Evaluating suitability for sustainable urban growth of Abuja by using MCE and GIS

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ABSTRACT

Abuja, the federal capital of Nigeria was created when Lagos failed to function as the Federal Capital due to the resultant urban problems as a result of land availability. Currently, the rate of implementation of the master plan and urban development is outpaced by the rate of urban growth due to urbanization, as a result exerting a lot of strain on the urban facilities of the city which affects the life of the residents. This study is aimed at identifying a suitable site for future sustainable urban growth in Abuja. The study evaluates urban growth policies namely; social equity, compact growth and environmental protection into spatial layers as the framework for multi-criteria evaluation using the geographical information system. The spatial layers are the distance to road, distance to the central area, distance to educational facilities, distance to green/open spaces, soil, slope, vegetation, natural features, and pollution sites were evaluated and prioritized as per judgment of relevant experts. The influencing weights among the layers were computed using Analytical Hierarchy Process. The overall Consistency Ratio (CR) of the module was 0.04 and fulfilled the tolerable threshold (i.e., CR ≤ 0.1). The Weighted Linear Combination (WLC) function of ArcGIS model builder has been applied to generate a suitability map. The map clearly presents the areas that are suitable for future sustainable urban development and also areas that are not, reducing the possibility of future disaster.

1. Introduction

It is clear that all continents have been experiencing high rates of urbanization. According to United Nations, this rate will decrease progressively in the next 50 years, except in Africa where growth will continue. In addition to that, the urban populations in Africa are expected to triple in the next 50 years (UN, 2015). The number of Africa's urban dwellers is projected to increase from 471 million (40 per cent) in 2015 to 1.33 billion in 2050 and Africa is projected to pass the 50 per cent urban tipping point around 2035 (UN, 2016). It is also stated that 62 percent of population will be living in urban centers in Nigeria by 2020.

This type of urbanization create negative results urban centers such as shortage of housing quantitatively, slum dwelling, squatter settlements, inadequate infrastructural amenities, squalor, overcrowding and generally poor living condition. It is clear that this type high rise urbanization brings inadequate housing, unplanned development, and improper management in many fields.

Spatial planning can be used as a tool to implement socioeconomic development by preventing environmental problems and simultaneously protecting the natural environment and the cultural environment. It is a crucial tool for reaching sustainable urban development. Sustainability and planning have common features. Jepson (2001) also stated that "Sustainability and the field of planning are inextricably linked and mutual relevant.

GIS is a powerful application that provides decision-makers with a variety of tools for management and evaluation of spatial data in many fields. It can be described as a box with equipment for management of geographic data and to solve multitude of spatial planning problems. GIS also contains analytical tools intended to help with multi-criteria problems, providing the user with extra useful functionality (Carver, 1991). GIS is a computerized solution to the previous map overlay

method been used. It has modernized the method and eradicated all the errors and shortcomings associated with the method. Therefore, using GIS for land suitability analysis is the most effective way to ensure accurate result and outcome. GIS technology utilizes geographical science with tools for better understanding. It helps people to obtain actionable information from all types of data (NCGIA, 2005).

Land use suitability assessment which is a crucial application in urban planning and land use management, provides fundamental base for planning through decision making process (Long et al., 2009). GIS based land use suitability analysis has been applied in a many fields such as agricultural suitability, regional planning, geological planning, strategic environmental assessment, (Marull et al., 2007), natural source management (Steiner et al., 2000), Forestry Planning (Temiz and Tecim, 2009), Urban Growth Prediction in South Korea (Park et al., 2011). Additionally, it has been used in locating sustainable suburban centers in Palestine (AbuSada and Thawaba, 2011), Urban Growth Simulation in Guanghzou in China (Wu, 1998), simulating sustainable urban growth scenarios in Famagusta (Kara, 2013), sustainable hillside development in Malaysia (Chandio et al., 2014) selecting best locations for urban growth in Serembian, Malaysia (Aburas et al., 2017) land suitability analysis for environmental dimension of sustainable urban development in Tehran (Javadian et al., 2011), identifying potential sites for housing zones in Dire Dawa, Ethiopia (Weldu and Deribew, 2016), developing urban growth scenarios for protection cropland areas in central Iran (Asgarian et al., 2018). In these studies, MCE and Multi Criteria Decision Making(MCDM) approaches have been applied for planning and management process.

Basically, MCE is aimed at analyzing the amount of possibilities to choose from in a multiple of criteria. A big advantage about using MCE is the possibility to evaluate numerous complex factors at different scales to produce a composite suitability map for the intended project (Eastman, 1999). Vaz et al. (2012) suggested combining urban development modeling with MCE for the Algarve so as to help for selecting the optimum development different for the case keeping property as input development policy (Vaz et al., 2012).

AHP is an example of MCE and it's used for this study. This is because AHP is an effective tool that helps enumerate both the subjective and objective parts of a decision by simplifying the complex choices into a chain of pair-wise comparison for producing the output. It also has a valuable method for testing to make sure the evaluation done by the decision-maker is constant, thereby curbing partiality in the process of decision-making.

Sustainable City is defined as the concrete spatial reflection of the sustainable urban development (Nijkamp and Perrels, 2014). Additionally, sustainable city should has mixed use functions, compact form, quality of life, high accessible to services. In order to make cities sustainable, it is required to reduce the depletion of the depletion of spatial and natural resources and the depletion of spatial and natural resources (EEA, 1995).

It is clear that sustainable urban growth has many criteria to be achieved in many built environment. Within this framework, AHP and GIS is combined for urban planning perspective for separating policies and convert them into spatial layers in order to create land suitability analysis in Abuja.

2. Study area

Abuja is located at the center of Nigeria within latitude 9.07^0N and longitude 7.48^0E with a land area of 8,000km^2. Abuja has the savannah vegetation, giving it a rich soil for agriculture and a favorable climate that is neither too hot nor too cold all year round. Abuja is divided into six area councils; Kuje, Abaji, Bwari, Gwagwalada, Kwali and Municipal Area Council (AMAC). The focus of this study is the Municapal Area Council (AMAC) (Fig. 1). AMAC with land area of 1,993hm^2 is the administrative center with high concentration of secondary and tertiary economic activities. Consequently, the rate of urbanization is high (FCDA, 2018).
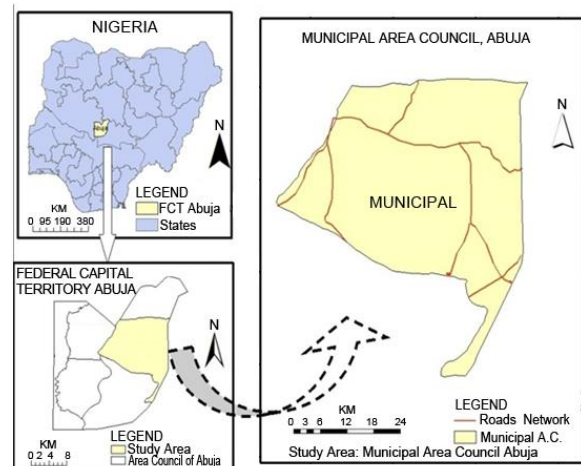

Fig. 1: Study area (Usman and Lay, 2013)

Abuja is experiencing rapid urbanization as a result of migration of people not only from the rural areas, but also from other states of the country in search of a better wage and salary (Okoye, 2013). This rapid urbanization as a result of population increase is putting a lot of strain on the amenities and infrastructures of the city as well as rapid change in the Land Use Land Cover in the city (Fig. 2) (Sorensen, 2000). Consequently, the city is experiencing urban degradation, due to lack of sufficient infrastructures, good maintenance of the existing infrastructures and environmental destructions (Gbadegesin and Aluko, 2010).

Furthermore, as the city grew and rapid urbanization, the areas marked out as "Green Areas" became the subject of abuse and were allocated to developers who converted them to other land uses (Fig. 3). This causes alteration of the initial design

and development of the City and also affects the livability of the city (Jibril, 2010).
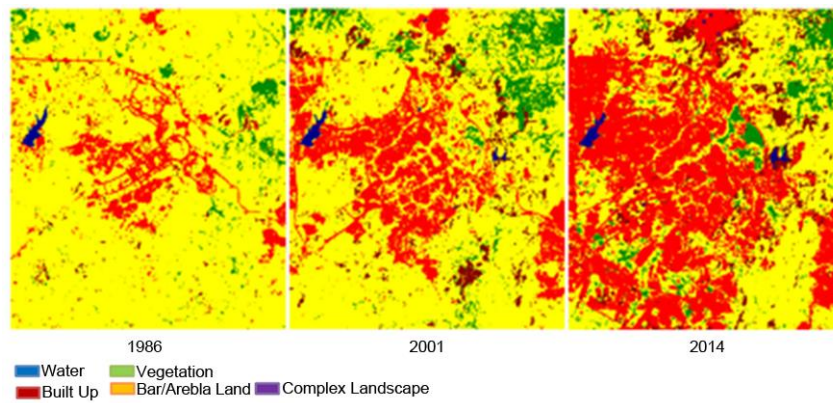

Fig. 2: Land use analysis (Mahmoud et al., 2016)

Maitama Sport Complex was converted to residential development

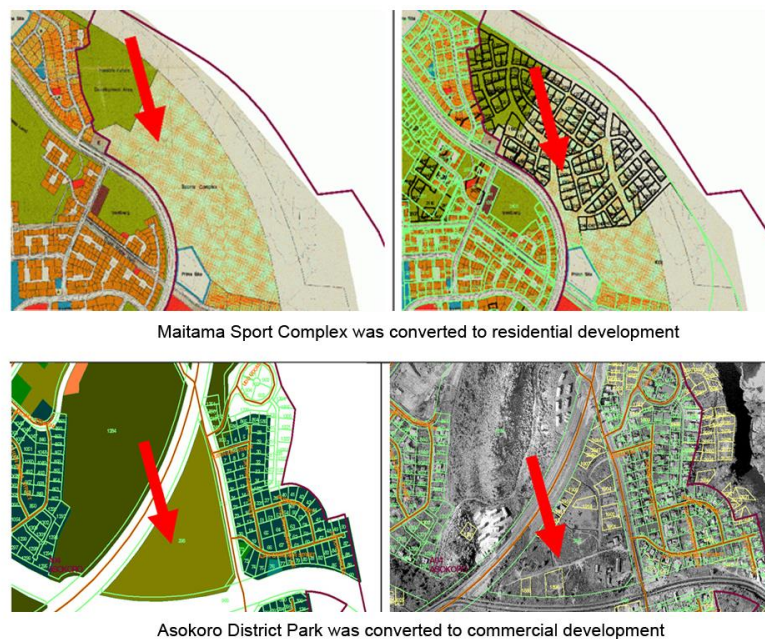Asokoro District Park was converted to commercial development

Fig. 3: Overview of the green and open spaces (Jibril, 2010)

3. Materials and methodology

This study will utilize the combination of GIS with MCE in order to analyze spatial data in order to find suitable sites for future sustainable urban growth in the city of Abuja. Sustainable growth policies of Compact Growth (EEA, 1995; EC, 1999; APA, 2002), Social Equity (EC, 1999) and Environmental protection (EC, 2003; EC, 1999) will be translated into spatial layers (Table 1), AHP technique will be utilized to compute their priority hierarchy which in the end determined how they conclude the final suitability map (Fig. 4).

3.1. Data

The data needed for the development of the layers used for the evaluation are itemized in the Table 2. The availability of the required data is so critical to the study; as a result some data that could not be obtained from official sources were developed by the authors.

Table 1: Summary of policy and criteria selection from literature review with data availability

Goal	Policy	Sub-Policy	Criteria
	Compact Urban Form	Using existing infrastructure	Distance from Roads
		Increasing density of built up areas	Distance from City Center
		Selecting sites for proper Slope	Slope
Sustainable Urban Development	Environmental Protection	Protection of Soil Productivity	Soil Productivity
		Discourage growth in natural areas	Vegetation
		Protection of Natural Sites	Natural Sites
	Social Equity	Ensuring equal accessibility of basic services	Distance from educational services
		Ensuring equal accessibility to open spaces	Distance from open/green spaces
		Ensuring get away from undesirable pollution sites	Distance from pollution sites

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Compact Growth	Social Equity	Environmental Protection
-Distance to center	-Distance to education	-Soil
-Distance to roads	-Distance to green/open	-Vegetation
-Slope	-Distance from pollution sites	-Natural features

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        │           weight in AHP                  │        └──────────────────┘
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        │  Using GIS tools: overlay and raster     │
        │              calculator                  │
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        │  Creation of final suitability map for   │
        │         urban growth in Abuja            │
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Fig. 4: Methodological framework

Table 2: Spatial data and their sources used for the analysis

Data	Source	Layer
Soil class map	European Soil Data Center (ESDC) https://esdac.jrc.ec.europa.eu/content/soils-map-nigeria	Soil
Digital Elevation Model (DEM)	Office of the Surveyor General of the Federation Abuja, Nigeria	Slope
Satellite images	https://remotepixel.ca/projects/index.html#L8ba	Vegetation
Road network, natural features points, educational facilities, green/open spaces, pollution sites, center	The authors by means of on-screen digitization technique	Distance to roads, distance from natural features, distance to education, distance to green/open, distance from pollution sites, distance to center

3.2. GIS based MCE analysis

In this part of the study, the results of the analyzed data using the stated methodology are presented. The layers (criteria and sub-criteria) used to determine the suitable sites for sustainable urban growth in Abuja are explained;

3.2.1. Distance to center

Central business district is the center of Abuja municipality, containing structures for the administrative, economic and expatriate activities. For a sustainable urban growth, development should be closer to the center to curb the need for longer commute. Therefore, areas within 0 – 1 km, 1 – 5 km and 5km+ distance were determined for evaluation (Fig. 5).

3.2.2. Distance to road

Urban growth should be accessible to existing road network for effective mobility of the people. Therefore, areas within 0 – 250 m, 250 – 500m, 500m – 1km and 1km+ distance were determined for evaluation (Fig. 6).

3.2.3. Slope

From an economic point, sites that have fairly gentle slopes or flat terrain are more suitable because steep slope areas results in increase in the construction cost. Therefore sites with lower slope are most ideal for urban growth. For the analysis, areas with 0 – 2%, 2 – 5%, 5 – 10% and 10%+ slope are determined for evaluation (Fig. 7).

3.2.4. Distance to education

For a sustainable urban development, integration of educational facilities (primary and secondary schools) at close proximity for easy access by the people is vital. Therefore, areas within 0 – 250m, 250 – 500m, 500m – 1km and 1 km+ distance are determined for evaluation (Fig. 8).
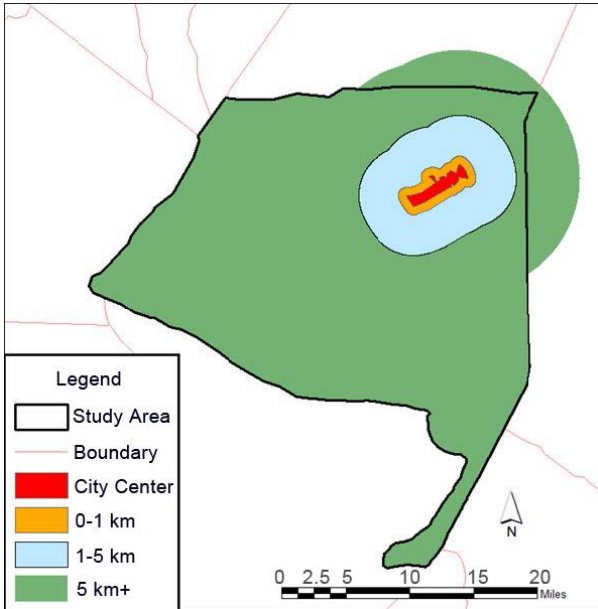
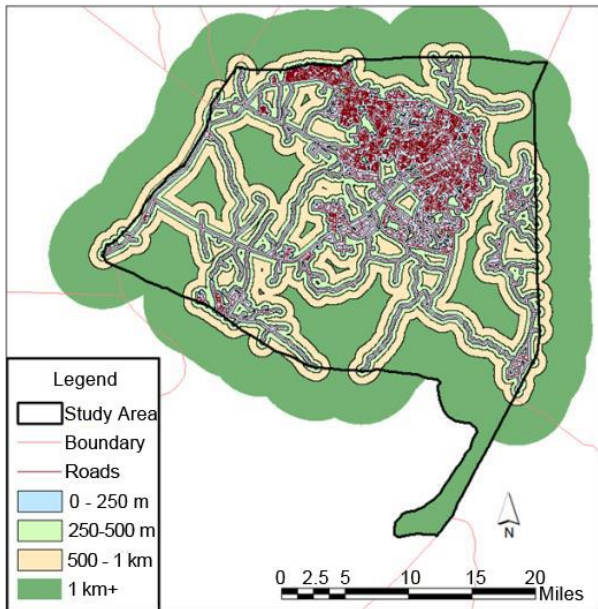**Fig. 5:** Distance to center criteria map

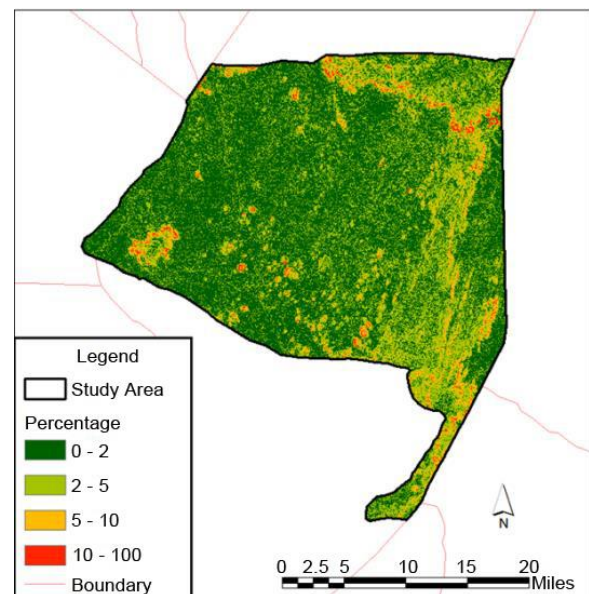**Fig. 6:** Distance to roads criteria map

Fig. 7: Slope criteria map

3.2.5. Distance to green/open

Green and open spaces such as parks, sports and recreational should be easily accessed by the people within an urban environment. As such, areas within 0 – 250 m, 250 – 500m, 500m – 1km and 1km+ distance are determined for evaluation (Fig. 9).

3.2.6. Distance from pollution sites

Sites such as quarries, treatment plant and airport causes noise and air pollution making them undesirable for living. Therefore, sustainable urban growth should be away from such sites. For this analysis, areas within 0 – 1km, 1 – 5km and 5km+ distance are determined for evaluation (Fig. 10).
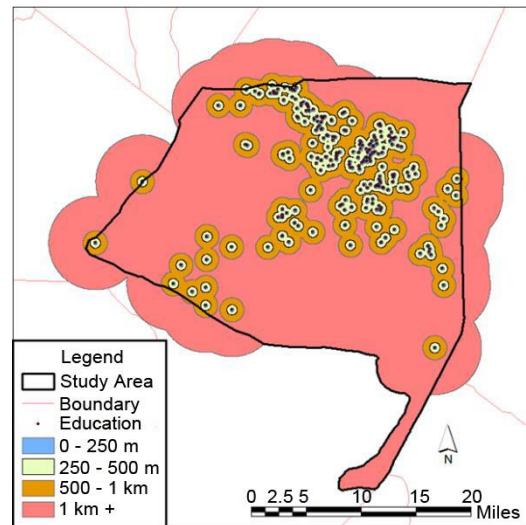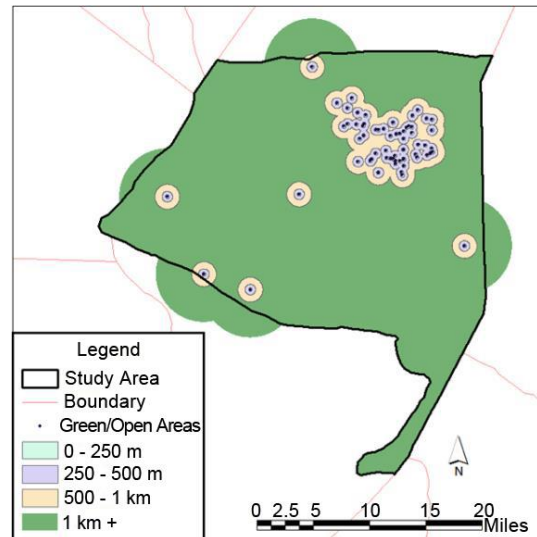

Fig. 8: Distance to education criteria map

Fig. 9: Distance to green/open criteria map

3.2.7. Soil

The soil class of Abuja municipality has geology of Undifferentiated Basement Complex and a relief of Undulating plains with scattered rock outcrops and hills. The soil is described as shallow to moderately deep with well drained to somewhat poorly drained soils of loamy sand to sand loamy. The soil is suitable

for both agriculture and construction. Therefore, areas with arable soil should not be used for urban growth (Fig. 11).
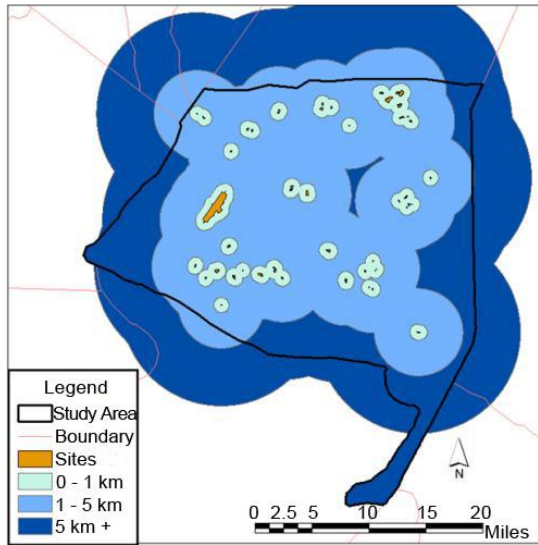

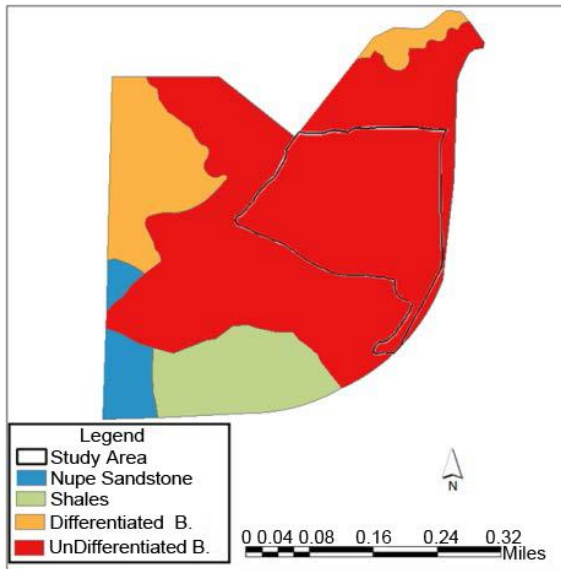**Fig. 10:** Distance from pollution sites criteria map

Fig. 11: Soil criteria map

3.2.8. Vegetation

Vegetation is also important to the ecological uniqueness of a place; as such need to be preserved. Forest and wetland vegetation are not to be cleared and used for urban growth, therefore, will be selected as constraints and subtracted from assessment process (Fig. 12).

3.2.9. Natural features

Natural features such as the lakes and river streams are delicate sites and vital to the ecosystem and need protecting. Therefore, should be encroached upon through urban growth so as not to destroy them. For the analysis, such sites are added to constraints for evaluation and areas within 0 – 500 m, 500 – 1 km and 1 km+ is determined for evaluation (Fig. 13).
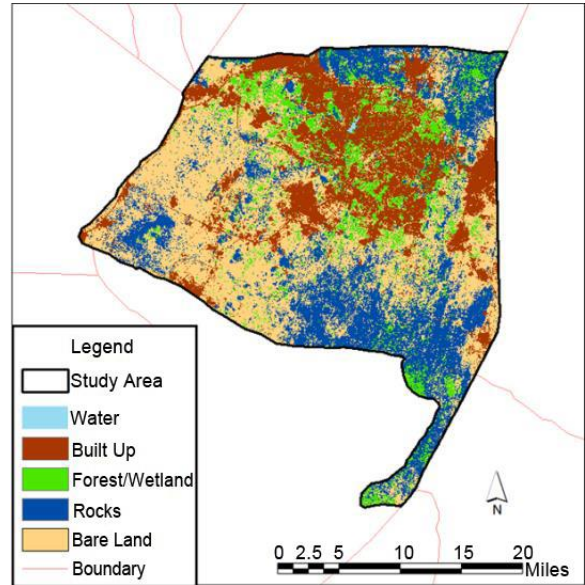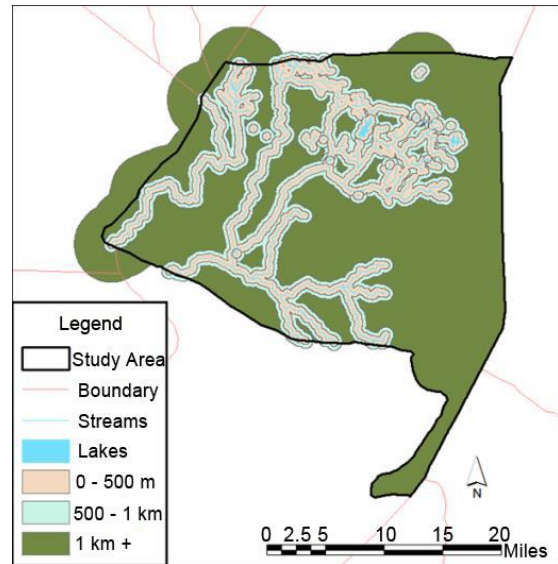

Fig. 12: Vegetation criteria map

Fig. 13: Distance from natural features criteria map

After the development of spatial criteria set, it is required to define criteria weights. Pairwise comparison matrices were formed through questionnaire with various experts and stakeholders from different disciplines. Decision-makers such as architects, environmental engineer, AMAC housing manager, project manager, planning and development surveyor, economist, quantity surveyor, landscape architect, building contractor, transport engineer and town planner ranked each criteria weights by comparing and filling the matrices.

After that, CR values for each comparison table were checked to confirm the reliability of these experts' choice. As proposed by Saaty (2008), pairwise comparison is carried out using the scale with numbers 1 to 9 to assign comparative importance (Table 3).

When value of CR is ≤ 0.1 (10%), the inconsistency is satisfactory. But if value of CR is > 0.1 (10%), the inconsistency is non-satisfactory and the expert decision needs to be looked over. The

result of the AHP calculation for the main policies and criteria are explained in the Tables 4 and 5.

The priority values is to gauge the importance of the evaluation value with 1 = least important and 9 = highly important.

4. Results and discussion

The final suitability map (Fig. 14) is the outcome of the combination and overlay of all the criteria maps using the suitability index formula;

$$SI = \sum[Policy\ Weight * Criteria\ Map * Criteria\ Weight].$$

Therefore; suitability map = [(0.318*distance to center*0.306) + (0.318*distance to roads*0.404) + (0.318*slope*0.29)) + (0.32*distance to education*0.333) + (0.32*distance to green/open*0.44) + (0.32*distance from pollution sites*0.227)) + (0.363*soil*0.205) + (0.362*vegetation*0.171) + (0.363*natural features*0.624)].

Table 3: Pair-wise comparison values (Saaty, 2008)

Level for importance	Translation	Description
1	Exact importance	Criteria are the same in the overall objective
2	Slight importance	
3	Moderate importance	A criterion is a little more preferred than the other
4	More reasonable importance	
5	Essential importance	A criterion strongly favored over the other
6	More essential	
7	Demonstrated important	A criterion is preferred more intensely than the other
8	Really essential	
9	Absolutely important	A criterion is completely more significant than the other.

Table 4: Weights and CR values for main and sub-criteria

Main Policy	Weights	CR	Criteria	Weights	CR
Compact Growth	0.318		Distance to Center	0.306	
			Distance to Roads	0.404	0.02
			Slope	0.29	
Social Equity	0.32	0.04	Distance to Education	0.333	
			Distance to Green/Open	0.44	0.03
			Distance from Pollution sites	0.227	
Environmental Protection	0.363		Soil	0.205	
			Vegetation	0.171	0.03
			Natural Features	0.624	

Table 5: Evaluation values and priority for the sub-criteria

Criteria	Sub-Criteria	Priority (1, 3, 5, 7, 9)
Distance to Center	0 – 1km	9
	1 – 5km	7
	5km+	5
Distance to Roads	0 – 250m	9
	250 – 500m	7
	500 – 1km	5
	1km+	3
Slope	0 – 2%	9
	2 – 5%	7
	5 – 10%	5
	10 – 100%	3
Distance to Education	0 – 250m	9
	250 – 500m	7
	500 – 1km	5
	1km+	3
Distance to Green/Open	0 – 250m	9
	250 – 500m	7
	500 – 1km	5
	1km+	3
Distance from Pollution sites	0 – 1km	3
	1 – 5km	7
	5km+	9
Soil	Nupe Sandstone	1
	Shales	1
	Differentiated Basement Complex	1
	Undifferentiated Basement Complex	9
Vegetation	Water	1
	Built Up	3
	Forest/Wetland	5
	Rocks	7
	Bare Land	9
Natural Features	0 – 500m	5
	500 – 1km	7
	1km+	9

The final suitability map (Fig. 14) indicates that the suitability of Abuja for a sustainable urban growth is classed into five categories. Table 6 enumerates the output from the suitability map;

Table 6: Suitability categories and area size coverage

Suitability category	Area (km^2)	Coverage (%)
Not suitable	187.05	10.57
Low suitability	372.35	21.05
Moderate suitability	161.85	9.15
High suitability	547.70	30.96
Very high suitability	500.05	28.27
Total	1769	100

From the Table 5, its shows that 59.23% of the total land area in Abuja Municipality falls under high suitability and very high suitability, while 31.62% falls under the unsuitable and low suitability. The growth and development plans should be in accordance with the suitability of the site. Areas of very high suitability should be developed first descending down the suitability rank. Areas of moderate and low suitability can be developed as recreational centers and facilities to make-up for the green areas that were re-appropriated and developed for a different land use.
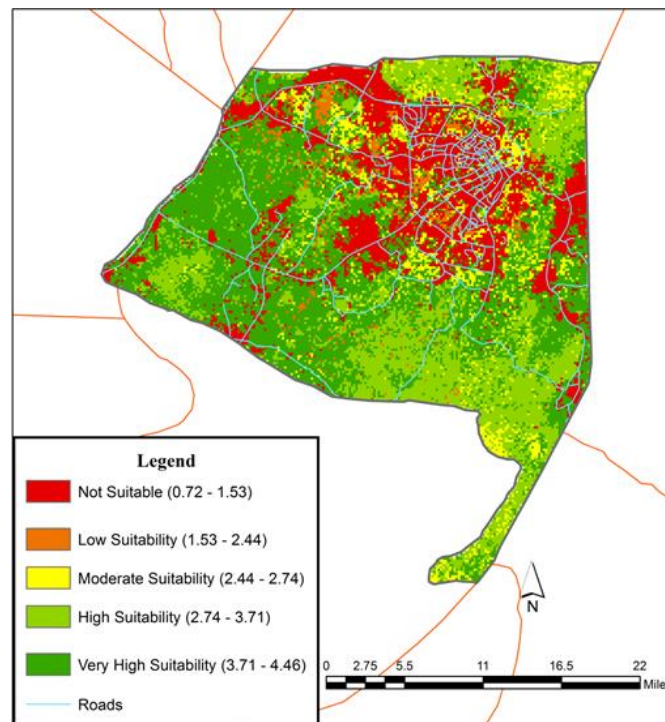
Fig. 14: Suitability map for sustainable urban growth

5. Conclusion

This study is a step towards finding solution to the looming urban problems in the city of Abuja. The study focuses on identifying suitable sites for sustainable urban growth of the city. To that end, the study implored the spatial analysis tools; GIS with MCE to handle the suitability analysis so that environmentally safe and economically feasible sites for urban growth can be identified. It is imperative that the city thrives and not fail as Lagos did, so as to serve as a model for the development of other cities.

The study highlights the effectiveness of GIS based MCE technique as a decision support system, serving as a guideline to overcome future environmental hazards. GIS based MCE provides planners with support tool for effective urban planning and land-use management. Its simplicity in understanding and application made it a widely used technique for spatial analysis.

This pilot study can further be used by planners or researchers as guideline for future research and development of other cities in Nigeria.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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