Site Suitability Analysis for Waste Disposal in Kano Metropolis, Nigeria (Using Multi-Criteria Evaluation, AHP, and GIS Techniques)

Abubakar Aminu Usman, Mukesh Kumar

ABSTRACT
In Nigeria, Landfill is one of the most important method of managing Municipal Solid Waste (MSW). The landfill remains the last option for the disposal of waste in developing countries including Nigeria. This study was based on site selection for Municipal Solid Waste dumpsite in Kano Metropolis (Nigeria) using multi-criteria evaluation, AHP, remote sensing and GIS techniques. Eleven criteria were used for the study. This criteria were classified in to two: the constraint criteria (major road, airport, railroad, river, dumpsite, and a border). While the factor criteria involves population, advance road, soil, slope and land use. The study was divided in to three phase. In the first phase the constraint criteria were standardize using Boolean logic, a score of 0 was assigned to the restricted area, while 1 to unrestricted area. Then all the five criteria were overlaid to generate a restriction map. For the second phase, factor criteria were standardize using fuzzy membership, with a range of numbers from 0 –1. The factor criteria were then weighted using AHP and then overlaid, to get a suitability map. The final phase combine the result of the first and second phase to get most suitable sites for landfill. The result revealed five different sites; the Unsuitable site occupy 324 km2 (65%), Poorly suitable site covers 30 km2 (6%), the Moderately suitable site covers only 5km2 (1%) and then Suitable site covers 6% (30km2). Finally the Most suitable site for the waste disposal covers 110 km2 (22%) out of the total area of 499km2.

Key word: Multi-Criteria Evaluation (MCE), Analytic Hierarchy Process (AHP), Remote Sensing, Geographic Information System (GIS). Weight Linear Combination (WLC) and Boolean Logic

1.0 Introduction

Waste disposal is the process of collecting and removing waste and relocating it to a place where it will kept or recycled. With rapid grow in urban population (which lead to expansion of many cities, high consumption rate and formation of squatter settlement) and industrial revolution that result in high production which in turn leading to generation of more waste. Waste management becomes the second prominent problem (after water quality) affecting many cities in developing countries (Bartone, 2000; Shahabi, et al., 2013). Based on the World Bank (2012) projection the global urban waste generation increases to 70%, with developing countries facing the highest consequences. In line to this projection, the amount of waste generation per annum will rise from 1.3 billion tonnes to 2.2 billion tonnes by the 2025. This will have effect on the annual global costs of waste management as it will rise from $205 billion to $375 billion. The increase in population, coupled with the socioeconomic activities in the metropolis has implications for solid waste generation, disposal and management in the area (Ogwuche, 2013).

Like all other developing countries, Nigeria is having problem of managing her waste in a modern ways. This can be attributed to lack of awareness or ignorance (from both government and people) regarding the modern practices of handling waste. In Nigeria, Landfill has been and continuous to be the only and the most efficient method of handling waste. With expansion of human settlement, most of the existing landfills are encroached. Hence, the settlements which are adjacent to landfills are severely affected. Unplanned siting of landfill, this has subsequently polluted water resources, air and making the environment becoming unfriendly (Clemson, 1995).

This research will be conducted due to the need for a new landfill in Kano Metropolis, as the present landfills are facing serious problems among which is improper handling. This is as a result of the increase in human population (lead to the rapid urbanization) which led to the sharing border between some of the landfills with build-up areas. This research upon completion will help those in charge of waste management, government and even the people of Kano Metropolis (Fatta, Saravanos, & Loizidou, 1998) by preventing them and the generation yet to come from different problems and diseases resulting from poor handling of landfill. The selection of suitable sites for locating a landfill was done using Multi-criteria evaluation, AHP, and remote sensing and geographical information system techniques.

Management of solid waste is one of the challenges facing many if not all urban areas in the world (Hoornweg & Bhada-Tata, 2012). This is because an aggregation of human settlements has the potentials of producing large amount of solid waste. Collection, transfer and disposal of such waste have been generally control by municipal governments in developed countries (Oyinloye, 2011).

Many researches has been conducted in Kano Metropolis about waste, for example: Nabegu (2008a) analyses Municipal Solid Waste in Kano Metropolis, Nigeria. Mukhtar (2008) analyses Plastic Waste Recycling in Kano Nigeria. An assessment by Refuse Management and Sanitation Board (REMASAB) on waste management in Kano metropolis. Nabegu (2008b) Analyses municipal solid waste characteristics in three residential zones of Kano metropolis. Nabegu (2008c) analyses the organization of plastic waste recycling in Kano Metropolis, and many others.

But for the Landfill, the main concern is how to minimize the waste in it, not how the landfill will respond in time (as a result of increase in population and urbanization). For this reason comes the need for selecting new sites for landfill in Kano Metropolis using GIS and RS techniques.

As stated by Howard, (1978), 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. The study intended to come out with a suitable sites for waste disposal (landfill).

Geneletti (2010), Eskandari, et al (2012), Olusina & Shyllon, (2014), carried out a research on landfill

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site selection using GIS and multi-criteria evaluation. They all came out with a good result showing the effectiveness of the techniques in site selection. Gbanie, et al., (2013), conducted a research on Modelling of landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA). They came out with a result which reveals that 83.3% of the study area is not ideal for landfill location whilst only 2.1% is very, very suitable for landfill siting.

2. Materials and Methods

2.1. The study area

Kano Metropolis is the largest city in the Sudan region of Nigeria, it is located between Latitude 12°25′ to 12°40′ North of the equator and Longitude 8°35′ to 8°45′ East of the Greenwich Meridian. It has a total land area of 499 km2 and comprises of eight local government which includes: Dala, Tarauni, Kumbotso, Fagge, Nassarawa, Ungogo, Kano Municipal, and Gwale.

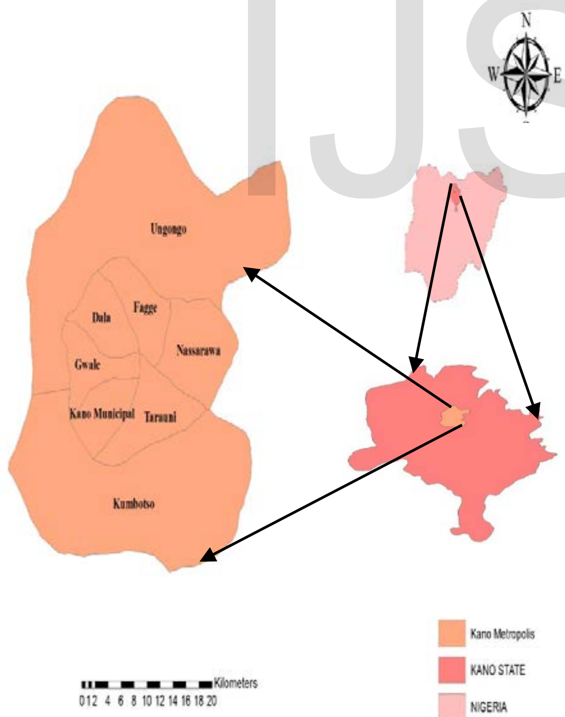

Figure 1: Study Area Source: divagis.org

The Area has a population of 2,828,861 (National Bureau of Statistics, 2006), and the projected population by the Nigerian Census Board was around 3,333,300 in 2011. The region has a, semi-arid climate. Kano lied on average elevation of about 690 m and 27.2 in of precipitation per year, and receives its peak rainfall from June through September (Olofin, 1987).

Solid waste disposal methods adopted in Kano are largely collected by public authorities and dumped in both approved and unapproved dump site. A high proportion burn the waste while others buried the waste (Falola, 2013).

2.2 Data source and Software's Used;

Satellite Image, DEM, Google Earth Map, GPS, Census Data, Shapefile Map, Internet, ArcGIS 10.2, AHPcalc-2015, Erdas 2014, Microsoft Office, Edraw Max.

2.3 Methodology

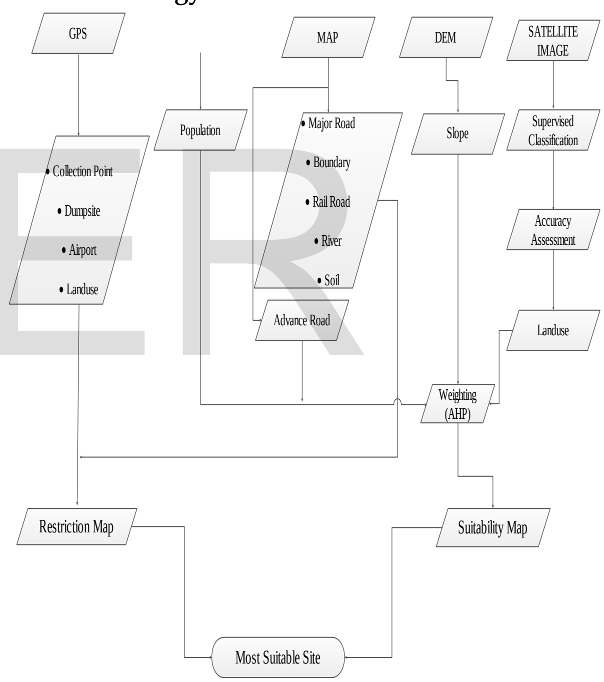

Figure 2: General methodology flowchart

The above flowchart was used in achieving the aim of the research. Eleven criteria's were identified that suits the area, among which includes; distance to river, railroad, existing dumpsite, airport, major road, advance road, slope, soil type, population and lastly land-use types. A very important criterion was not include which is the geological map, and this is because the area had a uniform geological structure (basement complex of older granites) so this will have no effect in the siting. Also, lack of available data about underground

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level of table water, which makes the research to skip this criterion.

The research was grouped into three phase and to locate and compound maps, the layers were standardized. This means that decision-making principles were used to transform layers into scales that will allow all to be combined. In the study, three methods were used, Boolean, Fuzzy Membership and AHP.

The phases were used to identify the most suitable site for landfill using multi-criteria evaluation, AHP and GIS techniques. Boolean evaluation and Weight Linear Combination (WLC) were applied for the MCE. As known that multi, means more than one, decision is a choice between alternatives. Criteria can be of two kinds that is factors and constraints. A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. Boolean evaluation and Weight Linear Combination (WLC) were applied for the MCE. The constraint serves to limit the alternatives under consideration which was expressed in the form of Boolean logical map that is 0 and 1(Olusina & Shyllon, (2014), Mohammad, et al. (2009), Eastman, (2012), and Shahabi et al., (2013)).

The following equation was used for Multi Criteria Evaluation (MCE)

$$S = \sum_{i=1}^{n} w_i c_i * \prod_{j=1}^{m} rj \qquad \text{……… (Eq.1)}$$

Where;

S = suitability for a waste disposal site, W_i= weight of factor i (ci), C_I= criterion for suitability of factor i, rj = criterion for suitability of constraint j, and $\prod$ = product.

2.3.1 Phase 1: Restriction Model

In the first stage, a model was prepared and named Restriction Model, it is the model that result the study into a Boolean logic. The formula used in achieving the logic was extracted from the multi-criteria evaluation as;

$$S = \prod_{j=1}^{m} rj \qquad \text{………….. Eq. 1a}$$

S= (rroad * rairport * rrailroad * rdumpsite * rriver * rborder).

Where;

rroad; restriction to location related to river site

rairport; restriction related to airport site

rrailroad; restriction related to railroad location

rdumpsite; restriction related to dumpsite location

rriver; restriction related to river site

rborder; restriction related to border site

2.3.2 Phase 2: Suitability Model

The second stage deals with the factor criteria, so a Suitability Model is applied in archiving the task which is Weight Linear Combination (WLC) together with the AHP. The WLC is the most common technique for analyzing multi-scale evaluations. This technique also is called a ''scoring method''. The AHP was used to capture aspects of decision. It was used in computing the weights for different criteria used by creating a pairwise comparison matrix. The following equation was used for the model:

$$S = \sum_{i=1}^{n} w_i c_i \qquad \text{……… (Eq.1b)}$$

S= (WluClu * WpCp * WrCr * WslCsl * WsoCso).

WluClu: weight and criteria for Land-use

WpCp: weight and criteria for population

WrCr: weight and criteria for road

WslCsl: weight and criteria for slope

WsoCso: weight and criteria for soil

2.3.3 Phase 3: Multi-criteria model

The third stage combined both the Boolean and Weight Linear Combination (WLC) which results to a final site using the following equation:

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$$S = \sum_{i=1}^{n} w_i c_i * \prod_{j=1}^{m} rj \qquad \text{......... (Eq.1)}$$

S= (WluClu * WpCp * WrCr * WslCsl * WsoCso) * (rroad * rairport * rrailroad * rdumpsite * rriver * rborder)

3.0 Result and Discussion

The result of phase 1 shows restricted and unrestricted areas for locating a landfill (figure 3a, b, c, d, e, and f). The restricted areas are the unsuitable sites that do not support the location of landfill in the area. While the remaining unrestricted sites are favourable for locating a landfill. Figure 4, shows the general restriction map after overlying all the restricted maps. The second phase deals with the continue criteria of the research, it shows a range of score from 0-1 (figure 5a, b, c, d, and e). Figure 6, shows the general suitability map after overlaying the different suitability maps. The score indicates suitability of the place as it moves toward 1.

The final suitable map reveals that the unsuitable site occupy 324 km2 (65%) of the study area, out of the total area of 499 km 2 , while poorly suitable areas covers 30 km2 (6%) of the study area. The moderately suitable sites were very negligible as they occupied only 5km2 (1%). Then comes the suitable site, this site covers 6% of the area which is to say it occupied 30km2 of the area. Finally comes the most important part of the research which is the most suitable site for the waste disposal. The most suitable site covers 110 km2 (i.e. 22%) out of the total area of 449km2 of the study area (Table 1).

Figure 7b, which was derived out of the most suitable site maps reveals that, the most suitable parcel is located at north-eastern part of Kano Metropolis. The parcel was found in Kumbotso local government area. So this site is the best among all, which favour the location of the landfill in the study area. Kumbotso is among the newly area attached to the metropolis and has a large area of land which can accommodate the siting of the landfill. Furthermore, the most suitable parcel are away from surface waters, settlement, with a flat slope and so also away from protected areas and away from quick urban expansion. The site has ease transportation access which is quite suitable.

Table 1: Final Suitable classes

Suitability Class	Suitability Index	Area (km2)	Percentage
Unsuitable	1	324	65
Poorly Suitable	2	30	6
Moderately Suitable	3	5	1
Suitable	4	30	6
Most Suitable	5	110	22

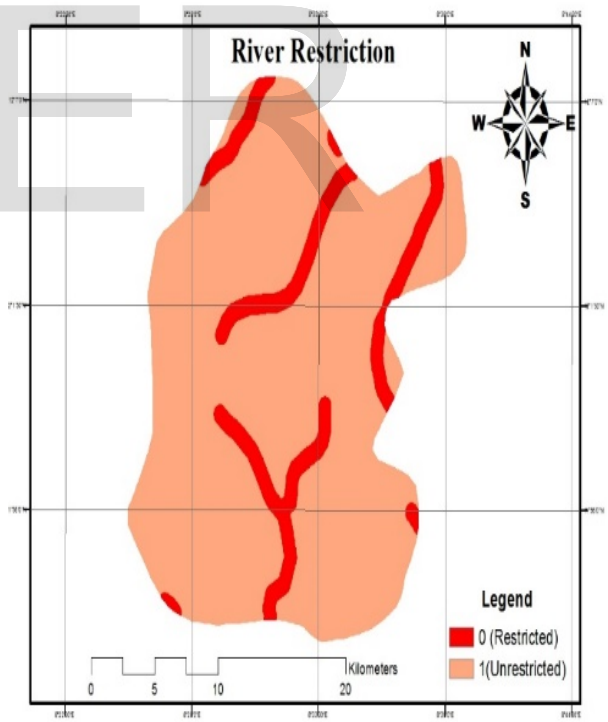

Figure 3a: River Restriction

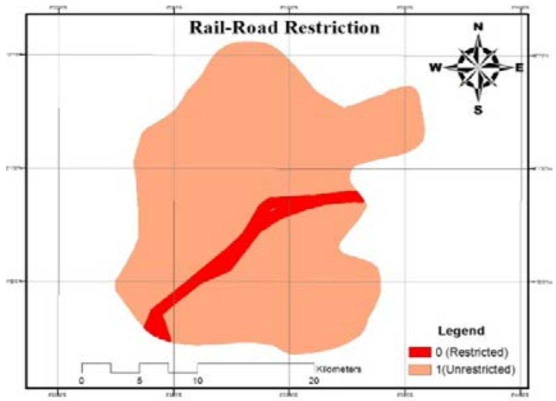

Figure 3b: Railroad Restriction

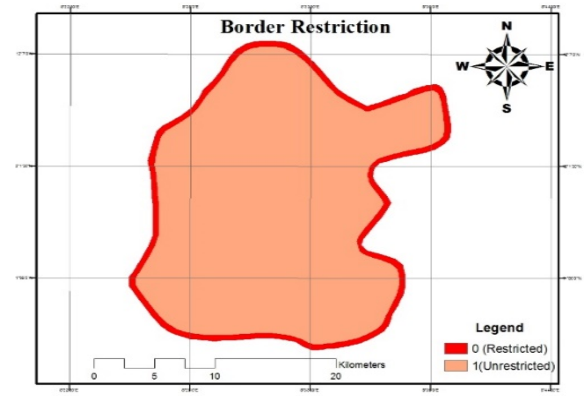

Figure 3e: Border Restriction

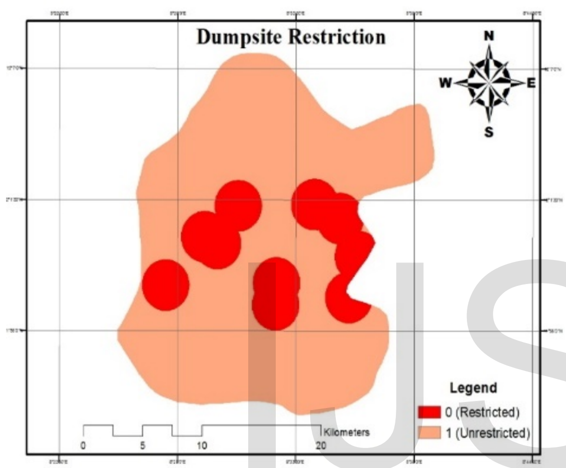

Figure 3c: Dumpsite Restriction

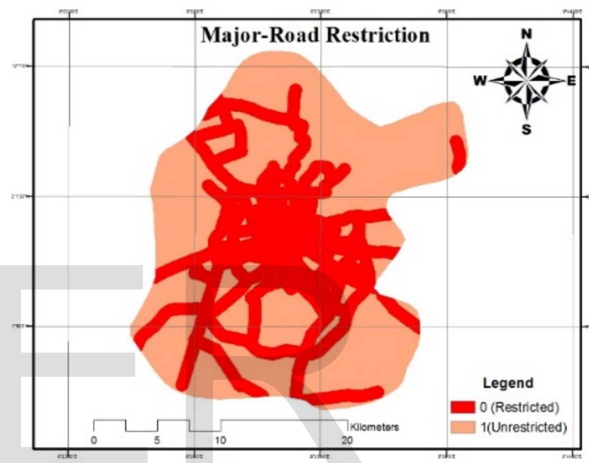

Figure 3f: Road Restriction

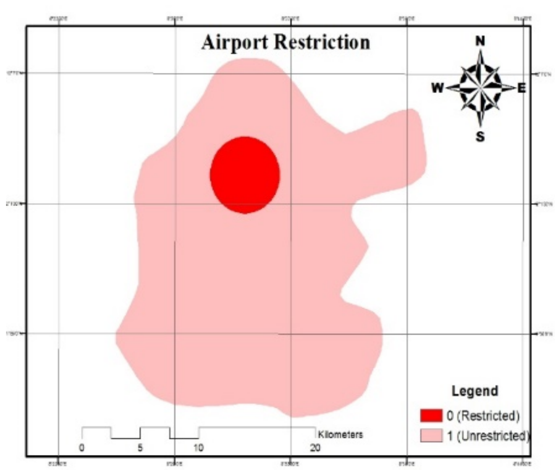

Figure 3d: Airport Restriction

Figure 4: General Restriction

Table 2: Weight factors using AHP method for site suitability (pair-wise comparison matrix)

	Slope	Soil	Road	Population	Land use	Eigen Values	Eigen Vector	Criteria weights
Slope	1	1	0.333	0.1429	0.125	5.2695	0.0772	0.0478
Soil	1	1	0.333	0.5	0.1429	-0.1182	0.01015	0.0628
Road	3	3	1	0.5	0.2	-0.1182	0.2053	0.1271
Population	7	2	2	1	0.2	-0.0165	0.3133	0.1939
Land use	8	7	5	5	1	-0.0165	0.9184	0.5684
Consistency	Ratio	CR=	0.0601					

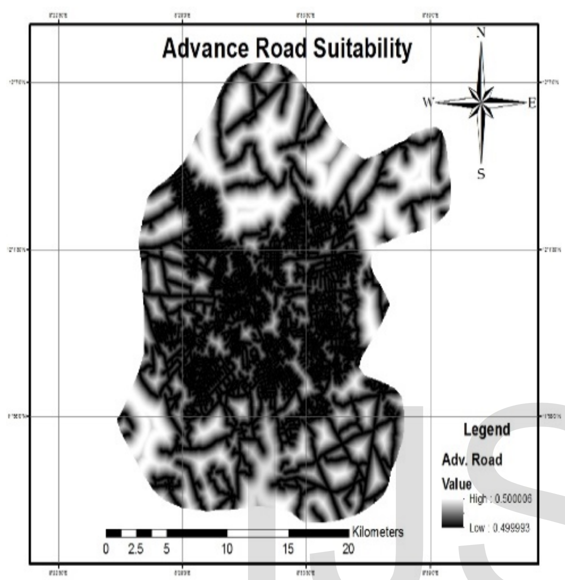

Figure 5a: Road Suitability

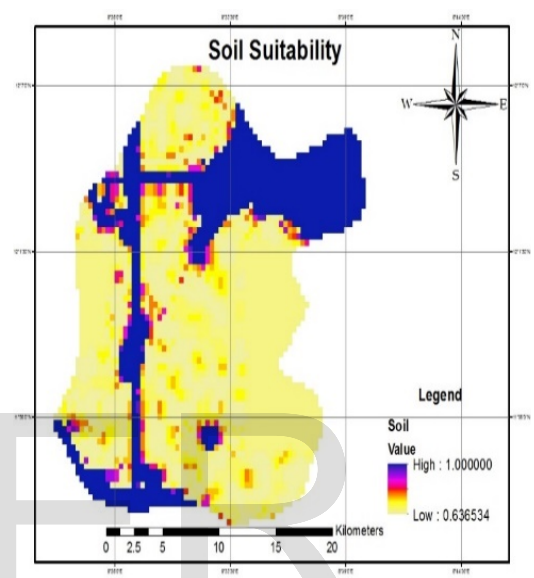

Figure 5c: Soil Suitability

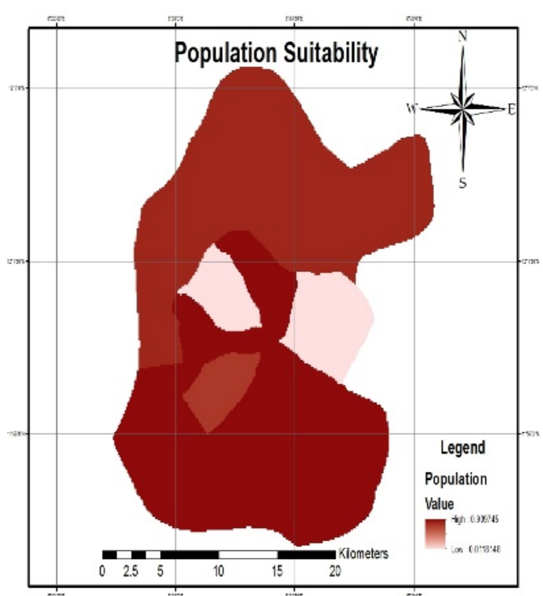

Figure 5b: Population Suitability

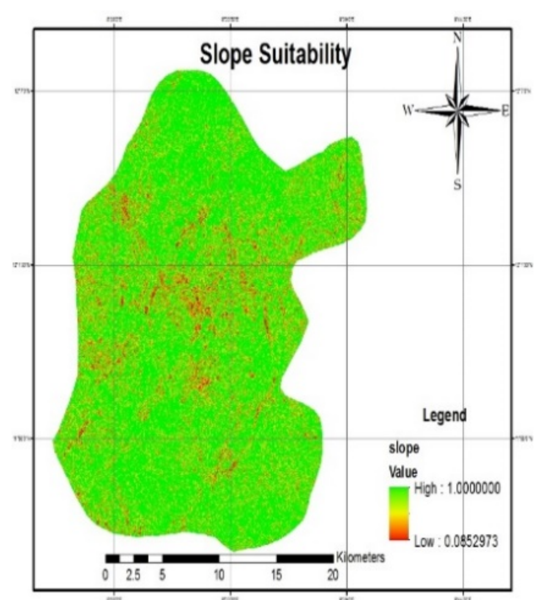

Figure 5d: Slope Suitability

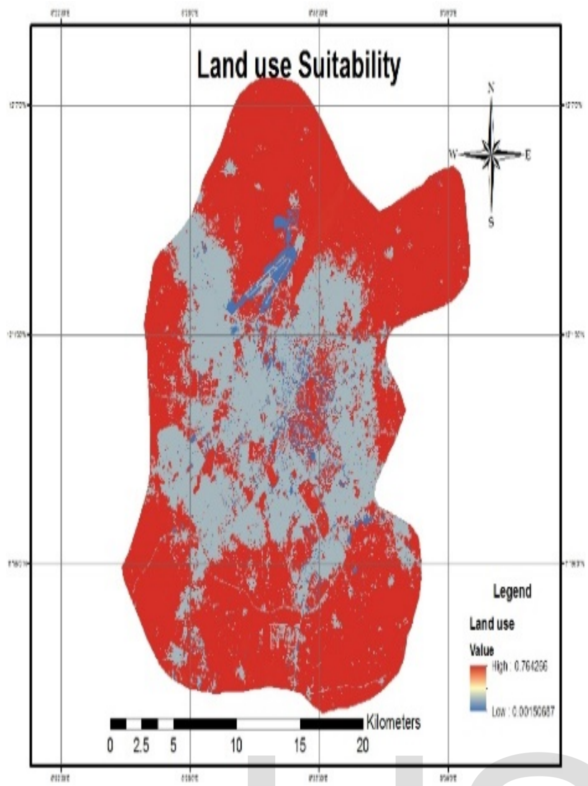

Figure 5e: Land Use Suitability

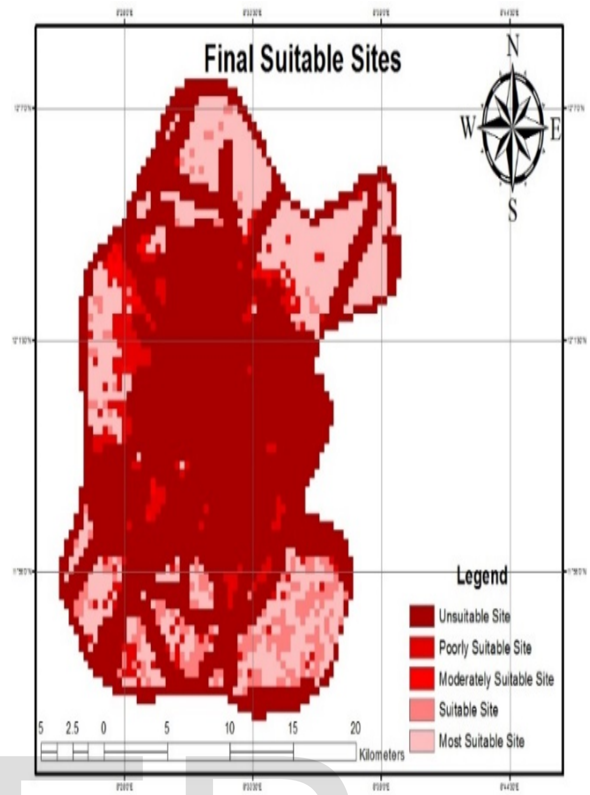

Figure 7: Final Suitable Site

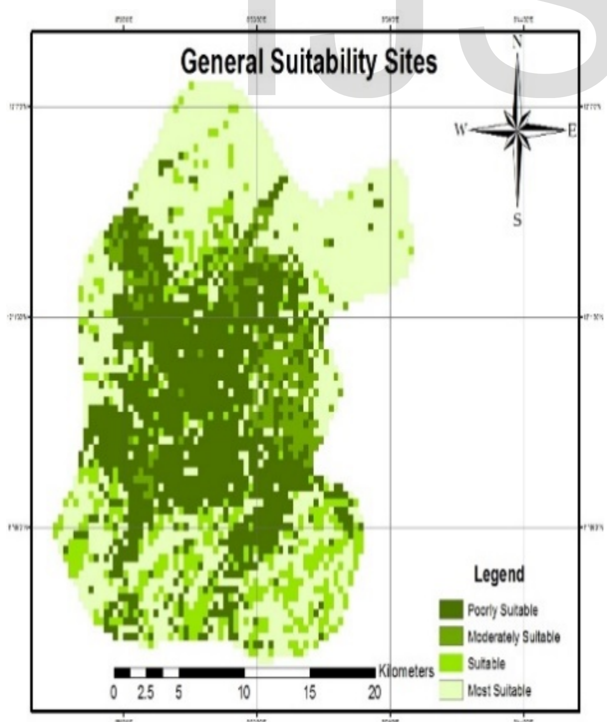

Figure 6: General Suitable Site

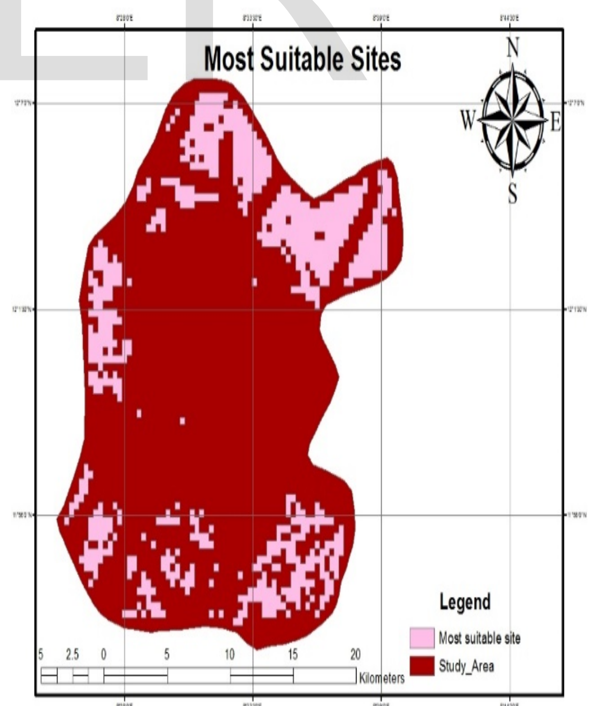

Figure 7a: Most Suitable Site

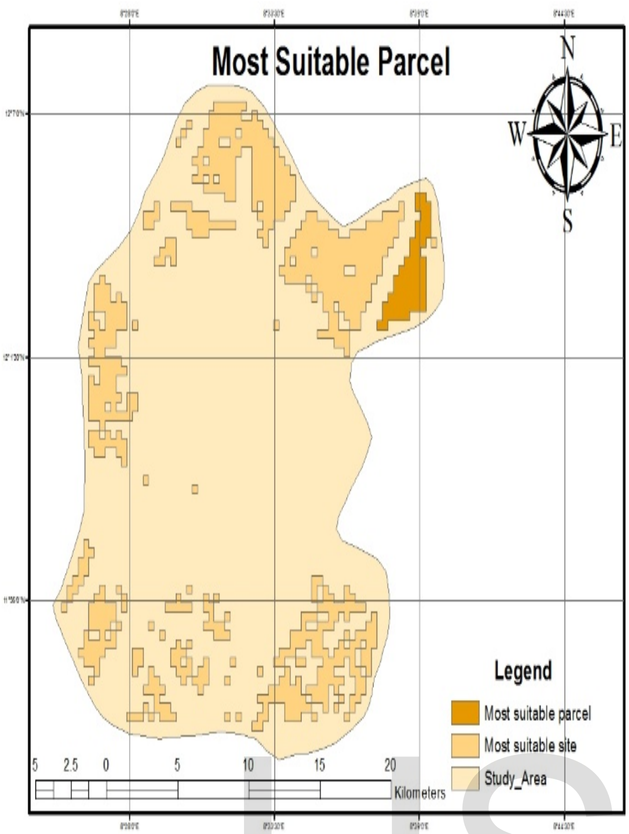

Figure 7b: Most Suitable Parcel

4.0 Conclusion

In the present study, the landfill site selection for municipal solid waste in Kano Metropolis was performed using GIS and remote sensing techniques. The study presents a method of determining site suitable for location of municipal solid waste landfills, using multi-criteria evaluation in conjunction with Fuzzy Function Standardization and AHP logic, in GIS environment.

The best parcel among the most suitable sites is located at the north-eastern part of the area in Kumbotso local government. The most suitable parcel happened to be away from surface waters, settlement, and also with a flat slope. The transportation is quite suitable for waste transport.

It is suggested that the general public need to be involved in decision making pertaining to waste management in order to create awareness to them about the implication of poor disposal of waste. Before locating a landfill, there is also need to consult Ministry for Urban Planning to find out if the selected site is not among the future plan for urban expansion Other criteria which were not considered in this study such as aspect, groundwater level, community preferences, cost of construction and urban master plan should be put into consideration in further research.

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