as the main Ethiopian rift fault in the study area. The major faults running east-west via Kesem to Ambo crossing Addis Ababa were the longest fault in the area. The faults trend in the direction of NE to SW and the rocks along this fault are brecciated. There are some faults in the direction of NW trachytic and basaltic dikes are oriented in the direction of NE, NNE, and very few in EW (Assegid, 2007). Faults can pose serious environmental threats in general and reduce the life span of the Abattoir in particular. GIS was used to generate multiple buffers around each fault and an extent of 1000m around the abattoir was taken as the minimum buffer zone. Abattoir should be away from faults (Akbari, 2008). Based on (Rafiee et al., 2011) the study area proximity buffer distance was performed based on the standard areas found within 1000m buffer distance from faults were considered as unsuitable for abattoir sites because of the high permeability of soil near the fault and to protect groundwater contamination from liquid waste which is produced from this industry. Whereas, areas above 1000 m proximity distance were classified as moderately suitable, suitable, and highly suitable with an increase in proximity buffer distance respectively.

**Fault Suitability of the study Area**

The fault suitability analysis was determined based on Rafiee *et al*., (2011) fault suitability classification.

**Table 7**: Sites to fault proximity suitability classes and area coverage:

| No. | Suitability classes | Suitability ranks | Buffer distance in (meters) | Area in (ha.) | Area in (%) |
|---|---|---|---|---|---|
| 1 | Highly suitable | 4 | >3000 | 13915.3 | 25.7 |
| 2 | Suitable | 3 | 2000 – 3000 | 11811.5 | 21.9 |
| 3 | Moderately suitable | 2 | 1000 – 2000 | 14127.8 | 26.2 |
| 4 | Unsuitable | 1 | 0 – 1000 | 14145.4 | 26.2 |
| Total | | | | 54000 | 100 |

Source: Extracted from reclassified fault map attribute table.

Based on the above fault proximity suitability (Table 9), 25.7% was highly suitable and 21.9% of the area was suitable whereas, 26.2% of the study area was found as moderately suitable and likewise, 26.2% of the area was unsuitable for abattoir sites. During the suitability reclassification phase the highest rank/weight was assigned to a buffer distance greater than 3000m and the lowest rank/weight was given to unsuitable areas.

**Road Network**

Road is also an important criterion in site suitability analysis. The need to transport processed meat, carcasses, slaughter animals, etc. is dependent on the proximity to the transportation facilities. Therefore, efforts were made to locate the site nearer to any existing road if possible but not suited less than 20m in order to avoid traffic congestion. Moreover, in order to find out better accessibility to the existing road, buffer zones have been created by taking distances between 20 to 400 meters from the existing major roads (EPA, 2002; LMA, 2000) to generate a suitable accessibility map. Then the buffer distance zones have been categorized into four levels based on the level of proximity to the abattoir site. Accordingly, the low buffer distance ranked as highly suitable whereas the longer and the very extreme nearest buffer distances ranked as the least suitable. Thus, the rank value of 4 was given for highly suitable road buffers and the rank value 1 was given for unsuitable road buffers (Table 10).

 

Table 8: Sites to road network proximity suitability classes and area coverage

| Suitability Class | Rank | Level of suitability | Areal (ha) | Area (%) |
|---|---|---|---|---|
| 20- 400m | 4 | Highly suitable | 35370 | 65.5 |
| 400m - 800m | 3 | Suitable | 12474 | 23.1 |
| 800m - 1200m | 2 | Moderate Suitable | 3942 | 7.3 |
| <20m &>1200m | 1 | Unsuitable | 2214 | 4.1 |
| **Total** | | | **54000** | **100** |

Source: Extracted from reclassified road map attribute table.

Based on the above road network proximity suitability (Table 10) shows from the total study area 65.5% and 23.1% were found as highly suitable and suitable respectively while, 4.1% of the area was unsuitable. The remaining 7.3% of the study area of road proximity is moderately suitable for Abattoir sites.

**Airport**

The proximity distance was determined based on Ayat (1994) and USEPA (2004), protected areas norms, and standards. Therefore, based on the standards areas found within 5000 meters from the airport were considered as unsuitable because there is the slaughter related organic wastes in the site and attracts various types of birds around and affect the flight process. This issue may interfere with the operation of airplanes. So it is essential to consider a suitable distance from the abattoir site according to airport and airplane types (Daneshvar, 2004). On the other hand, to protect such kinds of constraint areas above 9000 meters from the Airport were taken as highly suitable for abattoir sites for safety matters, 5000m buffer around the airport was omitted.

Table 9: Sites to Airport proximity suitability classes and area coverage:

| SUITABILITY CLASSES | BUFFER DISTANCE IN METERS | AREA IN (HA) | AREA(%) |
|---|---|---|---|
| HIGHLY SUITABLE | >9000 | 19,931.40 | 36.9 |
| SUITABLE | 7000 - 9000 | 11,724.60 | 21.7 |
| MODERATELY SUITABLE | 5000 - 7000 | 9,484.10 | 17.6 |
| UNSUITABLE | 0 – 5000 | 12,859.90 | 23.8 |
| TOTAL | | 54000 | 100 |

Source: Extracted from reclassified Airport map attribute table.

Based on the above Airport suitability (Table 11), the largest part of the study area was covered by highly suitable class (36.9%), 21.7% of the area was suitable and 17.6% of the area was moderately suitable whereas, 23.8% of the study area was unsuitable for abattoir sites.

**High tension lines**

These are power transmission lines. According to LMA, 2000, EPA, 2000, and UPI experience; to alleviate or avoid possible accidents that could be encountered because of big flying birds (e.g. scavengers) hovering over the abattoir, the site should be located at least 500 meters far away from high tension lines. By considering these suggested values, the safe distance for the high tension line was determined as a minimum of 500m far away from the abattoir site; so the suitability is increasing with increasing distance away from the high tension line. Therefore areas having more than 1000 meters from the high tension line were taken as highly suitable for abattoir sites for safety matters; areas within5000m buffer along the high tension lines were omitted.

Table 10 : Sites to high tension line proximity suitability classes and area coverage

| Suitability classes | Buffer distance (meters) | Area (ha.) | Area (%) |
|---|---|---|---|
| Highly suitable | >1500 | 20162 | 37.3 |
| Suitable | 1000- 1500 | 9560 | 17.7 |
| Moderately suitable | 500 - 1000 | 10723 | 19.9 |
| Unsuitable | 0 – 500 | 13555 | 25.1 |
| **Total** | | **54000** | **100** |

Source: Extracted from reclassified Airport map attribute table.

Based on the above high tension line suitability (Table 12) shows; the largest part of the study area was covered by highly suitable class (37.3%), 17.7% of the area was suitable and 19.9% of the area was moderately suitable whereas, 25.1% of the study area was unsuitable for abattoir sites.

**Borehole proximity**

The Ground water well points which are existing in use for drinking purpose were demarcated by AWSA. Proximity of abattoir site to a groundwater well is an important environmental criterion in the abattoir site selection so that wells may be protected from the runoff and leaching of the waste products from abattoirs. As some sources suggested that the location of abattoir sites should be 500m far from the groundwater wells. This factor was given a weighting of 0.07 to increase its importance of protecting the groundwater from pollution in addition to its direct influence on the community. Contamination of ground/surface water resources by waste is a principal concern in relation to abattoir site (Ekmekcioglu *et al*., 2010). By considering the contamination, the abattoir far from the water well and the minimum buffer zone is 500m and the suitability was increased with increasing distance. The study area was classified into 0-500m, 500-800m, 800-1200m and >1200m.

Table 11: Sites to borehole proximity suitability classes and area coverage:

| S.N | Buffer distance(m) | Suitability | Rank | Area (ha.) | Area (%) |
|---|---|---|---|---|---|
| 1 | 0-500 | Unsuitable | 1 | 9744 | 18 |
| 2 | 500-800 | Moderately suitable | 2 | 10627 | 19.7 |
| 3 | 800-1200 | Suitable | 3 | 13184 | 24.4 |
| 4 | >1200 | Highly suitable | 4 | 20445 | 37.9 |
| Total | | | | 54000 | 100 |

From the table, 37.9% of the total area is given more weight as highly suitability for the abattoir site. However, 18% of the total area is unsuitable as near to borehole and hence excluded from siting processes. Generally, the suitability levels and weights were increased as one move away from the borehole site. As a result, 24.4% and 19.7% of the total area were suitable and moderately suitable respectively. According to their weight, the borehole proximity map of the study area was standardized and a suitability map was prepared.

**Assigning Weight Using Pairwise Comparison Matrix**

In this phase, the researcher combined all the reclassified criteria in order to find the most suitable abattoir sites in the study area. The criteria being considered in this study couldn't have an equal degree of importance therefore; in this case, the importance of each criterion in relative to the other criteria for abattoir sites was determined. In this study weights for the criteria used to select abattoir potential sites were assigned and standardized based on the Analytical Hierarchy Process (AHP) which developed by Saaty, (1980) using a pairwise comparison matrix. Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion. In this approach, the decision-maker has to express his opinion about the value of one single pairwise comparison at a time.

The values of the pairwise comparisons in the AHP are determined according to the scale introduced by (Saaty, 1980). According to this scale, the available values for the pairwise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}. First provide an initial matrix for abattoir potential sites selection pairwise comparisons in which the principal diagonal contains entries of 1, as each factor is as important as itself. During assigning values in the matrix, the upper triangle holds the importance level of a row variable as compared to the column. The lower triangle is the reciprocal of the upper one. All possible combinations of two or more factors were compared based on expert judgment to prepare a pairwise comparison matrix. Table 15, below shows a pairwise comparison matrix for variables being considered and their relative weights.

Table 12: Weights of the criteria using pairwise comparison matrices

| CR | LU | DR | AP | RD | SL | BH | HT | FT | GL | SO | $n^{th}$ root | Eigenvector | Weight (%) | Normalization | N/E(Av) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LU | **1** | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 5 | 2.505 | 0.212 | 21 | 2.207 | 10.459 |
| DR | 1/2 | **1** | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 5 | 2.094 | 0.176 | 18 | 1.911 | 10.861 |
| AP | 1/2 | 1/2 | **1** | 1/3 | 2 | 2 | 2 | 3 | 3 | 3 | 1.335 | 0.113 | 11 | 1.233 | 10.909 |
| RD | 1/2 | 1/3 | 3 | **1** | 2 | 2 | 2 | 3 | 3 | 3 | 1.597 | 0.135 | 13 | 1.515 | 11.221 |
| SL | 1/3 | 1/2 | 1/2 | 1/2 | **1** | 2 | 2 | 1/3 | 3 | 3 | 0.933 | 0.077 | 8 | 0.855 | 11.104 |
| BH | 1/3 | 1/2 | 1/2 | 1/2 | 1/2 | **1** | 2 | 1/3 | 3 | 5 | 0.855 | 0.072 | 7 | 0.803 | 11.153 |
| H T | 1/3 | 1/3 | 1/2 | 1/2 | 1/2 | 1/2 | **1** | 1/3 | 3 | 3 | 0.707 | 0.060 | 6 | 0.620 | 10.403 |
| FT | 1/3 | 1/3 | 1/3 | 1/3 | 3 | 3 | 3 | **1** | 2 | 2 | 1.029 | 0.087 | 9 | 1.060 | 12.226 |
| GL | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1/2 | **1** | 2 | 0.464 | 0.039 | 4 | 0.422 | 10.821 |
| SO | 1/5 | 1/5 | 1/3 | 1/3 | 1/3 | 1/5 | 1/3 | 1/2 | 1/2 | **1** | 0.346 | 0.029 | 3 | 0.312 | 10.759 |
| **Total** | | | | | | | | | | | 11.865 | 1 | 100 | 10.938 | 109.916 |

Where, CR= Criteria, LU = Land use, HT= High tension line, BH = Borehole, DR= Drainage, SL = Slope, SO= Soil, GL= Geology, FT = Faults, AP = Airport, RD = Road and Av = Average

Eigenvector = the value of $n^{th}$ root1/$\Sigma n^{th}$ roots….$n^{th}$ root n/$\Sigma n^{th}$ root: where, $n^{th}$ root is each value of $n^{th}$ root and $\Sigma n^{th}$ root is the sum total of $n^{th}$ root. In our case (n) is number of matrix as it is indicated in the above table 4.16, it is 10 by 10 matrix therefore, the value of (n) = 10

Mean average/Lamda max (λ): Σ(N/E)/n = 109.9/10 = 10.99 where, N is each value of Normalization and E is also each value of Eigenvector Weight.

Consistency Index (CI) = (λ - n)/(n-1) = (10.99-10)/(10-1) =0.99/9 =0.11

CR = CI/RI = 0.11/1.49= 0.07

Where, CI = consistency index for a matrix, n = number of matrices, and RI = the corresponding index of consistency for random judgments from (saaty, 1980) AHP model, for 10 by 10 matrix the index from the table is 1.49. Based on the above Eigenvector weights (Table 4.16), Land use is the most important determinant factor of all other criteria to select abattoir sites in the study area and its Eigenvector weight was 21% because it is a very critical issue in a certain place; especially in Addis Ababa and all other factors are included under land use/cover of the study area. The second most important factor was a drainage of the study area with an Eigenvector weight of 18% because they should be free from contamination while the least important criteria employed in this study were geology and soil of the study area with Eigenvector weights of 4% and 3%

respectively. Saaty (1980), argues that a CR < 0.1 indicates that the judgments are at the limit of consistency and >0.1 indicates the judgments are out of the consistency limit as a result of this, the pairwise values/weights need to be reconsidered and the process is repeated till the desired value of CR < 0.1 is reached. In our case, the calculated CR value was 0.07 or 7% and found within the consistency limit and the value judgments were consistent; i.e. in this study CR = 0.07 which is less than 0.1, so the weight which given for each criterion were more reasonable.

Weighted overlay analysis is a process of combining all the standardized and weighted criteria used in the analysis to get the intended outcomes; in our case potential sites for abattoir in Addis Ababa.

**Weighted Overlay Analysis**

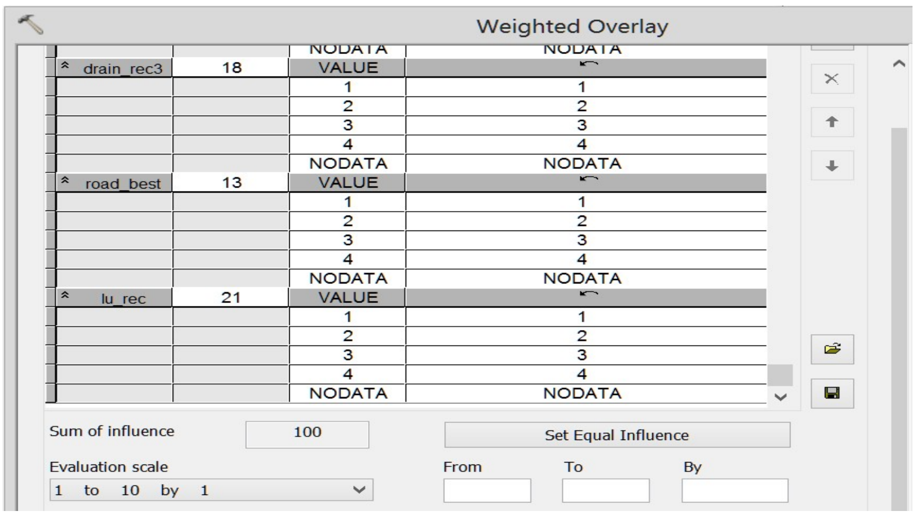


**Figure 3: Weighted Overlay Table.**

**Result and discussion**

The analysis of the weight assignment shows that land use/cover and water related factors are more influential than other factors (Table 4.16), because land use/covers are more critical issue in any place; specially in mega cities like Addis Ababa (NUPI, 1999b) and it is important to protect water from contamination of wastes Ersoy and Bulut, 2009, in this case from abattoir related waste. WLC result showed four classes of suitability level. These are unsuitable, moderately suitable, suitable and highly suitable (Table 13).

Table 13: Weighted Overlay results suitability classes and area coverage:

| SUITABILITY CLASS | VALUE | COUNT | AREA (HA) | AREA (%) |
|---|---|---|---|---|
| **UNSUITABLE** | 1 | 10,200.00 | 918.00 | 1.70 |
| **MODERATE SUITABLE** | 2 | 154,200.00 | 13,878.00 | 25.70 |
| **SUITABLE** | 3 | 329,400.00 | 29,646.00 | 54.90 |
| **HIGHLY SUITABLE** | 4 | 106,200.00 | 9,558.00 | 17.70 |
| **TOTAL** | | 600,000.00 | 54,000.00 | 100.00 |

Source: Extracted from reclassified Weighted overlay result map attribute table.

The value shown on the above table was derived from the site suitability map. The count values represent the number of pixels in each suitability class. Since a pixel has 30m*30m spatial coverage, it represents an area equals to $900m^2$ which is about 0.09 hectare when it was converted. Thus, the total number of pixels multiplied by 0.09 hectare would result 54000 hectare area. Based on the Weighted Overlay result suitability (Table 13), from the total study area 1.7% were found as unsuitable for abattoir potential sites; because these areas were unable to fulfill the important criteria or norms and standards formulated by (USEPA 2004) and (Rafiee *et al.,* 2011) for abattoir site. According to this standard abattoir potential sites must not be within 500 meters of borehole and high tension line, 100m from surface water, it should also be away from faults (Akbari, 2008) i.e. it should not be within 3000m from fault line and 5000m from airport areas; because in one hand to avoid opposition from different groups and on the other hand in order to maintain its life duration. Therefore, based on the standard; areas far away from the protected area but near to some infrastructure like road are more preferable for abattoir site, but these areas couldn't satisfied such criteria. In addition to this, the identified unsuitable sites were unable to meet land use norms and standard (lack of low economic value lands like open space and agricultural areas etc.) which proposed by (UNEP, 2005).This mean that sites with potential for higher economic value and uses; such as natural conservation, built-up area and residential development should not be used for Abattoir (Ekmekcioglu *et al*., 2010). After eliminating the above mentioned land, only 17.7% of the study area could be identified as most suitable together with their few limitations. The identified highly suitable areas were fulfilled the physical criteria (like geology, drainage, soil etc.), social and economic criteria (proximity to roads, Airport, etc.) and environmental criteria (conservation area, proximity to fault, borehole etc.) norms and standards used in the analysis part of this study. Therefore, based on overlay analysis result most of the highly suitable abattoir sites are suited in the eastern, southeastern, northeastern, some part of central and western part of the study area (Fig. 5).

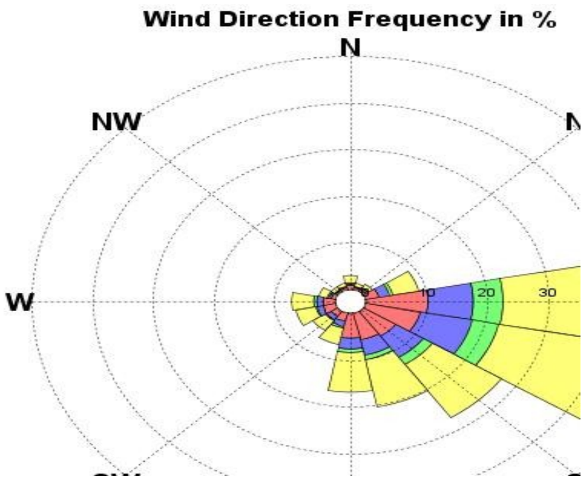


Figure 4: Wind direction frequency in (%) of the study area (source: Addis Ababa Observatory wind rose diagram from 1990 -2015).

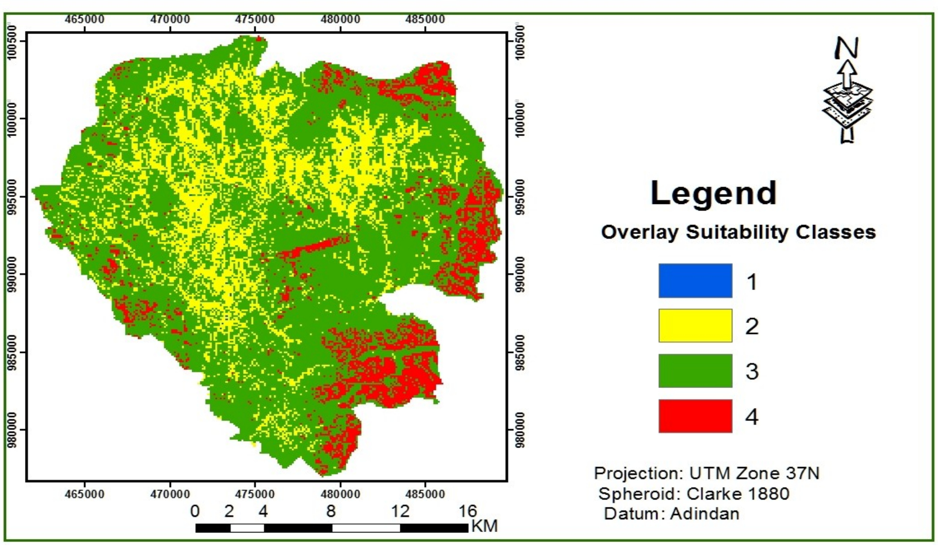


Figure 5: Weighted overlay result map of the study area.

 

From the overall suitable area it is important to give ranks by considering all the criteria to be satisfied, figure 6; from the figure the 1st suitable abattoir should be identified most preferably from the eastern part in Bole sub-city wereda10 particularly its local place is "Bole Arabssa", the 2nd and the 4th are from the northeastern and northern part of the study area respectively ( in yeka sub city woreda 12), the 3rd is from southeast in Akaki-kality sub city and the 5th site is selected from the boarder of Kolfe-keraniyo and Nifas-silk lafto sub cities (checked by taking x & y coordinates using GPS), because they satisfy the most important criteria like the requirement of the abattoir size, the criteria designed with respect to settlement, i.e. the abattoir should be planted 2 km away from residential areas and social services (Ethiopian standard basic requirement ES, 1118: 2005), borehole and surface water related criteria and others. Wind direction is also an important factor for abattoir suitability analysis. The abattoir shall be on the leeward of residential areas and social services (Ethiopian standard basic requirement ES 1118: 2005) hence these sites except a site which is located at the western part of the study area (AB_5) are found opposite to the blowing of wind direction so they couldn't affect the resident of the city and the environment at large, but AB_5 needs a special care to manage the produced odor during and after construction of abattoir. According to the national Metrological data (1990-2015) the wind of Addis Ababa is mainly blown from west to east (see figure 6), so these sites are the most suitable for abattoir not only in this regard but also other stated evaluated criteria. A site which is found in the southern part of the study area (southern Akaki / AB_11) has given the least rank among the selected area because this part of the study area is a potential source of ground water for the city and its surroundings and also it is very close to the industrial zone, but the plant shall be 2 km away from residential areas, social services and pungent or objectionable odor emanating industries (Ethiopian standard basic requirement ES 1118: 2005), so it needs a special care for abattoir site to protect ground water from contamination which is related to abattoir waste and for hygienic purpose. The remaining ranked sites are illustrated in (figure 6) while, the rest parts of the study area including the existing abattoirs were found as unsuitable for the abattoir sites and unable to fulfill the standards of abattoir potential site selection. Even though moderately suitable and suitable sites of the study area shown in the Weighted Overlay result unable to meet the most suitable class standards of the criteria used in this analysis, they can be used as the last alternative potential sites for abattoir.

Generally, the ranked map showed that Akaki sub-city took the largest area coverage (40.2%) followed by Bole (28.7%) and Yeka (8.3%) sub-cities respectively. From the total area of Akaki Sub- city 60.3% was found as highly suitable for abattoir; the remaining area is found close to the ground water well and industrial zone. In the case of Bole; out of the total area 75% was highly suitable; the remaining sites are very close to population density, governmental and non-governmental organization. The selected potential sites were bare lands and covered by agricultural activities. The result of this study shows that areas in the remaining sub-cities like Addis Ketema, Arada, Lideta, Gulele and Kirkose sub cities had not suitable for the abattoir sites. Because these areas were unable to fulfill the social and environmental standards of the criteria used in this analysis. Therefore these sub cities can get services from the nearby abattoir industry.

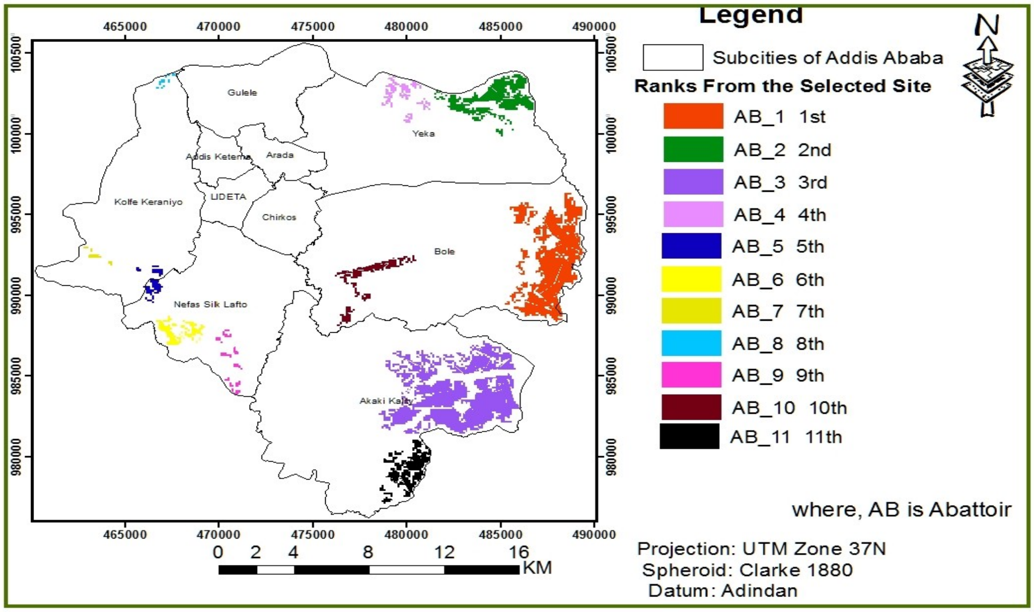


Figure 6: Ranked map from the selected abattoir site map of the study area.

## CONCLUSION AND RECOMMENDATION

Abattoir site selection is a complex procedure which involves evaluating numerous factors like, physical, environmental and socio-economic factors so the existing abattoir site was evaluated under these perspectives. A GIS is a good tool to help aid in the finding of suitable sites for abattoir siting purposes. The use of GIS for evaluation of future abattoir sites has shown to save time when there is a need for fast evaluation. The abattoir siting process requires evaluating many factors and criteria and processing much spatial information. This study considered many criteria, namely geology, slope, surface water, borehole, soil permeability, land use/ land cover, slope, road proximity, proximity to high tension line, air proximity, and other critical issues for proper abattoir site selection in Addis Ababa and prepared as input map layers. The output maps were dividing into four classes from unsuitable to highly suitable areas. In addition, a field check was implemented to determine the selected sites. A method that integrates both GIS and MCDM was used for the analysis. To compare the results and check the accuracy, one method of MCDA which is the Analytic Hierarchy Process was used. Multi-criteria Evaluation results showed that road, land use/land cover and surface water-related factors are more important in abattoir site selection, as a source of water needs protection from wastes arising out abattoir and protecting them from any kind of contamination. About 17.7% of the study areas are satisfied with the environmental, economic and social criteria set for the site selection and hence have the most suitable. Accordingly, 11 abattoir sites were selected. The sites are found in the eastern, southeastern, northeastern, central, and western parts of the study area. A Site which is found in the eastern part i.e. at Bole sub-cities Woreda10 (AB_1) is the most suitable of all due to the fulfillment of abattoir size and minimum environmental and social effects from it, because this site is found on the leeward side of residential areas and social services. The 2ndand the 4th lies in yeka ( around kara area), the 3rd suitable site lies Akakai kality and and the 5th lies at the boarder of kolfe-keraniyo and Nifas-silk lafto sub-cities, but the southern part (i.e. southern Akaki) needs special protection for abattoir due to close to the industrial zone and the presence of groundwater. The GIS-based multi-criteria evaluation technique is simple and flexible which can be used to analyze the potential sites for urban development and encourage public participation in the urban decision making process. Thus, planners and authorities to formulate suitable plan for sustained development of the city, need to practice the application of GIS. The present study considers physical, environmental and the socio-economic factors, so all factors with related to these are influence for abattoir site selection and therefore, the planner should be consider as evaluating criteria for site selection processes. To protect downstream surface water pollution, runoff must not flow into and out of the abattoir industry. Hence, drainage system should be constructed around the abattoir. This study has been intended to serve for solving the location problems associated with municipal abattoirs so the city will have more than one abattoir is required to export the standardized meat product which is expected from it.

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