Suitability Analysis for Urban Development in Kaduna Metropolis, Nigeria

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Abstract

The pursuit of identifying suitable land for urban development in Kaduna metropolis is crucial for enhancing agricultural production, sustainable development, and efficient resource utilization in Nigeria. This research aimed to assess and designate areas with optimal characteristics for urban development. The criteria considered for the suitability analysis encompassed land use land cover, slope, elevation, proximity to the road network, and proximity to water bodies. To establish a comprehensive assessment framework, all criteria were standardized, and the analytic hierarchy process (AHP) was employed to assign appropriate weights to each criterion through pairwise comparison. The weighted overlay technique was subsequently applied to generate a suitability map for urban development. The findings obtained from the weighted overlay analysis indicate that approximately 6% of the study area is marginally suitable, while more than 77% exhibits a moderate level of suitability. Furthermore, approximately 17% of the total land area demonstrates a high level of suitability for urban development. Given the results, it is highly recommended that the Kaduna State Urban Development Agency (KASUPDA) incorporates the use of geospatial technologies such as geographic information system (GIS) and remote sensing, along with the analytical hierarchy process, for conducting comprehensive and reliable land suitability evaluations in any future urban development endeavors within the metropolis. By adopting such an approach, KASUPDA and other relevant stakeholders can make informed decisions, optimize resource allocation, and ensure sustainable urban development in Kaduna metropolis.

Keywords: Land Suitability, GIS, Remote Sensing, Urban development, AHP

INTRODUCTION

Economic development, industrialization, rural-urban migration, and natural population growth have all contributed to unprecedented urbanization expansions in both developed and developing countries (Sabbar *et al* ., 2015). Physical (urban sprawl and the increase in artificial surfaces), geographical (population and employment concentration), economic (markets, agglomeration economies, and knowledge spillovers), and societal (social and cultural change) are all dimensions and perceptions of urbanization (Mitchell, 2004). Urban development has become a global issue, raising concerns among planners and decision-makers about the ecosystem's long-term effects (Bihamta *et al* ., 2014). For ecosystem protection and long-term development, simulating urban growth patterns has become critical. As a result, simulation techniques such as site suitability analysis can be used to improve and obtain accurate knowledge of growth factors that affect future land uses (Pijanowski *et al* ., 2002). Remote sensing and Geographic Information System (GIS) techniques aid in the understanding of spatial and temporal changes, as well as all effective elements (Punia and Singh, 2012).

The ability of a particular type of land to support a specific use is referred to as site suitability, and the process of land suitability classification involves evaluating the grouping of specific land areas in terms of their suitability for a defined use (Prakash, 2003). According to specific requirements, preferences, or predictors of some activity, site suitability analysis aims to identify the most appropriate spatial pattern for uses (Collins *et al.*, 2001). A GIS-based process for determining the suitability of a given area for a specific use is known as site suitability analysis (Javadian *et al.*, 2011). The basic premise of GIS suitability analysis is that each aspect of the landscape has inherent characteristics that are either suitable or unsuitable for the planned activities, such as educational land use (Murphy, 2005). A wide range of physical, cultural, economic, and environmental factors are used as model inputs (Lagro, 2001). The current land use/land cover, slope, elevation, soil, road accessibility, flood hazard, geology, and water availability are some of the characteristics of a site that can be considered for suitability modelling (Jain and Subbaiah, 2007).

Remote sensing and GIS can be used to link or integrate data that is difficult to associate with other methods, and you can create and analyse new variables using combinations of mapped variables (Bernharden, 2002). Multi Criteria Analysis (MCA) is an interactive and flexible geoinformation analysis management tool, perfect for simulating complex environmental issues. The MCA technique's main goal is to solve the problems that humans have had dealing with large amounts of complex data in a consistent manner (Malczewski, 2006). The Analytic Hierarchy Process (AHP) is a structured method of dealing with complex decisions. It's a Multi-Attribute Decision Method, which includes a variety of quantitative techniques for making decisions with multiple competing criteria. Rather than prescribing a "correct" decision, the AHP assists decision-makers in determining the best option for their goal and understanding of the problem (Steiguer *et al.*, 2003).

Urban expansion has become a common issue in most developing countries due to uncontrolled migration from rural to urban areas, which results in an increase in population (Scariah and Vinaya, 2016). Furthermore, the goal of urban expansion is to develop a well-planned infrastructure based on the concept of Sustainable development. As a result, finding suitable sites for urban development and growth is critical (Nitheshnirmal *et al.*, 2017).

Site suitability analysis has become more important as people strive to make better use of limited land resources because of rising demand for land due to population growth and urbanization in urban centres. Furthermore, choosing a suitable site for sustainable urban development is one of the most important and complex issues in urban planning because many criteria must be considered and analysed using the most effective techniques. Identifying suitable sites for urban development is a major concern due to the physical characteristics of the Kaduna metropolis (flood plain, topography, and other factors). Site suitability analysis can aid in sound and rational decision-making in urban planning and development. The cost of conducting a site suitability analysis can be drastically reduced by combining remote sensing and GIS together with AHP techniques. Previous studies in Nigeria (Chigbu and Nmeregini, 2016; Hussaini, 2017) and around the world (Mohammed *et al.*, 2016; Raddad, 2016; Mallick *et al.*, 2022) used MCA to assess site suitability, but the majority of the studies in Nigeria focused on land suitability for agricultural production and waste disposal. As a result, this study will perform land evaluation by using geospatial techniques and AHP to find the suitable areas to be considered for urban development in Kaduna metropolis.

Study Area

The study area lies between Latitudes 10° 25' 00 to 10°39' 00"N of the Equator and between Longitudes 7° 19' 00" to 7° 39' 00" E of the Greenwich Meridian (see Figure 1). The area comprises of Kaduna North Local Government, Kaduna South Local Government, part of Igabi Local Government, and part of Chikun Local Government. It covers roughly over 1300km². The soil of the Kaduna metropolis is mainly lithosols developed over the thoroughly weathered solid geology, the regolith is overlain by a thin layer of Aeolian drift (Udo, 1978). The morphology of the area on which Kaduna is built comprises of a gentle undulating terrain at about 30.48 meters above the 609.6 meters contour line above sea level 600m extending up to 50km outward but more to the north and south-east where it terminates at the foot of Jos Plateau. It is drained by river Kaduna. From Shiroro, there is another 200km flow before it finally discharges into River Niger on its Northern shores at Pategi (Sulaiman, 2001). Residential land uses occupy the largest area in Kaduna metropolis. This consists of low, medium and high residential neighbourhoods. Agricultural land uses cut across all categories of slope. However, agricultural land uses are found majorly in the rural areas as more residential neighbourhoods are springing up. With the increase in population, more pressure is being exerted on land as more people demand for land for residential, agricultural and other purposes. Basically, the land use of the area is industrial, agricultural and mostly residential.

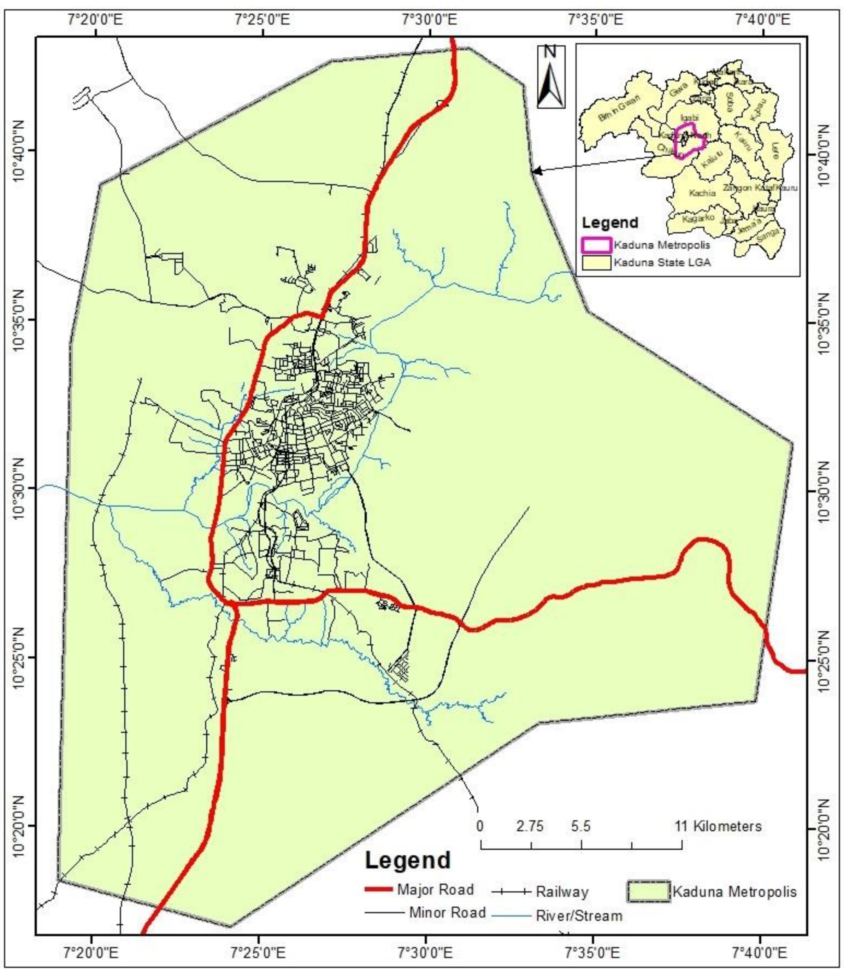


Figure 1: Kaduna Metropolis

MATERIALS AND METHOD

The types and sources of data used for the generation of suitability map for urban development in Kaduna metropolis are presented in Table 1.

Table 1: Types and sources of data

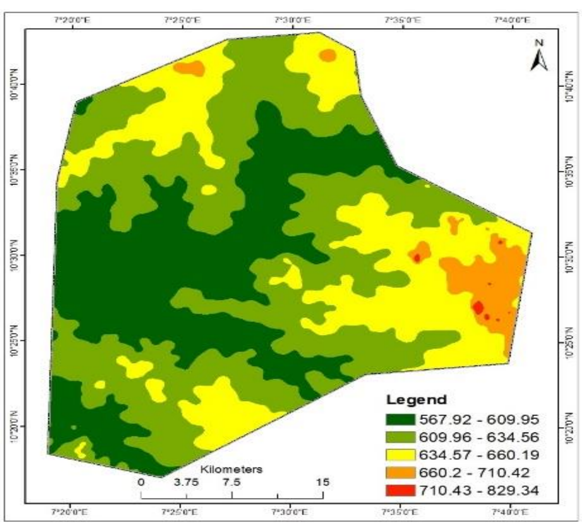
Data	Resolution	Source
Land Use Land Cover	10m	Downloaded from Sentinel-2 Land Use/ Land Cover Downloader; www.arcgis.com/apps/instant/media/index.html?appid=fc92d38533d440078f17678ebc20e8e2
Shuttle Radar Topographic Mission, (SRTM)	30m	To be downloaded from the United State Geological Survey (USGS); (http://glovis.usgs.gov)
Road, railway and river shape files	Nil	Downloaded from https://grid3.gov.ng

Mapping of Criteria

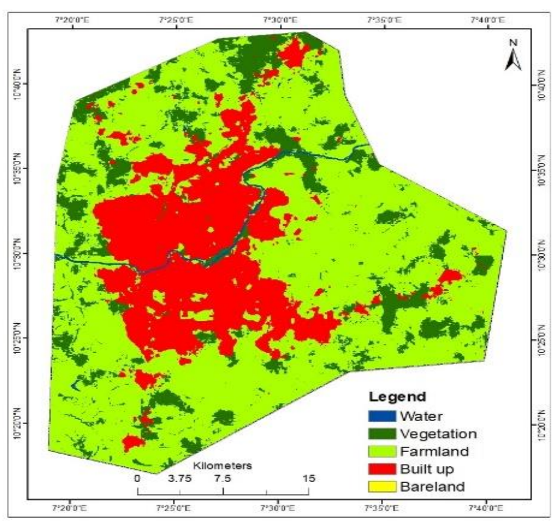
The suitability analysis for urban development was generated using five factors: land use land cover, elevation, slope, proximity to road, and proximity to river. The Euclidean distance tool in ArcGIS 10.6 was used to generate proximity to road and river rasters. The graphical representation of the five factors is shown in Figure 1.

Standardization of Variables

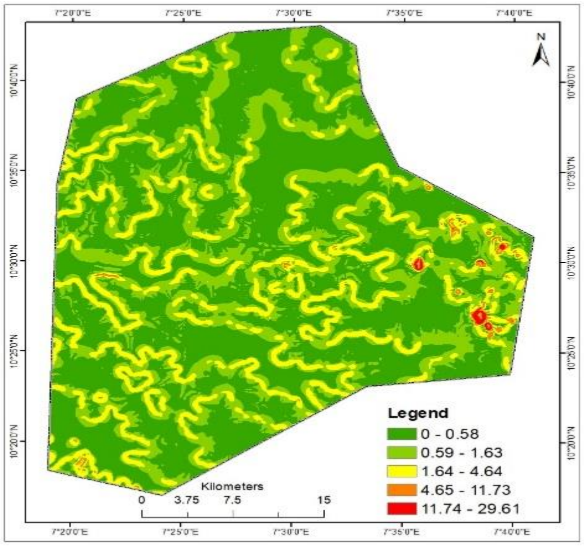
The factors (raster data layers) were measured in a variety of scales and units, and the attribute of each used to determine land suitability may not be equally important. As a result, the attributes of the variables were ranked based on their relative impact on land suitability for urban development using a common measurement scale. Using the reclassify tool in ArcGIS 10.6, the factors were categorized into a common scale of 1-9, with 9 being highly suitable and 1 being not suitable, as shown in Table 2.



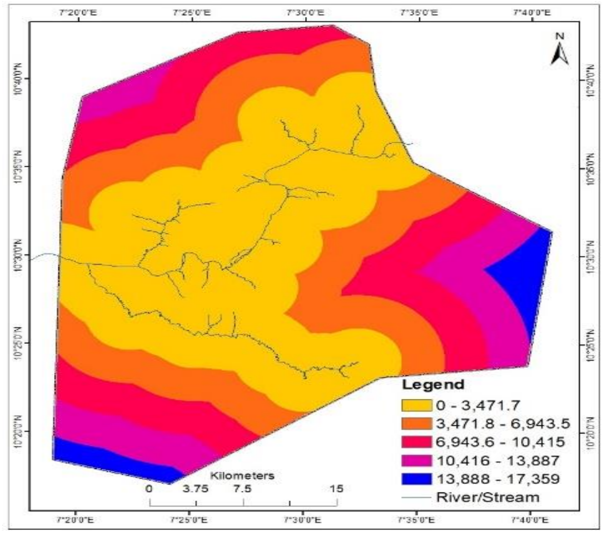
Elevation Map of Kaduna Metropolis



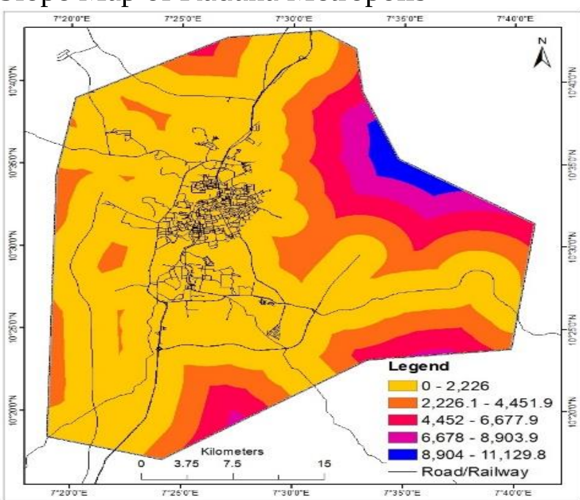
LULC Map of Kaduna Metropolis



Slope Map of Kaduna Metropolis



River/Stream Map of Kaduna Metropolis



Road Network Map of Kaduna Metropolis

Figure 2: Thematic Map of Factors

Determination of Criterion Weights Using AHP

Determination of criterion weights using AHP involves assigning a value to the criterion based on their relative importance. This process generally involves expert opinion, indigenous knowledge (Joerin, Theriault and Musy, 2001), field surveys (Corona *et al* ., 2008) and comparison of existing land use with location specific characteristics (Fischer *et al* ., 2005). Within a comparison matrix, a bigger value implies that one of the criteria is more important than the other for a particular pair of criteria. Whereas, value 1 means that the two criteria being compared are of equal importance. While, value 9 means the absolute importance of one criterion over the other and value 1/9 means the absolute triviality of one criterion over the other (Saaty and Vargas, 1991).

Suitability Map for Urban Development

All the factors were converted to raster at 30m resolution using the same coordinate system (UTM zone 32) and the suitability map was generated using the weighted overlay tool in ArcGIS 10.6. The results of weighted overlay are presented in Table 5 and illustrated in Figure 3.

RESULTS AND DISCUSSION

Mapping and Standardization of Criteria

According to the 2020 land use land cover map of Kaduna metropolis, farmland occupied the largest proportion of total land, accounting for more than 61% of the total area, followed by built-up areas accounting for about 24%. Water made up only 0.6% of the total, while vegetation made up about 14%. Bare land, farmland, and vegetation, according to Jain and Subbaiah (2007), are highly suitable, moderately suitable, and marginally suitable for urban development, respectively.

The slope analysis was conducted based on the classification strategy adapted from Mu (2006) and the result revealed that 99.4% of the land in Kaduna metropolis is almost flat, with slopes ranging from 0 to 5 degrees. In terms of slope, this area was deemed highly suitable for urban development. 0.6 percent of the total land area was covered by steep slopes greater than 5 degrees. Slopes that are too steep increase the cost of construction and thus not suitable for urban development.

Based on the method adapted from Patil and Jamgade (2019), five elevation suitability classes for urban development were created, with 58.5% of the study area rated as highly suitable and 23.9% as moderately suitable for urban development. The area covered by areas with an elevation of 700m to 750m accounted for 16.8% of the total area. Because this area was mostly on higher ground characterized by hills, it was deemed unsuitable for urban development.

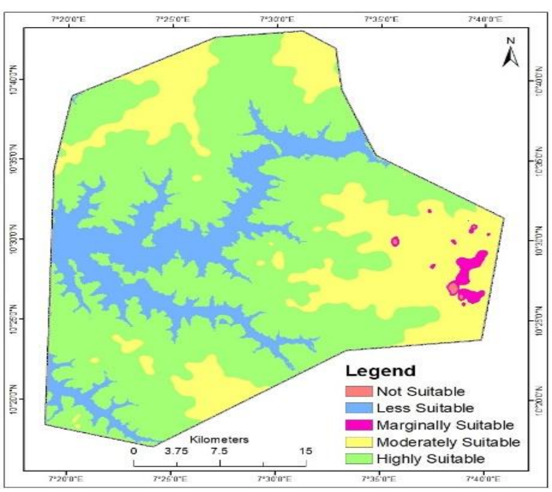
The road network is crucial for urban development because it connects different settlements and is also used in the transportation of goods and services. Proximity analysis to the road network in the study area was classified based on the framework adapted from Jain and Subbaiah (2007) the result showed that 15% of the total land area is within 0-200m distance from the road network and rated highly suitable for urban development, whereas areas more than 2000m away from the road network in the study area occupied approximately 37% of the proportion of land in the area and are classified unsuitable for urban development. The closer the area is to the access road, the better it is suited for urban development.

The study used proximity to river/stream to identify areas that are prone to flooding. The Euclidean distance tool in the ArcGIS 10.6 Spatial Analyst extension was used to generate the proximity to river raster. The proximity to the river was classified into five suitability classes using a classification scheme adapted from Abera (2019). Areas less than 150 meters from the river account for about 2.5 percent of the total land area and are unsuitable for urban development, while areas more than 1000 meters away from the river account for about 81% of the total land area and are highly suitable for urban development.

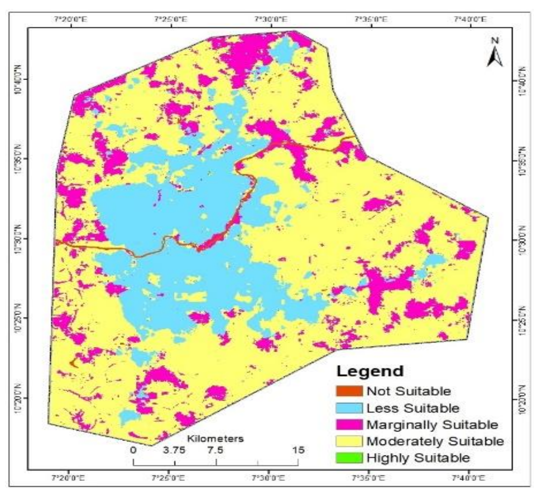
Table 2: Standardization of Criteria

Criteria	Category	Rank	Level of Suitability	Area (Ha)	%
LULC in Hectares (Ha)	Water	1	Not Suitable	844.74	0.6
	Built up	3	Less Suitable	31079.07	23.8
	Vegetation	5	Marginally Suitable	18668.25	14.3
	Farmland	7	Moderately Suitable	79754.04	61.2

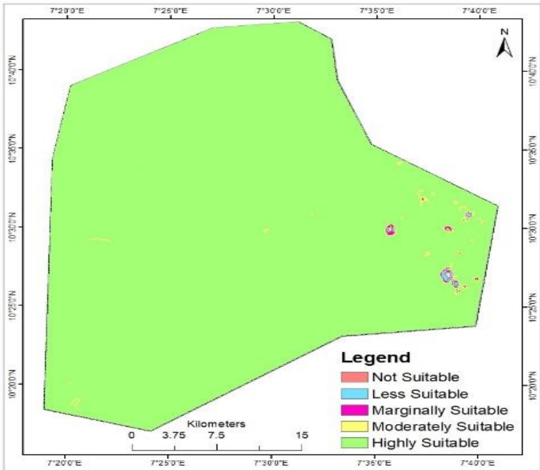
	Bare land	9	Highly Suitable	22.14	0.0
	Total			130368.2	100
Slope in Degrees	>25	1	Not Suitable	6.3	0.00
	15-25	3	Less Suitable	116.46	0.09
	10-15	5	Marginally Suitable	158.67	0.12
	5-10	7	Moderately Suitable	500.58	0.38
	<5	9	Highly Suitable	129586.23	99.40
	Total			130368.2	100
Elevation in Metres	>750	1	Not Suitable	106.74	0.08
	700-750	3	Less Suitable	21873.15	16.78
	650-700	5	Marginally Suitable	1035.9	0.79
	<600	7	Moderately Suitable	31139.1	23.89
	600-650	9	Highly Suitable	76213.35	58.46
	Total			130368.24	100
Proximity to Road in Metres	>2000	1	Not Suitable	48056.76	36.9
	1000-2000	3	Less Suitable	26637.21	20.4
	500-1000	5	Marginally Suitable	19620.36	15.0
	200-500	7	Moderately Suitable	16560.54	12.7
	0-200	9	Highly Suitable	19493.37	15.0
	Total			130368.2	100
Proximity to River in Metres	0-150	1	Not Suitable	3294.72	2.5
	0-300	3	Less Suitable	5514.39	4.2
	300-500	5	Marginally Suitable	5011.65	3.8
	500-1000	7	Moderately Suitable	11090.16	8.5
	>1000	9	Highly Suitable	105457.32	80.9
	Total			130368.2	100



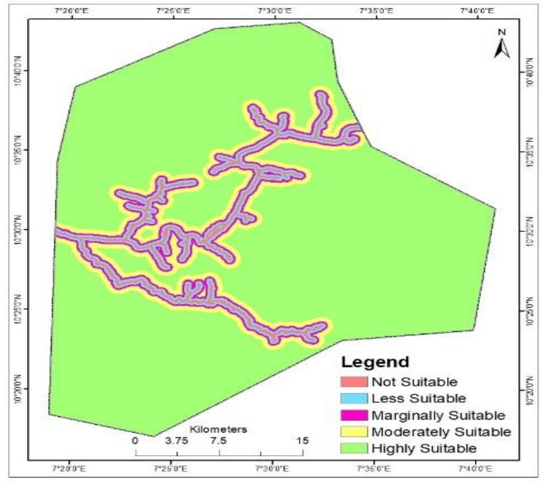
Reclassified Elevation Map



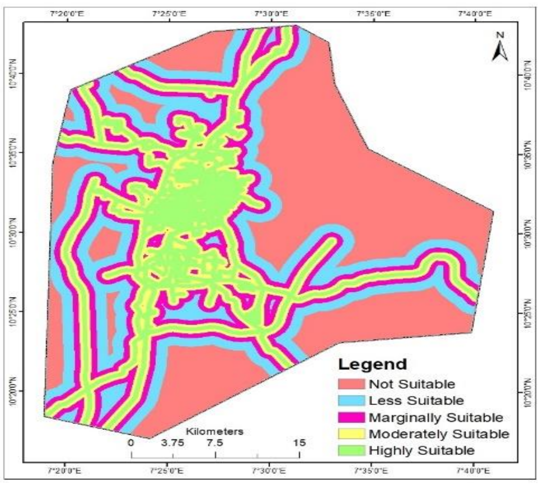
Reclassified LULC Map



Reclassified Slope Map



Reclassified River/Stream Map



Reclassified Road Network Map

Figure 3: Reclassified Maps the Factors

Pairwise Comparison Matrix

The weight of each factor was calculated using AHP, and the results of the pairwise comparison matrix show that slope has the highest weight of 0.39 (39%), followed by proximity to road with about 0.28. (28%). The weights of proximity to river and land use land cover are approximately 0.17 (17%) and 0.10 (10%), respectively, while elevation is only 0.06 (6%). The consistency index was calculated to be zero, which is satisfactory.

Table 3: Pairwise Comparison Matrix

	LULC	DEM	Proximity to River	Proximity to Road	Slope
LULC	1	2	2/3	2/5	2/7
DEM	1/2	1	1/3	1/5	1/7
Proximity to River	3/2	3	1	3/5	3/7
Proximity to Road	5/2	5	5/3	1	5/7
Slope	7/2	7	7/3	7/5	1

Table 4: Normalized Pairwise Comparison Matrix

	LULC	ELE	PRI	PRO	Slope	Average
LULC	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
Elevation (ELE)	0.0556	0.0556	0.0556	0.0556	0.0556	0.0556
Proximity to River (PRI)	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
Proximity to Road (PRO)	0.2778	0.2778	0.2778	0.2778	0.2778	0.2778
Slope	0.3889	0.3889	0.3889	0.3889	0.3889	0.3889
Total	1	1	1	1	1	1

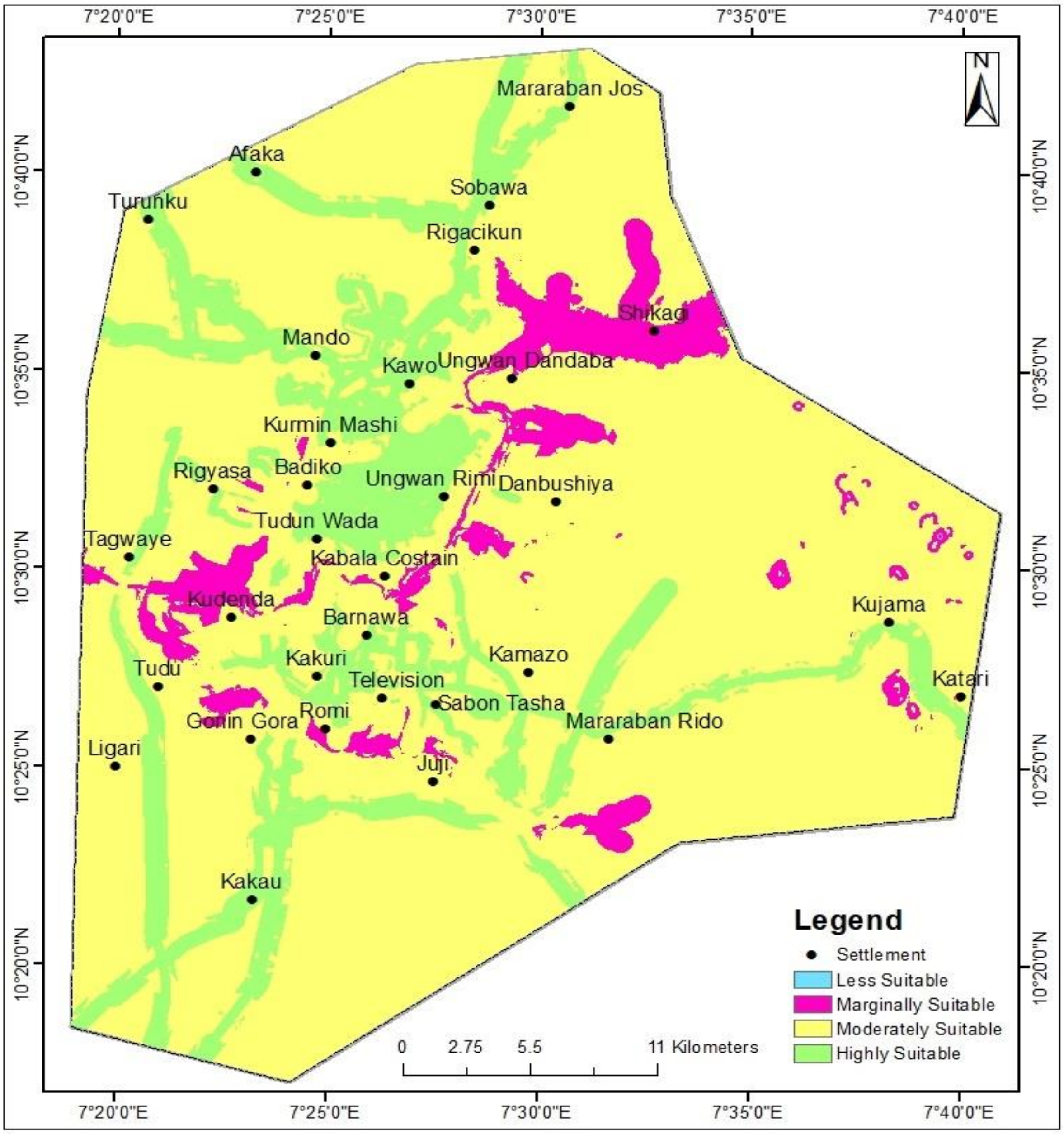


Figure 4: Suitability Map of Kaduna metropolis

Suitability Map for Urban Development

According to the results of weighted overlay analysis presented in Table 5, 6% of the area is marginally suitable, more than 77% is moderately suitable, and approximately 17% of the total land is highly suitable for urban development. Areas that are ideal for urban development have gentle slopes, are not prone to flooding, located near access roads, and are bare land. Highly suitable land for urban development can be found in the settlements of Ungwan Rimi, Barnawa, Kawo, Mando, and others. In the study area, marginally suitable land for urban development is generally found closer to the bank of River Kaduna. This is in line with the study of Mallick *et al* . (2022) who discovered that 12.7% of the land Sivas, Turkey was highly suitable for urban development.

Table 5: Suitability Analysis for Urban development

Rank	Level of Suitability	Area (Ha)	%
3	Less Suitable	6.66	0.01
5	Marginally Suitable	7847.82	6.02
7	Moderately Suitable	100732.9	77.27
9	Highly Suitable	21780.81	16.71
	Total	130368.2	100

CONCLUSION

Because the results of the suitability analysis for urban development revealed that over 77% of the total area in Kaduna metropolis is moderately suitable for urban development, the study area can be concluded to be predominantly suitable for urban development. It can also be concluded that the study area is primarily flat land, as slope analysis reveals that more than 99% of the study area has slopes ranging from 0 to 5 degrees. This research showed that a GIS-based multi-criteria analysis can be a useful tool for determining land suitability for urban development. It is recommended that Kaduna State Urban Development Agency (KASUPDA) employ the use of geographic information system, remote sensing, and analytical hierarchy process for conducting land suitability evaluations for any future urban development of the metropolis.

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