A GIS-BASED APPROACH FOR ASSESSING URBAN DEVELOPMENT POTENTIAL IN FEDERAL CAPITAL TERRITORY NIGERIA

Abstract -*Urban development potential assessment is essential for guiding the spatial expansion of cities, optimizing land use, and ensuring sustainable urban growth. In the context of rapidly urbanizing regions, such as Nigeria, understanding development potential helps mitigate the challenges of urban sprawl, infrastructure strain, and environmental degradation, hence, this study is aimed at a GIS based approach for assessing urban development potential in federal capital territory Nigeria. The objectives of the study are to: identify and categorize the key factors influencing urban development in FCT, Nigeria; assess the reliability of the identified factors using consistency index and sensitivity analysis; determine the potential areas for urban development in FCT, Nigeria using analytical hierarchical process; and produce an urban development potential map defining the extent of urban development potential across the urban landscape of FCT, Nigeria. The study employed the assessment of relative priorities in modelling and mapping urban development potential in FCT Nigeria. This assessment was based on a comprehensive set of criteria, including slope, elevation, proximity to road network, population density and proximity to developed areas. The Analytical Hierarchical Process (AHP) was utilized to compare and establish the relative importance of these criteria by means of matrix comparisons. Subsequently, these criteria were assigned relative weights. Weighted Overlay technique was applied to generate the final development potential map. The study revealed that Abuja Municipal Area had the highest potential development area, covering an area 851.40 km*^{2}*, with Bwari and Kuje Area Councils as having the second and third highest development potential with an area coverage of 312.40 km*^{2}* and 279.69 km*^{2}* respectively. Gwagwalada and Kwali Area Councils were ranked fourth and fifth with a developable area coverage of 180.20 km*^{2}* and 127.60 km*^{2}* respectively, while Abaji Area Council was ranked the least with developable area coverage of 40.27 km*^{2}*. The study successfully integrated an approach to investigate development potential within the FCT. This evaluation approach, is hereby recommended to be used as tool for planning and decision making in urban development in the study area*.

Keywords: Analytical Hierarchy Process (AHP), Federal Capital Territory (FCT), Geographic Information Systems (GIS), Multi-Criteria Decision Analysis (MCDA), Spatial Analysis, Sustainable Urban Development

1. Introduction

Urban development is a dynamic process influenced by various socio-economic, environmental, and infrastructural factors. The assessment of urban development potential is crucial for effective urban planning, sustainable growth, and resource allocation. Geographic Information Systems (GIS) provide a powerful tool for analyzing spatial data and evaluating urban development potential (Li *et al*., 2017; Chang *et al*., 2019). This study aims to assess the urban development potential in the Federal Capital Territory (FCT), Nigeria, using a GIS-based approach.

Urban development potential assessment is essential for guiding the spatial expansion of cities, optimizing land use, and ensuring sustainable urban growth. In the context of rapidly urbanizing regions, such as Nigeria, understanding development potential helps mitigate the challenges of urban sprawl, infrastructure strain, and environmental degradation (Jat *et al*., 2008; Wu, 2013). Effective assessment facilitates strategic planning and investment, enhancing the quality of urban life and supporting economic development (Vlahov& Galea, 2002).

Geographic Information Systems (GIS) have revolutionized urban planning by enabling the integration, analysis, and visualization of spatial data. GIS supports multi-criteria decision analysis (MCDA) methods, such as the Analytical Hierarchy Process (AHP), for evaluating urban development potential (Malczewski, 2004; Saaty, 2008). These tools help planners analyze diverse factors, including land use, infrastructure, topography, and socio-economic conditions, to identify areas suitable for development (Yeh & Xia, 2001; Church, 2002).

Nigeria has experienced rapid urbanization in recent decades, driven by population growth and economic activities. The urban population has increased significantly, leading to challenges in managing urban sprawl, infrastructure development, and environmental sustainability (UN-Habitat, 2014; World Bank, 2017). In the

Federal Capital Territory (FCT), Abuja's emergence as a major urban center has amplified the need for effective urban planning and development assessment (Gandy, 2006; Olokesusi, 2011).

The Federal Capital Territory (FCT) of Nigeria, home to Abuja, is characterized by diverse topography, land use patterns, and varying levels of infrastructure development (National Population Commission, 2010). Assessing urban development potential in this region requires comprehensive analysis of multiple spatial and socio-economic factors. A GIS-based approach enables the integration of these factors, providing a holistic view of development potential (Mishra *et al.*, 2011; Li *et al.*, 2016).

The Analytical Hierarchy Process (AHP) is a widely used multi-criteria decision analysis method for urban development assessment. AHP allows for the evaluation of multiple factors by assigning weights based on their relative importance, facilitating a structured decision-making process (Saaty, 1990; Saaty, 2008). Combining AHP with GIS enables spatially explicit assessment, allowing for the visualization of development potential across different areas (Eastman, 2006; Feizizadeh *et al.*, 2014).

Several factors influence urban development potential, including land use, topography, infrastructure, and population density. Land use patterns provide insights into the suitability of areas for different types of development (Anderson *et al.*, 1976; Weng, 2002). Topography affects the feasibility of construction and infrastructure development, with flat or gently sloping areas being more suitable (Bishop & Hulse, 1994; Bonham-Carter, 1994). Infrastructure, such as roads and utilities, is crucial for supporting urban growth and enhancing accessibility (Forman, 1995; Rodrigue *et al.*, 2016). Population density reflects the demand for urban development and services, influencing the allocation of resources (Angel *et al.*, 2005; Liu *et al.*, 2012).

Several studies have applied GIS and AHP for assessing urban development potential. Malczewski (2004) and Luan *et al*. (2016) demonstrated the effectiveness of GIS-based multi-criteria analysis in urban planning. Jat *et al*. (2008) and Mishra *et al*. (2011) utilized GIS to evaluate land suitability for urban development. Feizizadeh *et al*. (2014) integrated AHP with GIS for urban development assessment, highlighting its utility in identifying suitable areas for expansion.

The Federal Capital Territory faces challenges related to urban growth, including land use conflicts, infrastructure deficits, and environmental pressures. Rapid population growth has strained existing infrastructure, leading to issues such as traffic congestion, inadequate housing, and environmental degradation (Aluko, 2010; FCT Administration, 2014). Effective urban planning and development assessment are essential to address these challenges and ensure sustainable growth (Olokesusi, 2011; Akinmoladun& Adejumo, 2011).

Urban development in the Federal Capital Territory (FCT) of Nigeria has faced significant challenges due to rapid population growth, unplanned urban sprawl, and infrastructure deficits. As Abuja continues to expand as a major urban center, the need for effective urban planning and sustainable growth strategies becomes increasingly critical. Traditional approaches to urban development planning in the FCT have often lacked comprehensive spatial analysis and integration of multiple criteria, leading to inefficient resource allocation, land use conflicts, and environmental degradation.

The FCT, particularly Abuja, has experienced accelerated urbanization driven by economic opportunities and population growth (Aluko, 2010; FCT Administration, 2014). However, this rapid expansion has resulted in unplanned urban sprawl, straining existing infrastructure and services (Olokesusi, 2011; Jat *et al.*, 2008). Uncoordinated urban growth has led to inefficient land use, increased traffic congestion, and the proliferation of informal settlements (World Bank, 2017; UN-Habitat, 2014).

The rapid expansion of urban areas has outpaced the development of essential infrastructure, including roads, water supply, and sanitation systems (Gandy, 2006; Akinmoladun& Adejumo, 2011). This deficit hampers economic development and affects the quality of life for residents. Inadequate infrastructure exacerbates issues such as traffic congestion, poor waste management, and limited access to basic services (Forman, 1995; Rodrigue *et al*., 2016).

The FCT's diverse topography, including hills, valleys, and water bodies, presents challenges for urban development (National Population Commission, 2010; Bishop & Hulse, 1994). Uncontrolled development in environmentally sensitive areas increases the risk of flooding, erosion, and habitat destruction (Bonham-Carter, 1994; Chang *et al*., 2019).

Addressing these challenges requires a robust, data-driven approach that leverages Geographic Information Systems (GIS) for spatial analysis and integrates multiple criteria to assess urban development potential comprehensively (Li *et al*., 2017; Yeh & Xia, 2001). A GIS-based approach can facilitate the identification of suitable areas for development, optimize land use, and enhance infrastructure planning by: Incorporating various datasets, including land use, topography, infrastructure, and population density, to provide a holistic view of development potential (Luan *et al*., 2016; Mishra *et al*., 2011), utilizing the Analytical Hierarchy Process (AHP) to assign weights to different factors and evaluate their relative importance in urban development (Saaty, 1990; Jat *et al*., 2008) and producing spatially explicit maps that highlight areas with high, moderate, and low development potential, supporting informed decision-making (Chang *et al*., 2019; Li *et al*., 2016).

Despite the critical need for effective urban planning in the FCT, there is a notable gap in the application of advanced GIS-based approaches to assess urban development potential (Mishra *et al*., 2011; Feizizadeh *et al*., 2014). Existing planning frameworks often fail to comprehensively integrate spatial data and multi-criteria analysis, leading to fragmented and inefficient urban development strategies. This research seeks to address this gap by developing a GIS-based methodology that combines spatial analysis with AHP to assess urban development potential in the FCT.

2. Materials and Methods

2.1. Study Area

The study area for this study is Abuja Federal Capital Territory. Abuja is located in the heart of the country. The FCT stretches across approximately 8,000 square kilometers. With a geographic location of latitude $7^0$25'N and $9^0$20'North and longitude $5^0$45'E and $7^0$39'East, the FCT is bordered on the north by Kaduna, on the west by Niger, on the east by Plateau, and on the South-west by Kogi. The geographic location of Abuja is shown in figure 1 and 2. It comprises six Local councils, namely Abaji, Bwari, Kuje, Gwagwalada, Kwali and Abuja Municipal Area Council (AMAC) which is the metropolitan city of Abuja

Figure 1: Map of Nigeria showing FCT

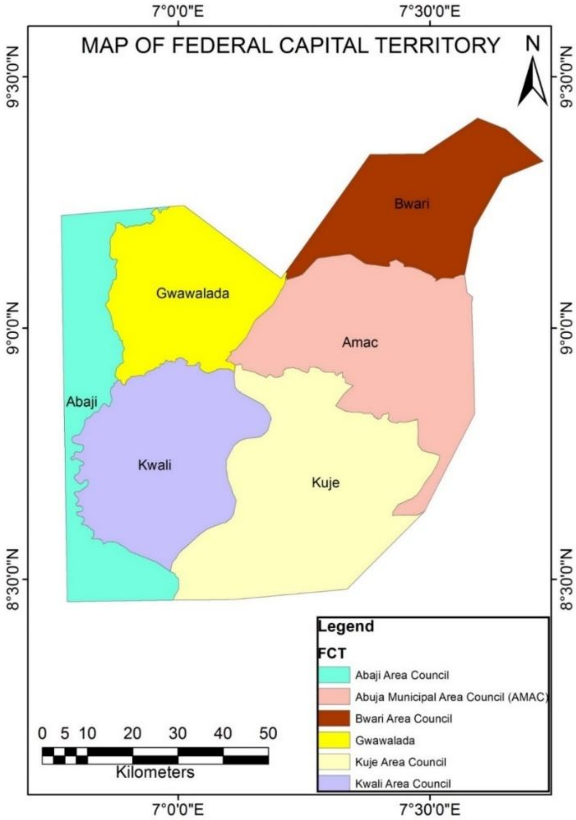

Figure 2: Map of FCT, Nigeria (Study Area)

The FCT experiences three weather conditions annually. This includes a warm, humid rainy season and a blistering dry season. In between the two, there is a brief interlude of harmattan occasioned by the northeast trade wind, with the main feature of dust haze, intensified coldness and dryness.

The rainy season begins from April and ends in October, when daytime temperatures reach 28 °C (82.4 °F) to 30 °C (86.0 °F) and night-time lows hover around 22 °C (71.6 °F) to 23 °C (73.4 °F). In the dry season, daytime temperatures can soar as high as 40 °C (104.0 °F) and night-time temperatures can dip to 12 °C (53.6 °F). Even the chilliest nights can be followed by daytime temperatures well above 30 °C (86.0 °F). The high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory.

The FCT falls within the Guinean forest-savannah mosaic zone of the West African sub-region. Patches of rain forest, however, occur in the Gwagwa plains, especially in the rugged terrain to the south-eastern parts of the territory, where a landscape of gullies and rough terrain is found. These areas of the Federal Capital Territory (FCT) form one of the few surviving occurrences of the mature forest vegetation in Nigeria.

TheFCT hasforalong timebeenrecognizedasaregionofdiversityofhuman cultures. Thisparticularfeatureisverymuchsimilar to thatofthecountryasawhole,withovertwohundredandfifty ethnicgroups. Therearesevendistinctindigenousethnicgroups in theFCT and theyincludeGwari, Gade,Ganagana,Gwandara,Koro Bassa and Ebira-Koto.

Thesepeoplesare regardedastheindigenesoftheFCT becauseoftheirverylong history ofuninterrupted occupation. Two other ethnic groups, Hausa and Agwai, are also to be found in small numbers at different levelsofthe settlements'hierarchyandinthevariousrural areasrespectively. Theyare, however, notregardedasindigenes in thesamesenseastheotherseven. Thisisbecausetheyarelate arrivalsand arenormallyregardedbyothersasguestswhohave madelessvisibleimprints onthecultural landscapeoftheFCT.

Auniquespatialfeatureofthe culturaldiversityhereisthatthe variousgroups,toa verylargeextent,liveintermingledwithone another. This istrueinindividualsettlementsaswellasinthe variouslocalities.Theveryhighdegreeofethnic mixinthe FCT,isdue totheintensesocio-culturalinteractionsat different levels, thathavetakenplaceamongthepeoplesover a verylongperiodoftime.

2.2. Methods

2.2.1. Data Requirement

The datasets utilized in this research include Sentinel-2, ALOS PALSAR, road data, developed area data, and population density data.Secondary datasets were obtained from existing sources. The map of the administrative boundary of FCT, Nigeria, as well as road and population density data, were acquired from the Federal Capital Development Agency (FCDA). Sentinel-2 data and ALOS PALSAR data were obtained from the Open Access Hub (copernicus.eu).

2.2.2. Image Pre-processing

Prior to any analysis, initial processing of the collected data was conducted to ensure accuracy. This step corrects any inaccuracies caused by the imaging system and environmental conditions during image acquisition. Although standard corrections were applied by ground station operators, additional steps were necessary to guarantee data accuracy. These included:

a) **Radiometric Correction:** Adjusts for differences in sensor response across the image.

b) **Geometric Correction:** Removes distortions caused by Earth's rotation or other imaging conditions.

c) **Geo-referencing:** The image was transformed to the UTM Zone 32 North map projection system using ground control points (GCPs) to precisely align the image with a specific map.

Additionally, band combination and image subsetting were performed during the initial processing of the raw data. Band combination merges different spectral bands of a remote sensing image to create a composite image highlighting specific features. Image subsetting involves extracting a smaller, relevant portion of the image to reduce the amount of data processed and analyzed. These steps are crucial for ensuring the highest quality and accuracy of the data used in subsequent analysis.

2.2.3. ALOS PALSAR Processing

The ALOS PALSAR provides a topographical model containing elevation records for specific cell sizes. However, sunken areas not captured due to data errors or karst topography might exist. These errors arise from limitations in DEM resolution or errors in its generation. To address these issues, sinks were filled using ArcGIS Pro software. Subsequently, the elevation and slope of the area were calculated based on the corrected DEM data. These layers were then utilized as key components in the suitability analysis, serving as constraints and factors for further analysis.

2.2.4. Image Classification

Supervised classification techniques were applied using ArcGIS software. The Image Classification toolbar facilitated the creation of training samples and signature files. The primary classification method was the Maximum Likelihood Classification tool. This method required a signature file outlining the characteristics and statistics of the different classes being analyzed, generated by collecting training samples through the Image Classification toolbar.

2.2.5. Urban Development Potential

Urban development potential was modeled using the Analytical Hierarchy Process (AHP), introduced by Saaty (1980). AHP is an effective tool for complex decision-making, helping decision-makers set priorities and make optimal decisions by reducing complex decisions to a series of pairwise comparisons and synthesizing the results. AHP captures both subjective and objective aspects of a decision, weighing both benefits and risks by assigning numerical values to each criterion.

The AHP process involved several steps:

Comparing Factors: Judgment values for each factor relative to other factors were obtained from expert judgments sourced from the literature, based on Saaty's (1980) scale (Table 1).

Table 1: Relative Importance in Pairwise Comparison

Judgment Value	**Description**
1	Equal importance
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important

The Judgment value of each factor in relation to other factors was obtained to a higher degree of consistency from the judgment of experts in various field of concern. These judgments of experts were obtained through literatures where the experts provided the relative importance of the factors under consideration based on Saaty (1990) judgment value in Table 1. Table 2 shows the coding of factors that were considered where F1 to F6 represent the factors.

Table 2: Coding of Factors

Factor	**Code**
Land Cover/Land Use	F1
Proximity to Developed Areas	F2
Proximity to Road Network	F3
Elevation	F4
Slope	F5
Population Density	F6

Forming Pairwise Comparison Matrix: Using judgment values, a pairwise comparison matrix was created. Matrix elements reflect the relative importance of factors. The normalized pairwise comparison matrix was then formed by dividing each element by the sum of its column. The average of each row in this normalized matrix provided an estimate of the relative weights of the criteria.

Computing Criteria Weights: The normalized sum of each row was divided by the number of criteria to obtain the criteria weights. These weights were converted to percentages for prioritization.

Consistency Ratio (CR): The CR was used to check the reliability of the judgment values relative to large samples of purely random judgments. If CR < 0.1, the weights are considered consistent. If CR > 0.1, the weights need revision.

The consistency ratio is calculated as follows:

$$CR = CI/RI$$

Where RI is the random index based on the size of the matrix (Table 3).

Table 3: Random Index by Saaty

Size of Matrix (n)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

If CR < 0.1, the pairwise comparisons are considered consistent.

3. Results

3.1. Identification and Selection of Evaluation Criteria

Selection of the criteria and factors for urban development evaluation using AHP was achieved based on their theoretical relevance as documented in (Park, Jeon, Kim and Choi, 2011; Bagheri, Sulaiman and Vaghefi, 2013; Trung *et al*., 2006; Mohammed, Sahebgharani and Malekipour, 2013 and Manish and Vasim, 2013).

The following criteria (table 4) were used in this research.

Table 4: Criteria (Factors/Constraints)

S/N	Criterion	Factor/ Constraint	Requirement	Reason for Selection	Original Data Structure	Resolution
1	Land Cover/ Land Use	Factor	Barren/Open spaces	Barren/open spaces are prime areas for development	Raster	30m
2	Proximity to developed Areas	Factor	< 500m from developing areas	< 500m from developing areas are adjudged to attract faster developments due to edge expansion development pattern in FCT	Euclidean Raster	30m
3	Proximity to Road Network	Factor	< 500m road networks	< 500m from road networks are considered high development potential	Euclidean Raster	30m
4	Elevation	Factor	Between 140m – 378m (Flat, Undulating and Rolling terrains)	Flat, Undulating and Rolling terrain are considered typical terrain for development	Raster	30m
5	Slope	Factor	Between 3 – 13 degrees	Steady slopes are considered typical terrain for development	Raster	30m
6	Population Density	Factor	Areas with highest	Areas with high population density	Raster	30m

			population density	are considered to attract development		

Based on the criteria selected (table 4), the data used for achieving the aim of the research were assembled. Land cover/landuse was extracted from image classification performed on the Sentinel-2 image, slope and elevation were extracted from the SRTM downloaded from www.earthexplorer.usgs.gov. The road proximity and urban proximity areas were derived from FCT road network and FCT urban areas using Euclidean distance algorithm, then population density was gotten from NASA Earth database. These data are shown in figures 3 – 8.

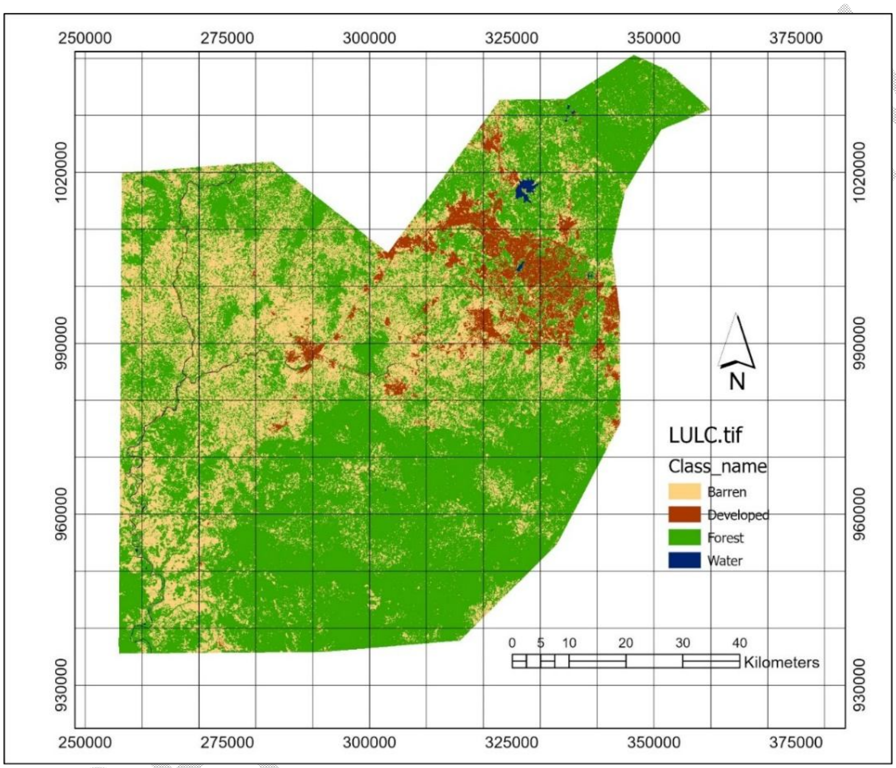

Figure 3: Landcover/landuse data

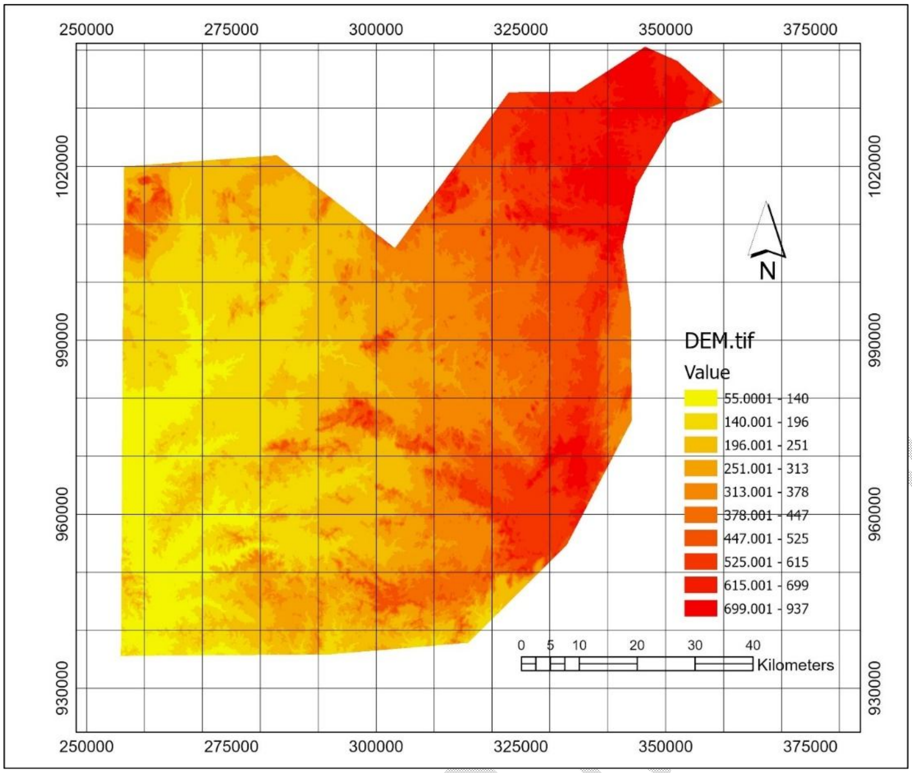

Figure 4: Elevation data

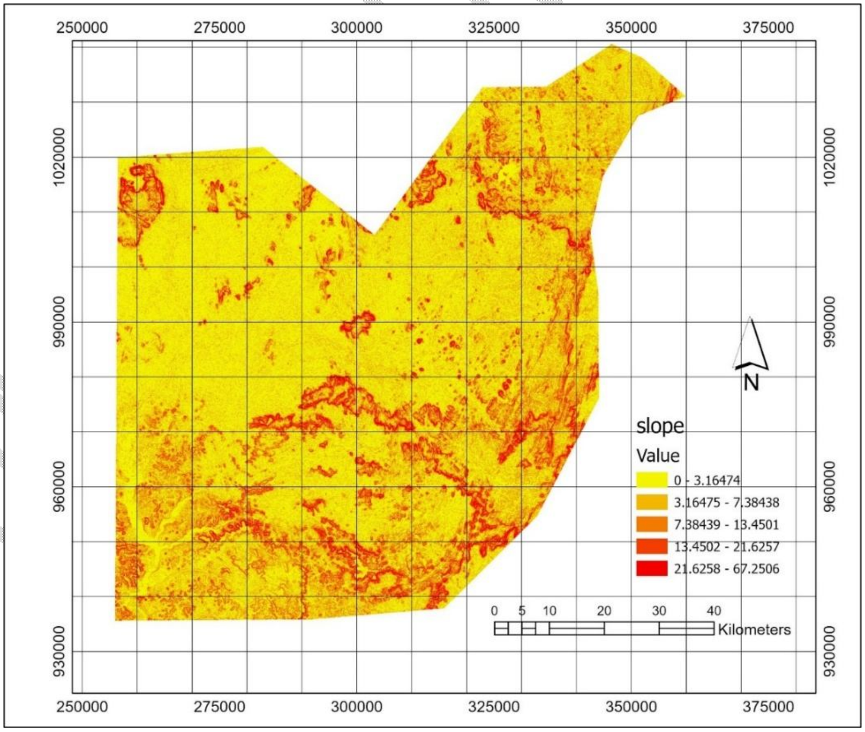

Figure 5: Slope data

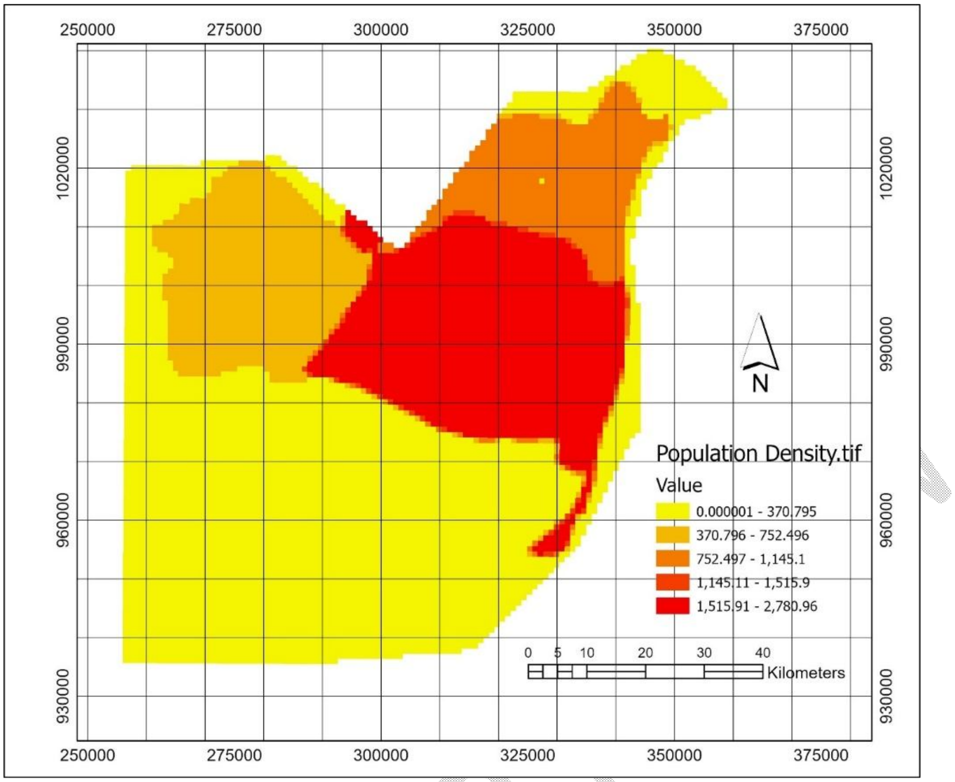

Figure 6: Population density data

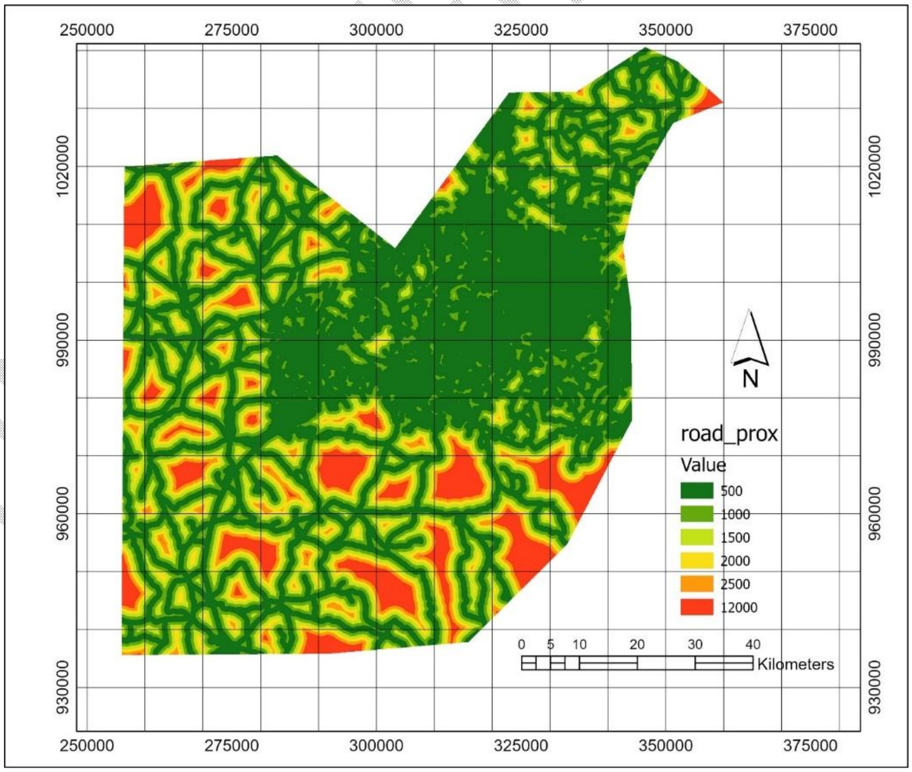

Figure 7: Road proximity data

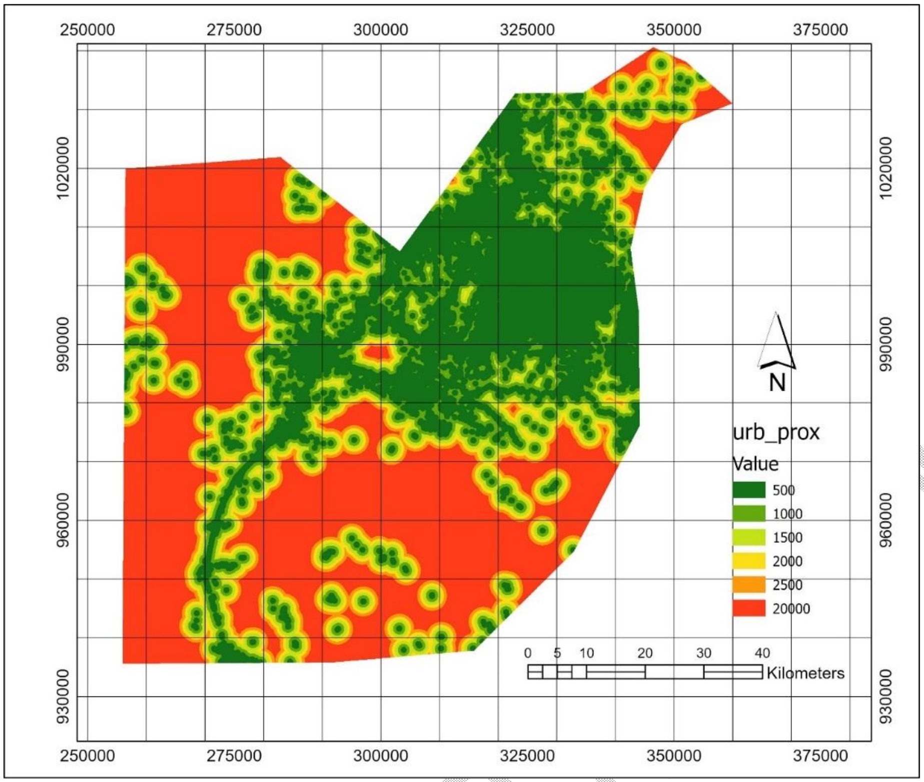

Figure 8: Urban area proximity

3.2. Reclassification and Standardization of Criteria

Reclassification and standardization of criteria is the first step when implementing AHP and weighted linear combination model. Each of the cells has a value for each input criteria. At this stage it will be practically impossible to combine the criteria, hence the need for reclassification of each of the individual datasets. Different number systems cannot be directly combined effectively (ESRI, 2014). For instance, combining a cell value in which slope is 2˚ with a cell value in which distance to is 50m is almost impossible because of disparity in units. However, standardizing them to a common measurement system that represents a relative weighting scale permits analysis to be completed freely between the datasets and show the suitability level for each of the standardized criteria. To combine datasets, there is a need to standardize or transform all the individual datasets into a common measurement scale.

For this research, all the datasets were reclassified into three classes: (1) for high potential areas (2) moderate potential areas and (3) low potential areas. The initially derived datasets values categorized into ranges were floating and continuous in nature and there was a need for them to be reclassified so that each range of value can be assigned one discrete integer value such as 1, 2, 3 according to the measurement scale. This is because the inputs of the weighted overlay must contain discrete integer values. The reclassified and standardized criteria are shown in figure 9 - 14.

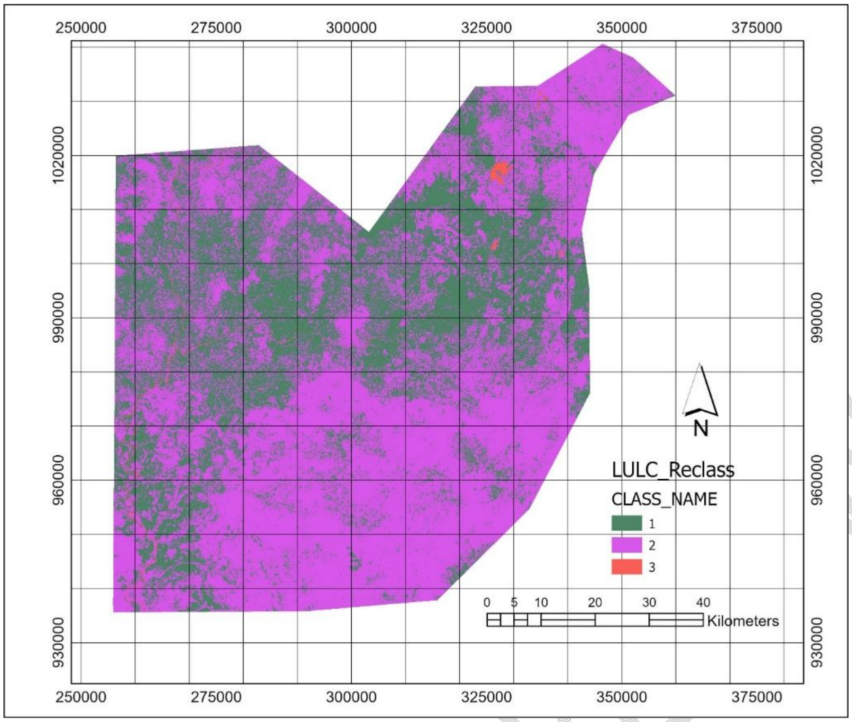

Figure 9: Landcover/Landuse reclassification and standardization

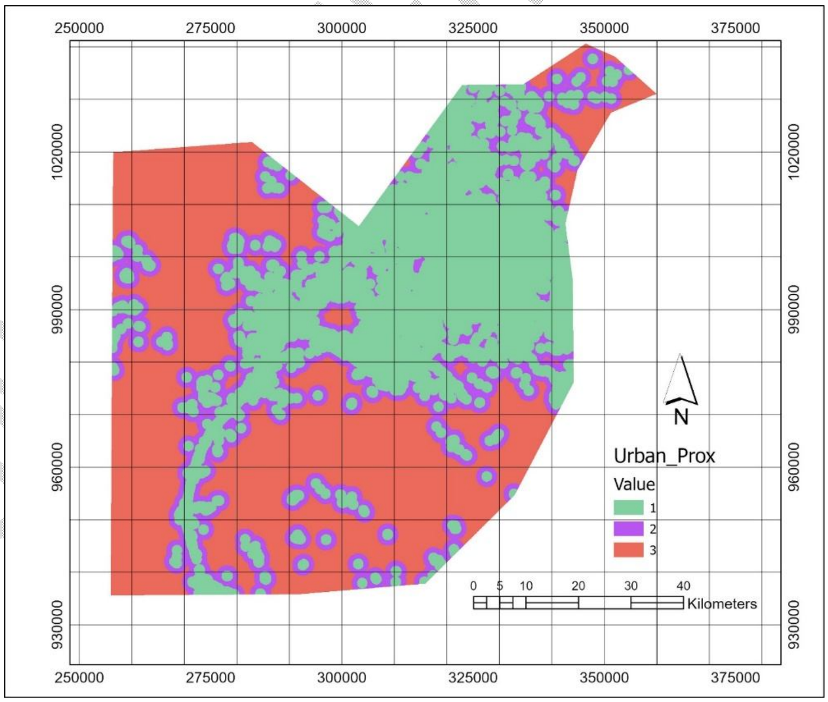

Figure 10: Urban area proximity reclassification and standardization

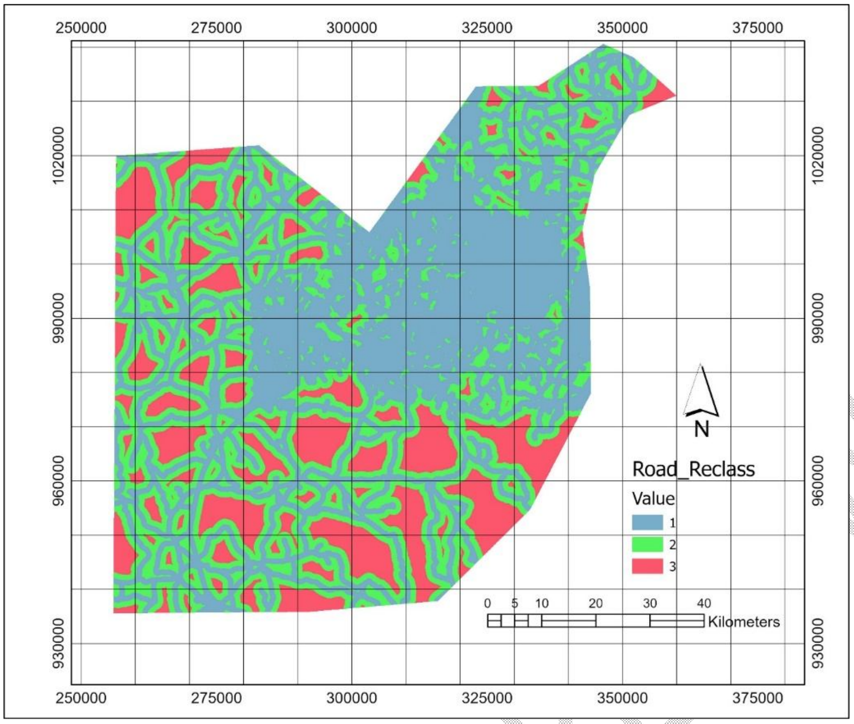

Figure 11: Road proximity reclassification and standardization

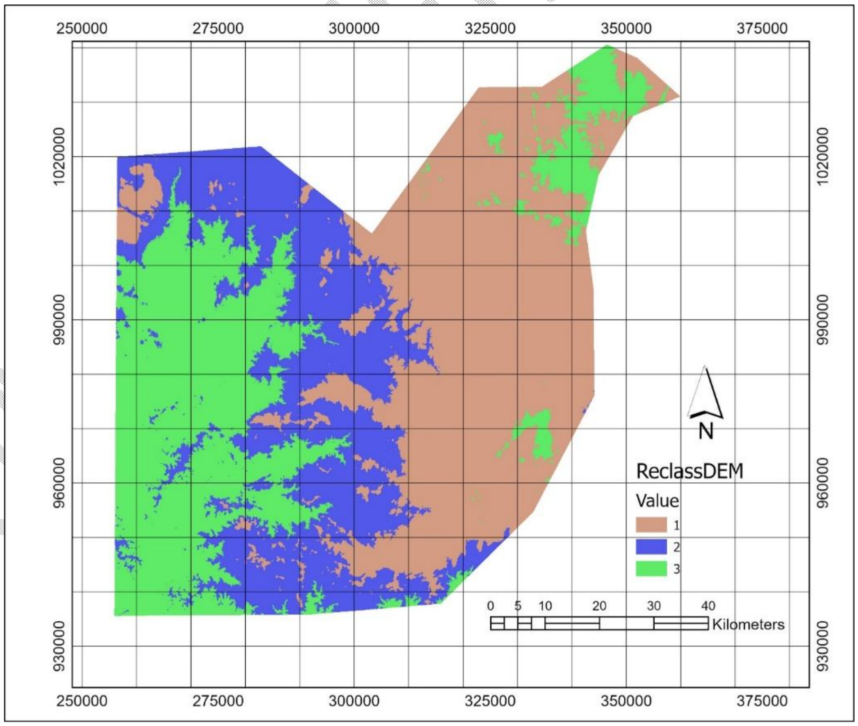

Figure 12: Elevation reclassification and standardization

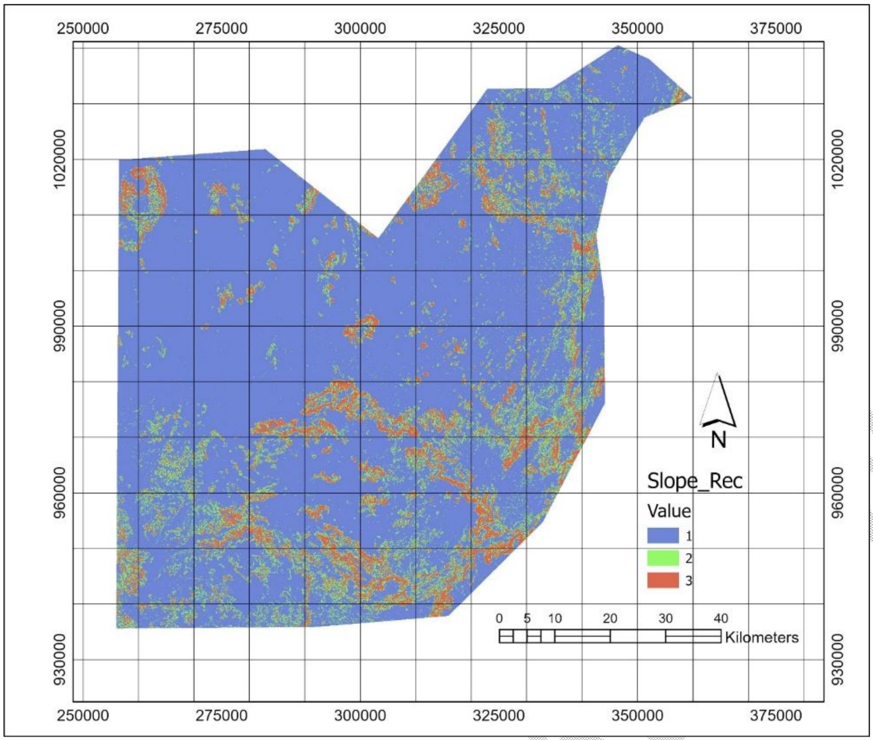

Figure 13: Slope reclassification and standardization

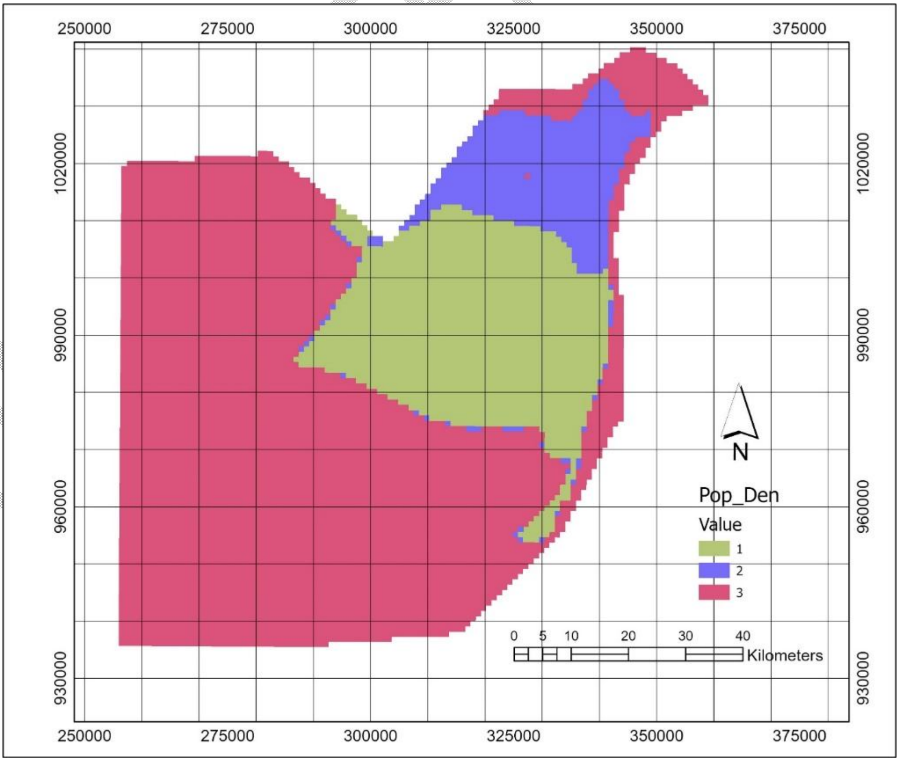

Figure 14: Population density reclassification and standardization

3.3. Analytical Hierarchy Process and Determination of Criteria Weight

Analytical hierarchy process is an effective tool for dealing with complex decision-making, and may aid the decision maker to set priorities and make best decisions by reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results. AHP helps to capture both subjective and objective aspects of a decision. Again, both benefits and risks can be weighed, assigning a number value to each criterion (benefit or risk factor under consideration), with more important benefits receiving a higher number on the scale to determine which projects have the highest overall value, or the most valued benefits and least risks.

AHP approach uses a ratio matrix known as the Eigenvector method to compare one criterion with another. Additionally, it uses a numerical scale with values ranging from 1 to 9, where 1 means that the two factors are equally important and 9 means that the one factor is absolutely more important than the other as shown in Table 5. If a factor is less important than another then this is indicated by reciprocals of the 1 to 9 values (1/1 to 1/9)

*Table 5: Relative Importance in Pairwise Comparison*Source: (Saaty, 1990)

Judgment value	**Description**
1	Equal importance
3	Moderately importance
5	Strongly Importance
7	Very strongly important
9	Extremely important

3.4. Pairwise Comparison Matrix Formation

Pairwise comparison matrix was formed by inputting the judgment value between factors as the matrix elements by following the basic rules as established by Saaty. Using the table 5, table 6 was formulated using pairwise comparism matrix.

Table 6. Pair-wise comparison matrix of the study

	Land Cover/ Land Use	Proximity to developed Areas	Proximity to Road Network	Elevation	Slope	Population Density
Land Cover/ Land Use	1	2	2	2	3	3
Proximity to developed Areas	0.5	1	2	2	2	3
Proximity to Road Network	0.5	0.5	1	2	2	3
Elevation	0.5	0.5	0.5	1	2	2
Slope	0.33	0.33	0.5	0.5	1	2
Population Density	0.33	0.33	0.33	0.5	0.5	1
Total	3.16	4.66	6.33	8	10.5	14

3.5. Computation of the Criterion Weights

After the formation of pair-wise comparison matrix, computation of the criteria weights was done. The computation involved the following operations:

i. Finding the sum of the values in each column of the pair-wise comparison matrix.

ii. Division of each element in the matrix by its column total (the resulting matrix is referred to as normalized pair-wise comparison matrix).

iii. Computation of average of elements in each row of the normalized matrix, i.e., dividing the sum of normalized scores of each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared. It should be noted that for preventing bias through criteria weighting, the consistency ratio (CR) was used.

3.6. Normalized Pairwise Comparison Matrix

Table 4 shows the normalized pairwise comparison matrix that was formed. For example, to get the element of the normalized matrix of Landcover/Landuse (row) against Landcover/Landuse column i.e., matrix element in 1, 1, where 3.16 and 1 from the pairwise comparison matrix is the sum of the element of the first column and the judgment value of Landcover/Landuse (row) against Landcover/Landuse (column), therefore, normalized F1, F1 = (1/3.16) = 0.32 as shown in the table 7.

Table 7: Normalized Pairwise Comparison Matrix

	Land Cover/ Land Use	Proximity to developed Areas	Proximity to Road Network	Elevation	Slope	Population Density	Mean
Land Cover/ Land Use	0.32	0.43	0.32	0.25	0.29	0.21	0.30
Proximity to developed Areas	0.16	0.21	0.32	0.25	0.19	0.21	0.22
Proximity to Road Network	0.16	0.11	0.16	0.25	0.19	0.21	0.18
Elevation	0.16	0.11	0.08	0.13	0.19	0.14	0.13
Slope	0.10	0.07	0.08	0.06	0.10	0.14	0.09
Population Density	0.10	0.07	0.05	0.06	0.05	0.07	0.07

3.7. Prioritization weight matrix

Table 8 shows the prioritized weight matrix. In computing the element of this matrix, the normalized sum of each row is divided by the total number of its criteria. The obtained averages provide an estimate of the relative weights of the criteria being compared. For instance, the criteria weight of flow accumulation as a factor can be obtained thus;

Landcover/Landuse = 0.32 + 0.43 + 0.32 + 0.25 + 0.29 + 0.21 (sum of the elements in row 1)

Total number of criteria in row 1 = 6

Therefore, A {weight of factor 1 (F1)} = 1.81/6 = 0.3016 = 0.30

A% (criteria in percentage) = A x 100 = 0.30 * 100 = 30%, see table 4 for more details.

Table 8: Prioritization weight matrix

	Land Cover/ Land Use	Proximity to developed Areas	Proximity to Road Network	Elevation	Slope	Population Density	Mean	W%	row total of normalized matrix
Land Cover/ Land Use	0.32	0.43	0.32	0.25	0.29	0.21	0.30	30.19	1.81
Proximity to developed Areas	0.16	0.21	0.32	0.25	0.19	0.21	0.22	22.39	1.34
Proximity to Road Network	0.16	0.11	0.16	0.25	0.19	0.21	0.18	17.97	1.08
Elevation	0.16	0.11	0.08	0.13	0.19	0.14	0.13	13.38	0.80
Slope	0.10	0.07	0.08	0.06	0.10	0.14	0.09	9.25	0.55
Population Density	0.10	0.07	0.05	0.06	0.05	0.07	0.07	6.82	0.41
Total	1	1	1	1	1	1	1	100	6

3.8. Estimation of the Consistency Ratio

This stage involved calculating a consistency ratio (CR) to check reliability of the judgments values which are relative to large samples of purely random judgments. The AHP deals with consistency explicitly because in making paired comparisons, just as in thinking, people do not have the intrinsic logical ability to always be consistent.

To determine consistency ratio, the analytical hierarchy process compares it by random index (R.I.). Mathematically, Consistency Ratio (C.R.), can be defined as:

$$CR = CI/RI \quad \dots (1)$$

In calculating the constituency value, the mathematical formula CR = CI/RI was be used.

Random index (RI) is the consistency index of a randomly generated pair-wise comparison matrix of order 1 to 10 obtained by approximating random indices.

Table 9: Random Index by Saaty

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Source: (Saaty, 2001).

Note: If the value of the obtained Consistency Ratio is less than 0.1, it means that there is a reasonable level of consistency in the pairwise comparisons, and that the computed weights are within the acceptable limit. If the reverse is the case (CR > 0.1) it means that the weights obtained are inconsistent and needs to be checked.

The value of Consistency index, CI was calculated from the preference matrix according to equation below

$$CI = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1}$$

λmax is the Principal Eigen Value; n is the number of factors

λmax = Σ of the products between each element of the priority vector and relative weights

λmax = (3.16*0.30) + (4.66*0.22) + (6.33*0.18) + (8*0.13) + (10.5*0.09) + (14*0.07)

= 0.94 + 1.02+ 1.13+ 1.04+ 0.94 + 0.98

λmax = 6.05

CI = (6.05 – 6)/ (6-1) = 0.01

CR = 0.01/1.24 = 0.008

CR = 0.008 < 0.10 (Acceptable)

The consistency ratio (CR) is design in such a way that if CR<0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however, CR $\geq$ 0.10, the values of the ratio are indicative of inconsistent judgments. From the judgment a Consistency Ratio (CR) of 0.010 was achieved which was less than the maximum allowable ratio of 0.10.

3.9. Development Potential

The development potential was determined by obtaining the summation of the product of the weight of each criterion with its standard suitability score according to Equation 1.

$$\text{DP} = \Sigma\ w\mathit{i}x\mathit{i} \qquad \text{... (2)}$$

Where;

DP = Development Potential,

w*i*= the relative importance (weight) of each criterion

and x*i* = the standardized score of each criterion *i*.

Hence the development potential with the constraints was derived from equation

$$\text{F} = (\textstyle\sum_{i=1}^{n} wi \ \times xi) \times \prod \text{cj} \qquad \dots (3)$$

With c_j=Boolean value of limited criterion

In order to make the map easily understandable, a reclassification was performed to reclassify the result to index levels/categories—low, moderate and high, then from which high potential areas were extracted. The natural breaks reclassification method in ESRI's ArcGIS Pro was used for this purpose. The natural breaks (jenks) classification algorithm finds data break points between classes depending on the natural patterns in which the data are clustered. Class break points are set where there are relatively huge jumps in the data values. Hence a model was developed using the formula and weighted linear combination to determine the development potential. The formular used is: FI is = **(**F1*0.30) + (F2*0.22) + (F3*0.18) + (F4*0.13) + (F5*0.09) + (F6*0.07)

Note: F1, F2, F3, F4, F5, and F6 are thematic layers representing the constraints, see table 10. The results are displayed in figure 16 and figure 17.

Table 10: Coding of Factors

F1	Land Cover/ Land Use
F2	Proximity to developed Areas
F3	Proximity to Road Network
F4	Elevation
F5	Slope
F6	Population Density

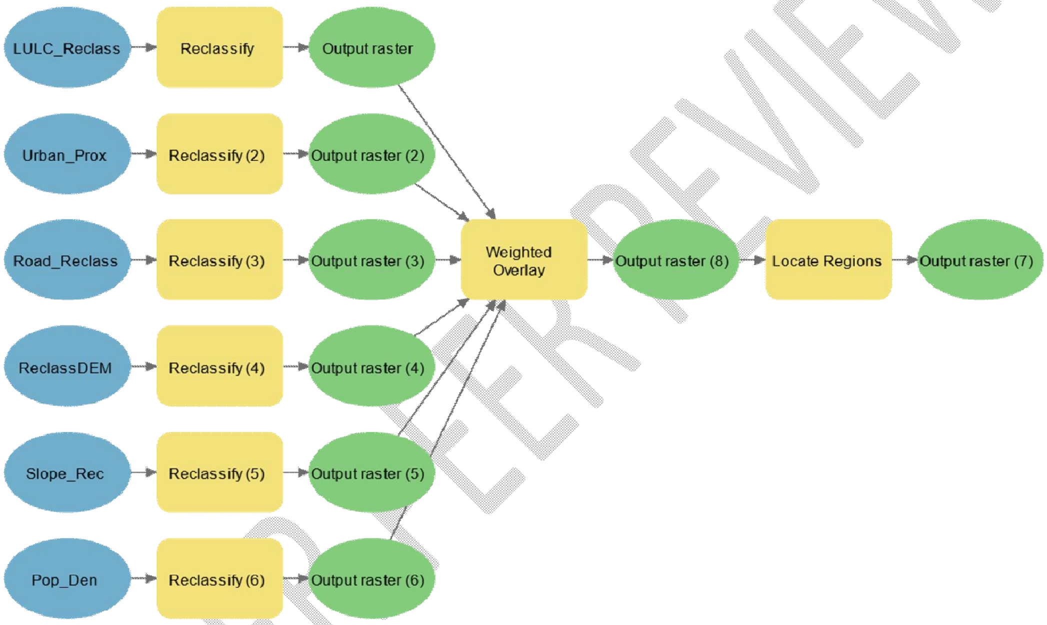

Figure 15: Urban Development Potential Model

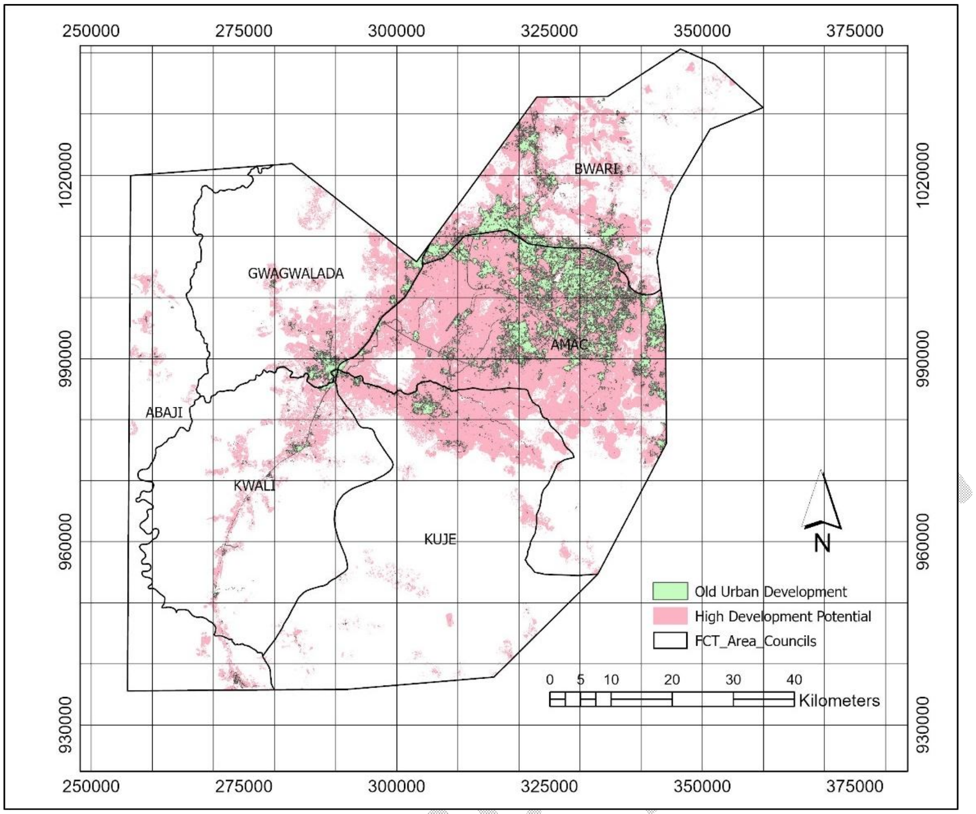

Figure 16: High Development Potential map

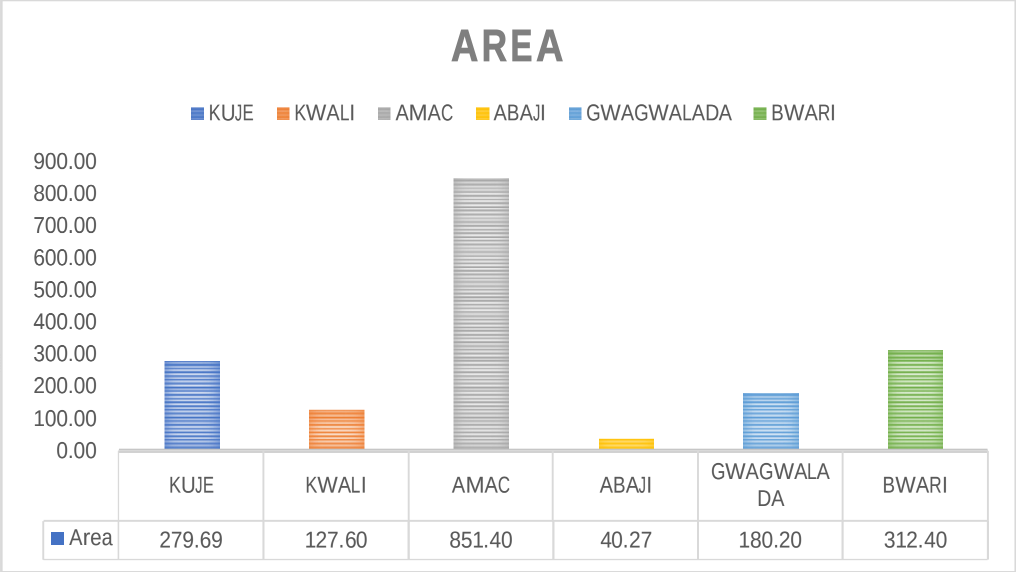

Figure 17: High Development Potential map

From the results, the development potential analysis in the Federal Capital Territory (FCT), Nigeria, reveals insights into the spatial expansion capabilities of the study area. The Abuja Municipal Area, exhibiting the highest development potential with an area of 851.40 km², stands out due to its centrality as the nation's capital. This area's high development potential is driven by favorable topography, extensive public infrastructure, such as roads and urban centers, and substantial population growth over the past two decades. This indicates the necessity for focused urban planning to manage and sustain its rapid expansion.

The Bwari and Kuje Area Councils, with area coverages of 312.40 km² and 279.69 km² respectively, rank second and third in development potential. These areas benefit from their strategic proximity to Abuja and ongoing improvements in infrastructural frameworks, which make them prime targets for urban development.

Gwagwalada and Kwali Area Councils, with developable area coverages of 180.20 km² and 127.60 km² respectively, rank fourth and fifth. These emerging urban centers are characterized by growing infrastructure and enhanced accessibility, contributing to their development potential. Strategic planning in these areas should focus on bolstering infrastructure and ensuring that development is managed to prevent potential issues related to urban sprawl and congestion.

Abaji Area Council, ranked lowest with a developable area coverage of 40.27 km², presents unique challenges and opportunities. Despite its lower ranking, targeted investments in infrastructure and strategic development initiatives could spur growth in Abaji, demonstrating that even areas with initially low development potential can become significant urban centers with the right planning and investment.

The implications of these findings are profound. For urban planners and policymakers, the detailed mapping of development potential provides a data-driven foundation for strategic decision-making. Understanding which areas have the highest potential for development allows for efficient allocation of resources, ensuring that infrastructure investments and urban planning efforts are directed towards regions that will yield the greatest benefit. This approach can mitigate the risks of urban sprawl, reduce infrastructure strain, and promote sustainable urban growth.

For the scientific community, this study's methodological approach is particularly relevant. The combination of Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) in this research offers a robust framework for evaluating urban development potential. This integrative approach can be applied to other rapidly urbanizing regions, providing a valuable model for comparative studies and contributing to the broader body of knowledge on urban expansion and sustainable development.

Moreover, the value of this research extends to enhancing existing knowledge in several ways. First, it provides an understanding of the spatial distribution of development potential within the FCT, Nigeria, identifying key areas for targeted development. Second, it highlights the critical drivers of urban growth, such as suitable topography, infrastructure availability, and population dynamics, offering insights that can inform future urban development policies and strategies. Third, by presenting a replicable methodological framework, this study enables other researchers and urban planners to conduct similar assessments in different contexts, fostering a more comprehensive understanding of urban development dynamics globally.

4. Summary and Conclusions

This study effectively leveraged the Analytical Hierarchy Process (AHP) to evaluate urban development potential in the Federal Capital Territory (FCT), Nigeria. The comprehensive approach integrated diverse datasets, including land cover, slope, elevation, road proximity, urban proximity, and population density, into a coherent analytical framework. The reclassification and standardization processes ensured that disparate data types could be combined into a unified model, facilitating a robust evaluation of development potential across the region.

The AHP method proved instrumental in assigning weights to the various criteria, reflecting their relative importance in determining urban development suitability. The high consistency ratio (CR = 0.008), well below the acceptable threshold, attests to the reliability of the pairwise comparisons used in this study. The methodological rigor applied in this evaluation underscores the robustness of the resulting development potential map.

The spatial analysis revealed significant variations in development potential across different areas of the FCT. The Abuja Municipal Area emerged as the region with the highest development potential, suggesting a concentration of favorable conditions such as suitable topography, existing infrastructure, and dense population. Conversely, areas like Abaji were identified as having lower development potential, indicating less favorable conditions for urban expansion.

The findings of this study offer valuable insights into the spatial dynamics of urban development in the FCT. They highlight key factors driving urban growth, including the availability of infrastructure and population pressures, which are critical for effective urban planning and management. These insights can inform policymakers and urban planners in making data-driven decisions that align with the region's development goals.

Moreover, the methodological framework established here, combining AHP with geospatial data analysis, provides a replicable model for evaluating urban development potential in other regions. By integrating objective data and subjective judgments, this approach ensures a balanced and comprehensive assessment, supporting sustainable urban development strategies.

Finally, this study not only maps the current urban development potential in the FCT but also provides a strategic tool for guiding future urban planning efforts. The identified high-potential areas should be prioritized for infrastructure development and investment, while the lower-potential areas may require targeted interventions to enhance their suitability for urban expansion. This balanced and informed approach can contribute significantly to the sustainable growth and development of the FCT and similar urban environments.

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