GIS Application for Suitability Assessment of Sites for Municipal Solid Waste Disposal in Kano Metropolis, Nigeria

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Indiscriminate dumping of solid wastes is a serious problem in urban environment of the cities of developing countries. The attending environmental challenges and health implications confronting the urban dwellers call for urgent attention to forestall possible outbreak of epidemics. The study explored potentials of Remote Sensing, Geographic Information System (GIS) and Multi-Criteria Decision Analysis for efficient and effective management of solid wastes in Kano metropolis. The study used fieldwork Global Positioning System (GPS) to capture the existing dump sites. In addition, Landsat 8 OLS 2016, ASTER 2016 and Quick Bird 2012, the geological map of 2006, soil map of 1997 and the topographical map area were utilized using GIS techniques. Pair-wise comparison matrix under Analytical Hierarchical Process (AHP) was used to determine the weight for each of the factors. Multi Criteria Evaluation (MCE) module for Weighted Linear Combination (WLC) of overlay analysis was used to overlay all the maps to provide the final suitability map. The results for site selection of solid waste dumping sites in Kano metropolis indicated that suitable area occupied 15.35% of the total study area and ranked (1), moderately suitable occupied the largest portion with about 62.63% of the total study area and ranked (2) while unsuitable occupied 22.02% of the total study area and ranked (3). Based on the final suitability map, parts of Ungogo and Kumbotso areas provided the suitable ground and location for solid waste disposal facility in the study area. The study advocates adoption of site suitability map as guiding tool in designating and approving locations for dumpsites to avert consequential environmental health hazards in the respective cities.

Keywords: Urban environment, Solid waste disposal, GIS, Mul-criteria Evaluation, Site suitability map

Introduction

Globally, waste generation has been increasing with increasing wealth and economic growth. In developing countries, the waste generation is growing rapidly and may keep increasing in quantum as a result of improvement in standard of living, economic activities and population growth (UN-HABITAT, 2010). Municipal solid waste (MSW) has become a serious problem in many developing countries, especially in the urban areas of large and rapidly growing cities (Hassan et *al*., 2009).

Provision of suitable waste disposal system appears to be a major problem due to the complication and the wide nature of waste production. Due to the different parameters involved, deciding upon a suitable location is also very complicated, costly and time consuming. Thus, an ideal waste disposal site is the one that is located reasonably close to the source of the waste, has convenient transportation access, is not situated in a low-lying area or floodplain, and is underlain by geologically stable, strong and competent rock material, very large area of land for ease of expansion; a suitable topography, preferably flat but certainly not sloppy site; the site should not drain into surface water body; should be far away from existing settlements and proposed residential communities; should be far away from any river, stream or spring or other water bodies. The Refuse Management and Sanitation Board (REMASAB) in Kano Metropolis has not comprehensively utilized the potentials of GIS, Remote Sensing Technology and Multi Criteria Decision Analysis (MCDA) methods in the selection of solid waste disposal sites in the study area. This study, therefore, focused on potentials of GIS, Remote Sensing techniques and MCDA to provide appropriate information about geographic data to assist in selecting suitable solid waste disposal sites in the Kano Metropolis.

Materials and Methods

Research Locale

Kano Metropolis is the largest city in northern Nigeria; it is located within Latitudes $12^{o}25'$ and $12^{o}40'$ N and Longitudes $8^{o}35'$ to $8^{o}45'$ E. It has a total land area of 499 km^2 and comprises of eight Local Government Areas (LGAs), namely Dala, Tarauni, Kumbotso, Fagge, Nassarawa, Ungogo, Kano Municipal, and Gwale (See Figure 1). Kano metropolis has a tropical continental climate and it lies on average elevation of about 690m above mean sea level and 850-870mm of precipitation per year, and receives its peak rainfall between June and September (Olofin, 1987). The geology is of basement complex and Chad formation. Hadejia River constitutes the main drainage which contributes about 80% of the historic flow system which comes from three main tributaries: Kano, Challawa and Watari. The remaining 20% of the river discharge comes through Jakara system which disappears underground in the Chad formation (Olofin, 1987).

The major soil type is Latosol, which is a ferruginous soil with a laterite had-pan in its profile. Other types of immature soil include mineral soil at the foot of slopes and in rocky area known as lithosol, the heavy valley soils in floodplains and Fadama areas known as hydromorphic soils and very sandy infertile sediments at the bed of the river channels. The vegetation is predominantly semi-arid savannah (Sudan Savannah) sandwiched by the Sahel Savannah in the north and the Guinea Savannah in the south.

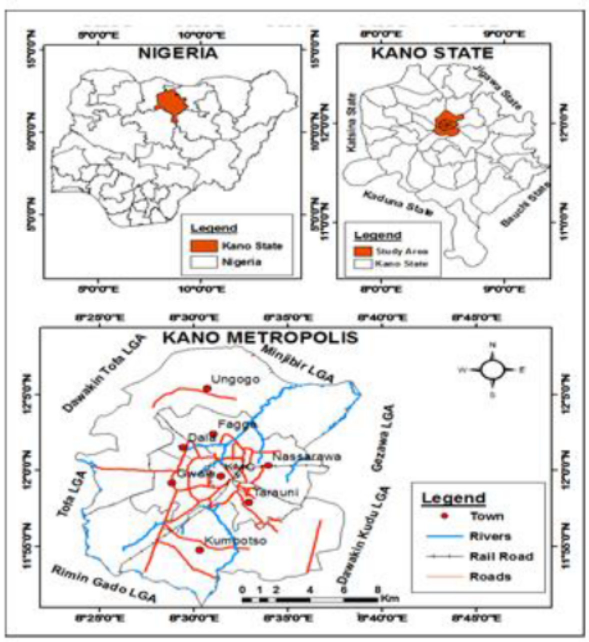


Figure 1: Location of the Study Area
Source: Author's Map Production, 2017

Data Types

The study used both primary and secondary data. The primary data used include ground control points of the exiting solid wastes dump sites collected with Garmin GPS during the field work. Digital camera was also used to take the pictures of the existing solid waste disposal sites. The secondary data include Landsat OLI 2016 obtained from the United States Geological Survey (USGS) platform; Aster 2016 Imagery also acquired from United States Geological Survey (USGS); Quick Bird 2012 iimagery with 2.4m resolution obtained from Kano State Ministry of Land and Physical planning; geological data obtained from Nigeria Geological Survey Agency for the year 2006 at a scale of 1: 400,000; soil data obtained from Nigeria Geological Survey Agency for the year 1997 at the scale of 1:300,000, and aadministrative map obtained from United Nation Humanitarian Data Exchange (UNHDE) for 2016 at a scale of 1: 250,000.

Data Processing and Analysis.

The coordinates were imported to the ArcGIS 10.3, converted to shape-file and overlaid on the study area map to determine the location of twelve (12) legal and thirty-nine (39) illegal existing solid waste dumpsites. The study utilized nearest neighbourhood analysis to show the spatial distribution pattern of the existing solid waste dump site using geostatistical tool of Arc GIS 10.3 software.

The study considered a number of factors for determining suitable solid waste disposal sites in the study area. The factors include land use/land cover, slope, geology, soil, built-up, road, rivers, airport and railtoad. The processes and methods involved in the extraction and analysis of these factors are described as follows:

Landsat OLI image 2016 was subset to extract the study area image, georeferenced and classified into land use/land cover of the study area using supervised classification technique in the ENVI 5.1 software environment. The land use/land cover categories extracted include built-up area, savannah vegetation, water body, agricultural land and barren land. The classified map was then imported into ArcGIS 10.3 software and converted from vector to raster using rasterisation tool. The map was further reclassified into various suitability classes.

Digital Elevation Model was extracted from the ASTER image to generate the slope of the study area using spatial analysis tool of ArcGIS 10.3 software. The slope map was further converted from polygon to raster and reclassified into suitability classes for locating solid waste dumpsites.

The geological map of Nigeria was imported into ArcGIS 10.3. The map was geo-referenced and digitized to extract the geological types of the study area using GCS_WGS_1984 and clipped with the study area map. The map was then converted from polygon to raster and was reclassified into suitability classes.

The Nigeria soil map was imported to ArcGIS 10.3 software, and projected on GCS, WGS 1984, UTM zone 31^0N. The map was geo-referenced and digitized to extract the soil types. The study area map was clipped on the soil map and two types of soil were identified. The vector map was converted to raster. The soil types were reclassified based on the criteria that must be satisfied to determine the suitable locations for solid waste disposal sites in the study area according to the Enviromental Protection Agency's landfill manual (EPA, 2006) and other literatures such as Oyinloye and Fasakin (2013) and Rajan et al. (2014). The soil types were reclassified into two classes of suitability (suitable and unsuitable).

The Quick Bird image of Kano metropolis 2012 was imported to ArcGIS 10.3 software and clipped with the study area map to extract the built-up areas using on-screen digitization. Multiple ring buffers under proximity analysis tool were used to determine the specific distances for solid waste sites suitability. The buffered distances set was categorized into 0-500m, 500-1000m, 1000-2000m, and 2000m-above. The built-up map of the study area was further reclassified to show the areas that were unsuitable, moderately suitable, suitable and highly suitable.

The road layers were digitized from Quick Bird image of Kano metropolis using ArcGIS 10.3 software. Multiple ring buffers were also used to determine the distances based on the criteria that must be satisfied to determine site suitability location for solid waste disposal sites as 0-100m, 100-500m, 500-1000m, and 1000m-above. The road map was further reclassified into four suitability classes - namely unsuitable, moderately suitable, suitable and highly suitable.

The river layers were also extracted and imported to ArcGIS 10.3 software, converted to a shape file and digitized with the use of polyline. Multiple ring buffer from analysis Tools was used to prepare multiple polygons around each river within the following distances: 0-300m, 300-500m, 500-1000m, and >1000m. The map was further reclassified using spatial analysis tools to show the areas that were unsuitable, moderately suitable, suitable and highly suitable. Airport was extracted through digitizing using ArcGIS 10.3 software and converted to shape file and clipped with the study area map. There are different values related to the safe distances from airports. Multiple ring buffer was used to determine distances as 0-1000m, 1000-2000m, 2000-3000m, and >3000m. The map was further reclassified into suitability classes.

Railway layer was digitized and clipped with the study area map. Therefore, multiple ring buffers from analysis tools were used to determine the distances satisfied for solid waste disposal sites suitability in the study area and the buffers set as 0-100m, 100-500m, 500-1000m and >1000m. The buffered layers were further reclassified into four suitability classes as moderately suitable, highly suitable, suitable and unsuitable.

The study employed MCDA to select the suitable solid waste disposal sites. The weights of criteria were computed using pairwise comparison matrix of Analytic Hierarchy Process (AHP) by using scale values of 1 – 9 as shown in Table 1.

Table 1: Comparing the Binary Scale

Definition	Extent of importance
Equal importance	1
Equal to average importance	2
Average importance	3
Average to strong importance	4
Strong importance	5
Strong to very strong importance	6
Very strong importance	7
Very strong or super strong importance	8
Super strong importance	9

Source: (Malczewski, 1999)

The consistency ratio was estimated using the calculated weight of each of the factor in order to determine if the comparisons are consistent. With a weighted linear combination, factors were combined by applying a weight to each and overlaid under spatial analysis tool of Arc GIS 10.3 software to provide the final suitability map.

Results and Discussion

Spatial Distribution of Solid Waste Disposal Sites in Kano Metropolis

Figure 2 shows the spatial distribution of the existing solid waste dump sites in Kano Metropolis while Figures 3, 4 & 5 show clustering spatial distribution of both legal and illegal solid waste dump site points, dispersed spatial distribution of the legal solid wastes dumping sites and random spatial distribution of illegal solid waste dump sites in the study area. Twelve (23.5%) legal and thirty-nine (76.5%) illegal dump sites were identified. It was observed during the field work that, the present solid wastes disposal system in Kano metropolis was not in compliance with the acceptable practice. This is in agreement with (Nabegu, 2008) who observed that the existing management and facilities could only evacuate about 20% of the solid waste generated in the metropolis daily due to lack of adequate disposal facilities, inadequate coverage and iefficient operation as well as difficulties that limit the management of REMSAB in the form of technical, financial, institutional, economic and social factors. In addition, the predominance of illegal dump sites over the legal ones is not environment friendly and portends a serious threat to the public health. In areas of high-density layout with narrow streets and poor road conditions, the solid waste collection system involved the use of handcarts. Accordingly, in such area handcart solid wastes collectors (HSWCs) moved from one house to the other to collect waste and dump it along the main road for the Refuse Management and Sanitation Board (REMASAB) to evacuate and dispose it at the main dump sites. However, it was noticed that evacuation of refuse and solid wastes was conducted on irregular basis. There was no definite schedule for the collection of solid waste. This resulted to large accumulation of solid wastes at some collection points such as Jakara, Kwari Filin Fakin, Mandawari among others. Based on the information gathered from the Refuse Management and Sanitation Board (REMASAB) responsible for solid wastes management in Kano metropolis, approximately 3,000 tonnes of solid waste were evacuated per day (Nabegu, 2010) while 4,000 tonnes of solid waste were evacuated daily in 2016 (Salihu, 2016).

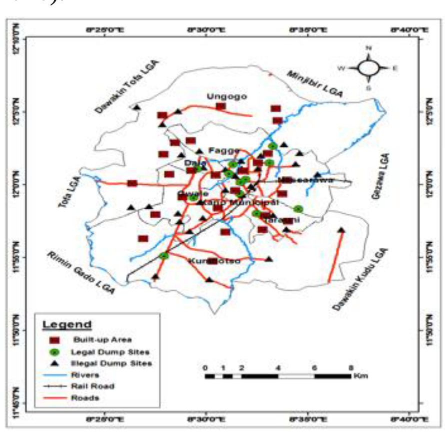
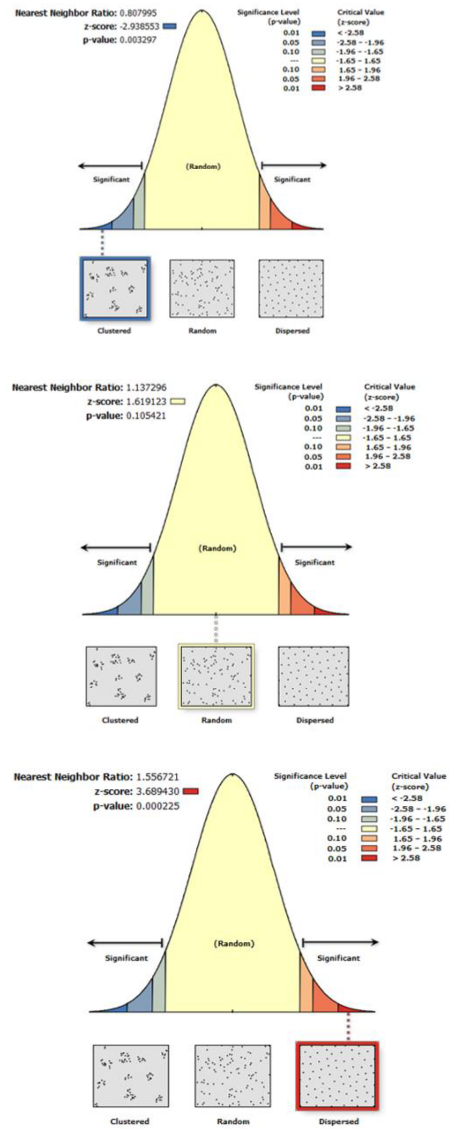


Figure 2: Spatial Distribution **of Existing Solid Waste Disposal Sites.**



Figures 3, 4 & 5: Showing Clustering spatial pattern of existing solid waste dumpsites, Dispersed spatial pattern of existing legal solid waste dumpsites and Random spatial pattern of illegal solid waste dumpsites.

Selection of new Solid Waste Disposal Sites in Kano Metropolis

Land Use

Land use land cover of the study was selected as one of the factors to be considered in selecting suitable areas for locating solid wastes disposal sites in Kano metropolis (Figures 6)

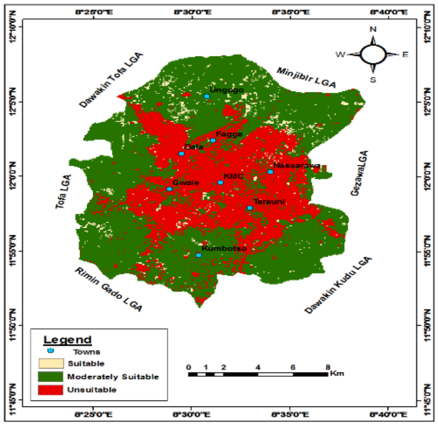


Figure 6: Land use/Land cover Suitability Reclassification of the Study Area

Figure 6 shows land use/land cover suitability classes in the study area for locating solid waste disposal sites. The suitability classes were ranged from suitable, moderately suitable to unsuitable. Barren land was considered as suitable. Savannah vegetation and agricultural land was described as moderately suitable. Built-up area and water body were categorized as unsuitable area for locating solid wastes disposal sites. This is in agreement with the works of Rajan *et al.* (2014), Oyinloye and Fasakin (2013) and EPA manual (2006) who considered barren land as suitable area for solid waste disposal sites, agricultural land and vegetation as moderately suitable, and built-up area as unsuitable.

Slope Factor

The slope map was further reclassified using GIS spatial analysis tool after converting the vector map to raster. The map was reclassified according to suitability levels; ranging from unsuitable, suitable, highly suitable, moderately suitable and less suitable for solid waste disposal site as shown in Figure 7.

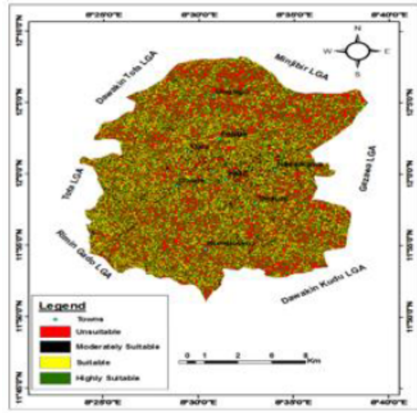


Figure 7: Slope Suitability Reclassification of the Study Area

Geology

The geological types were further reclassified according to suitability classes as shown in Figure 8. The Figure showed that the geology was reclassified into two suitability classes, suitable and unsuitable. The area covered by basement complex was classified as suitable area for locating solid waste disposal site while area covered by Chad formation was classified as unsuitable area. The areas under the basement complex have well structured soil. Whilst the area covered by Chad formation had poorly structured soil (Tanko and Momale, 2014).

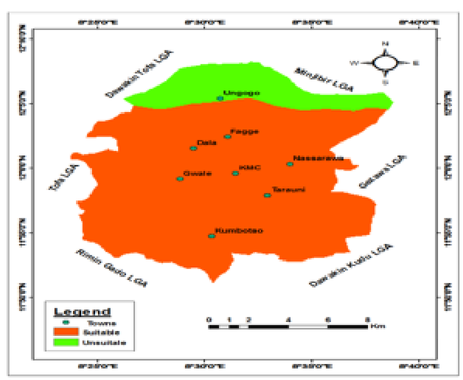


Figure 8: The Geological Suitability Reclassification of the Study Area

Soil Factor

The soil of Kano metropolis was classified into two major types namely lithosol and regosol soil. The soil was further reclassified into suitable and unsuitable as shown in Figure 9. The figure showed that area covered by lithosols soil was considered suitable while area covered by regosols soil was regarded as unsuitable.

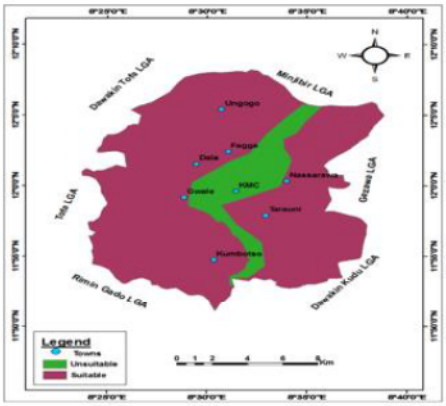


Figure 9: The Soil Suitability Reclassification of the Study Area

Proximity from Built-up area

Figure 10 shows the built-up area suitability according to the buffering distance. The distance from 0-500m was described as unsuitable, 500-1000m as moderately suitable, 1000-2000m as highly suitable and above 2000m as suitable. This is in line with the outcomes of the researches carried out by Hassan et al. (2009) and Umit and Cuney (2016) that built-up areas with distance between 500-2000m are regarded as the best site for solid waste disposal/landfill.

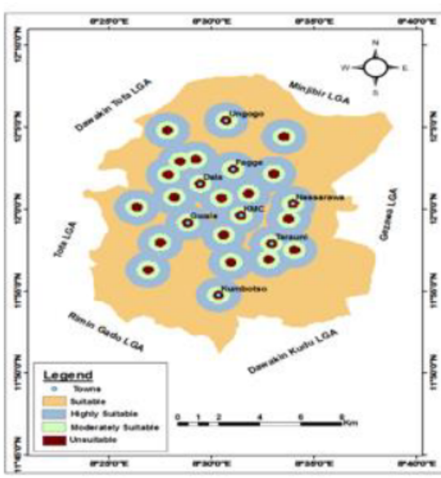


Figure 10: The Built-up Area Suitability Reclassification of the Study Area

Airport

Figure 11 shows the suitability reclassification classes for locating solid waste disposal site where there is an airport. Far away from the airport was regarded as highly suitable, and closer to it as unsuitable. The areas with the distance of 3000m and above away from the airport was considered highly suitable while the areas with less than 1000m away was regarded unsuitable. The finding is in agreement with Olusina and Shyllon (2014) who proposed, in different studies, that minimum distance of solid waste dumpsite from airport should not be <3000m.

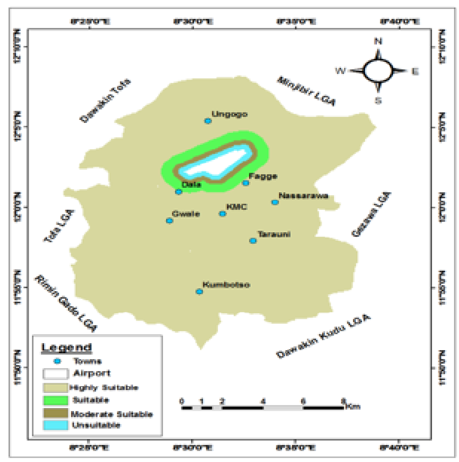


Figure 11: Airport Suitability Reclassification of the study area

Road Proximity

Siting a solid waste disposal site very close to roads may have public health problem as dump site can have hazardous effect to health. Moreover, solid waste disposal site very far from road network is also not recommended due to high transportation cost. Therefore, to minimize such problems, it must not be sited very close to and very far from roads. Thus, the study used buffer distances of 0- 100m, 100-500m, 500-1000m, and 1000m and above (Figures 12) and observed that the distance range from 100m to 500m is highly suitable, 500m to 1000m is suitable and 1000m above is moderately suitable. This finding is in contrast to Chang et al. (2007) who set 75m buffer in agreement with Hassan et al. (2009); EPA (2006); Umit and cuney, (2016) that used 50- 100m buffering from road as a minimum distance within which disposal site or landfill should not be located.

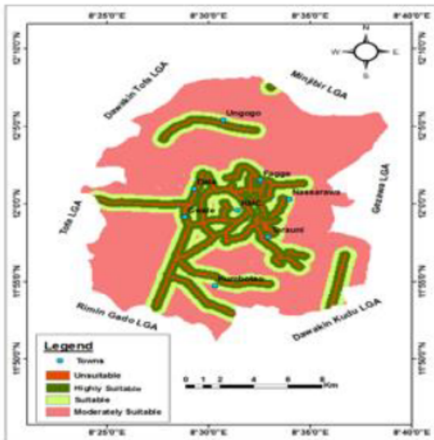


Figure 12: Road Network Suitability Reclassification

Water Body

The distance 0-300m was described as unsuitable for locating solid waste disposal site and 300m-500m as suitable while 500m-1000m and >1000m were described as highly suitable and moderately suitable respectively (Figures 13). This finding disaggrees with Hassan et al. (2009) who used 100m buffer distance but aligns with EPA (2006) and Shahabi *et al*. (2013) that used 300m-500m as a minimum buffer distance, and Nas *et al.* (2009) who employed 300m minimum distance.

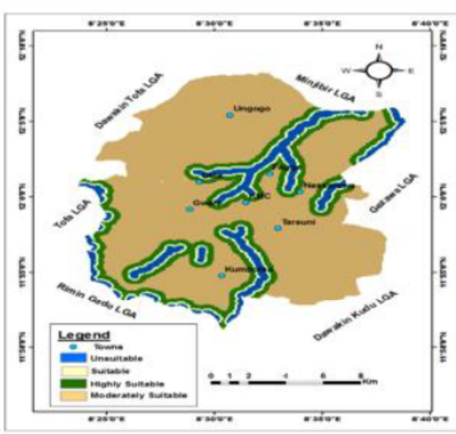


Figure 13: The Rivers Suitability Reclassification

Railroad

Figures 14 show suitability classes for siting solid waste disposal locations where there is railway. Area around the railroad with distance of 0-100m was described as unsuitable, 100m-500m as suitable, 500m-1000m was described as highly suitable and greater than 1000m was moderately suitable for siting solid waste disposal in the study area. This is in agreement with Kimwatu1 and Ndiritu (2016) who reported distance in a study carried out in Nyahururu municipality, Kenya.

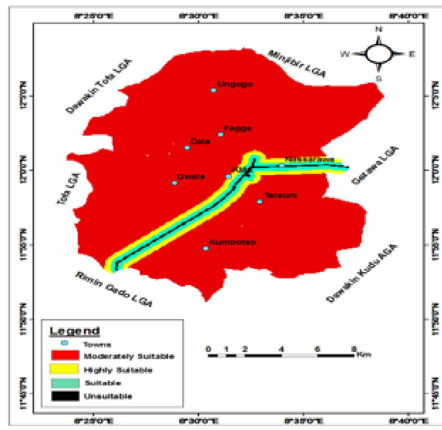


Figure 14: Railroad Reclassification

Potential Solid Waste Disposal Site Suitability Thematic Map using MCDA

Finally, all the parameters were weighted with their respective percentage of influence as and overlay was performed to produce the suitability map as shown in Figure 15.

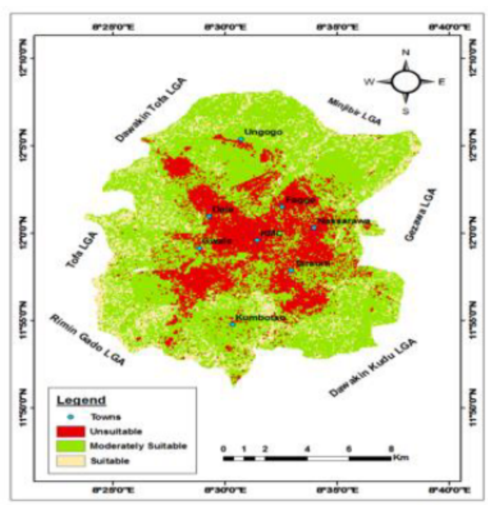


Figure 15: Final Suitability Map for the Study Area.

Conclusion

The study has shown the capability of GIS, remote sensing techniques and MCDA in identifying the existing and proposed suitable municipal solid waste disposal site for the Kano metropolis. Based on the final suitability map, parts of Ungogo and Kumbotso areas provided the suitable ground solid waste disposal location in the study area. Using GIS for locating solid waste disposal sites is an economical and practical way as it has capabilities of producing useful, high quality maps for suitable solid waste disposal sites selection in a short period of time. Hence, the capability to use GIS and remote sensing technology for the effective identification of suitable solid waste disposal sites will minimize the environmental risk and human health problems. The study advocates that relevant Environmental Departments of the State and Local Government Area, including Town Planning Authority should put the site suitability map into use as a guiding tool in approving locations for dumpsites to avert consequential environmental health hazards.

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