

Spatial Urban Land Suitability Assessment for Risk-Sensitive Planning in A Rapidly Urbanising Nigerian City: A GIS–AHP–MCDA Approach for Ilorin, Nigeria

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Abstract

Rapid urban expansion creates complex demands for land allocation, infrastructure provision and environmental management, particularly across heterogeneous urban environments. This study developed a GIS-based Multi-Criteria Geospatial Evaluation (MCGE) framework to assess urban land suitability in Ilorin Metropolis, Nigeria. Remote sensing and GIS techniques were integrated with the Analytic Hierarchy Process (AHP) and weighted overlay using seven criteria: slope, land use/land cover (LULC), Normalised Difference Vegetation Index (NDVI), land surface temperature (LST), population density, proximity to roads, and proximity to water bodies. Sentinel-2 imagery was classified to derive the LULC layer, achieving an overall accuracy of 92.5% and a Kappa coefficient of 0.89. The resulting LULC distribution comprised rangeland (65.01%), built-up land (17.46%), cropland (10.53%) and water-related features (6.98%). AHP assigned the highest weights to NDVI (24.72%), LULC (19.19%) and population density (16.22%), while the consistency ratio of 0.055 indicated acceptable judgement consistency. Weighted overlay generated an Urban Land Suitability Index classified into five levels. Moderate suitability was dominant (35%), followed by Low and High (20% each), Very Low (15%) and Very High (10%). High and Very High suitability were concentrated around the urban core and major infrastructure corridors, whereas lower suitability occurred mainly near river corridors, steeper terrain and thermally stressed areas. The findings show the utility of integrating remote sensing, GIS and AHP as a transparent decision-support framework for guiding sustainable urban development and land-use planning.

Keywords: urban land suitability; GIS-MCDA; Analytic Hierarchy Process; remote sensing; land-use/land-cover; land surface temperature; spatial planning.

1. Introduction

Rapid urbanisation is reshaping cities' spatial structure, environmental conditions, and resource demands globally. The expansion of built-up areas, increasing infrastructure requirements, and shifting population distributions intensify competition for limited urban land. Inadequate spatial planning during urban expansion can

lead to encroachment on agricultural and environmentally sensitive areas, increased infrastructure pressure, and new patterns of exposure to environmental hazards (Seto *et al.*, 2012; Güneralp *et al.*, 2020; Dodman *et al.*, 2023). The Intergovernmental Panel on Climate Change (IPCC, 2022) recognises that urbanisation, land-use change, and infrastructure location interact with climate hazards to influence urban exposure, vulnerability, and risk. Therefore, identifying land that is relatively suitable for urban development is a critical component of evidence-based and sustainable spatial planning (Malczewski, 2006; Parry *et al.*, 2018; Ustaoglu *et al.*, 2021).

Urban land suitability is inherently multidimensional, as development conditions result from interactions among physical, environmental, socio-economic, and accessibility factors (Ismael & Kumar, 2024). Terrain and slope affect construction feasibility and infrastructure requirements. Existing land use/land cover (LULC) reflects prevailing landscape conditions. Vegetation indicates ecological characteristics, while land-surface temperature (LST) captures spatial variation in surface thermal conditions. Population density signals development pressure, and road accessibility and proximity to water bodies introduce key planning considerations (Malczewski & Rinner, 2015; Parry *et al.*, 2018; Ustaoglu *et al.*, 2021). Reliance on a single variable yields an incomplete representation of urban development suitability. Geographic Information System-based multi-criteria decision analysis (GIS-MCDA) offers a systematic framework for standardising heterogeneous spatial variables and integrating them according to their relative importance (Malczewski, 2006; Malczewski & Rinner, 2015).

The Analytic Hierarchy Process (AHP) is particularly valuable within GIS-MCDA, as it provides a structured procedure for pairwise comparison of criteria, derivation of relative weights, and assessment of consistency in expert judgements (Saaty, 1980, 1987). When integrated with GIS, AHP enables spatial integration of weighted criteria and the generation of suitability surfaces that reveal geographical variations in development potential. Previous studies have demonstrated the effectiveness of GIS-AHP for urban land suitability, urban service planning, and potential development assessment (Parry *et al.*, 2018; Şahin *et al.*, 2024). Comprehensive reviews of GIS-AHP applications also identify the method as an effective

approach for supporting urban growth and land-use policy where multiple criteria must be considered simultaneously (Aburas *et al.*, 2017). Recent research has further extended this approach by incorporating remotely sensed environmental variables alongside physical, socio-economic, and accessibility criteria (Joy *et al.*, 2024; Rane *et al.*, 2024).

Remote sensing serves as a critical data foundation for these assessments by providing spatially continuous information on land cover and environmental conditions. Multispectral satellite imagery enables detailed LULC classification, while spectral indices characterise vegetation and other surface properties. For instance, Sentinel-2 imagery combined with Random Forest classification demonstrates strong potential for urban land-cover mapping and representation of heterogeneous urban landscapes (Zhang *et al.*, 2021). LULC is particularly significant because the conversion of agricultural and vegetated surfaces to impervious urban land alters surface characteristics, ecological functions, and the spatial configuration of urban environments (Seto *et al.*, 2012; Güneralp *et al.*, 2020).

Vegetation, represented in this study by the Normalised Difference Vegetation Index (NDVI), serves as a key indicator of vegetation condition and landscape characteristics. Including NDVI is particularly relevant for environmentally informed urban planning, as vegetation and green infrastructure provide ecosystem services and contribute to urban cooling and climate resilience (Herath & Bai, 2024; Galalizadeh *et al.*, 2024). Systematic reviews indicate that urban greening influences thermal conditions through mechanisms such as shading and evapotranspiration, underscoring the importance of vegetation-related information in climate-sensitive urban planning (Galalizadeh *et al.*, 2024; Loria *et al.*, 2025). Land-surface temperature (LST) offers complementary information by capturing spatial differences in surface thermal conditions. Integrating LST with NDVI and LULC enables the suitability assessment to incorporate environmental and thermal characteristics alongside conventional physical and accessibility criteria. However, LST should be interpreted as a surface environmental indicator rather than a direct measure of human thermal comfort or heat-health vulnerability.

Physical and environmental constraints must also be explicitly considered. Slope affects construction feasibility, earthwork requirements, and infrastructure provision, and is therefore commonly included in GIS-based suitability assessments (Parry *et al.*, 2018; Şahin *et al.*, 2024). Proximity to water bodies identifies locations that require additional attention to drainage, environmental protection, and flood-sensitive planning. Incorporating this factor aligns with MCDA approaches that use proximity to natural resources and environmental features to differentiate areas with varying levels of development suitability (Ustaoglu *et al.*, 2021). However, in this study, proximity to water bodies is treated as an environmental or planning constraint and should not be regarded as a substitute for hydrological or hydraulic flood modelling.

The socio-spatial dimension is captured by population density, which reflects existing development pressure and the spatial concentration of inhabitants. Accessibility is represented using a network-based accessibility measure that considers connectivity to the existing road network, rather than simple Euclidean proximity to roads. Physical closeness to a road does not necessarily imply ease of access, particularly where roads are poorly connected, discontinuous, or constrained by the surrounding network structure. The accessibility criterion therefore reflects the relative ease with which potential green-infrastructure locations can be reached through the existing transportation network. Accessibility is widely recognised as an important consideration in land-suitability analysis because infrastructure connectivity can influence development patterns and the efficiency of urban expansion (Malczewski & Rinner, 2015; Ustaoglu *et al.*, 2021). Furthermore, transportation corridors may interact with environmental conditions, including urban thermal patterns, underscoring the importance of evaluating accessibility in conjunction with environmental indicators rather than in isolation (Mirabi & Davies, 2024).

These considerations are especially pertinent to Ilorin Metropolis, where ongoing urban expansion and land-use transformation are increasing demand for residential, institutional, commercial, and infrastructure development. Previous studies have highlighted the value of geospatial information for understanding land-use dynamics and supporting urban planning in Ilorin (Ipadeola *et al.*, 2018; Ipadeola & Babalola, 2025). However, integrating individual datasets into a comprehensive spatial assessment remains essential for identifying areas with varying combinations of development opportunities and constraints. This spatial differentiation is consistent with contemporary risk-sensitive urban planning approaches, which recognise land-use decisions as key determinants of exposure, environmental quality, and adaptive capacity (IPCC, 2022; Dodman *et al.*, 2023).

Therefore, this study develops a GIS-AHP-based Multi-Criteria Geospatial Evaluation framework to assess urban land suitability in Ilorin Metropolis. The research characterises existing LULC, evaluates seven physical, environmental, socio-economic, and accessibility criteria, determines their relative importance using AHP, standardises and integrates the criteria through weighted overlay, and generates an Urban Land Suitability Index (ULSI). This framework offers a transparent spatial decision-support tool for distinguishing relatively favourable and constrained areas. By integrating land cover, vegetation, thermal conditions, terrain, population pressure, accessibility, and water-related environmental constraints within a unified decision framework, the study provides spatial evidence to support more environmentally informed and risk-sensitive urban planning in Ilorin Metropolis.

2. Description of the Study Area

This study was conducted in Ilorin Metropolis, Kwara State, North-Central Nigeria (Figure 1), a rapidly expanding regional urban centre and a significant administrative, commercial, educational, and transportation hub.

The metropolis consists of Ilorin West, Ilorin East, and Ilorin South Local Government Areas, located approximately between 8°24'–8°36'N and 4°26'–4°40'E. Ongoing spatial expansion has led to substantial land-use transformation and increased pressure on land and environmental resources. Recent research documents significant growth of built-up land and radial urban expansion along major transportation corridors, underscoring the need for integrated spatial planning and land-allocation strategies (Ipadeola *et al.*, 2018; Idress *et al.*, 2021; Ipadeola *et al.*, 2025).

Ilorin features generally gently undulating terrain with localised hills and ridges and is primarily drained by the Asa River and its tributaries. The area is part of the Nigerian Basement Complex, consisting mainly of gneisses, migmatites, granitic rocks, and associated metasedimentary units. These geological and topographic characteristics influence drainage, terrain stability, and the suitability of land for urban development. The region experiences a tropical wet-and-dry climate, with rainfall concentrated mainly between April and October and relatively high temperatures during the dry season. Annual rainfall ranges from approximately 990 to 1,320 mm, and temperatures frequently exceed 30°C during the dry season. Spatial variability in rainfall has been linked to urban flooding, erosion, and drainage management challenges (Ifabiyi & Ashaolu, 2017).

The natural vegetation is predominantly Guinea Savannah, although extensive urbanisation has converted significant areas of vegetated and agricultural land into built-up and other developed uses. Multi-temporal remote-sensing studies confirm substantial changes in Ilorin's land-use structure and ongoing outward urban expansion (Ipadeola *et al.*, 2018; Salami *et al.*, 2021).

The spatial structure of the metropolis is defined by variations in land cover, terrain, population concentration, transportation accessibility, and proximity to water features. These characteristics make Ilorin a suitable case for spatial suitability assessment, as the potential for future development is unlikely to be uniform across the metropolis.

3. Materials and Methods

3.1 Research design

The study adopted a quantitative geospatial analytical design. The analytical workflow consisted of four principal stages: acquisition and processing of spatial datasets; preparation of the LULC and seven suitability criteria; AHP-based criterion weighting and consistency assessment; and GIS-based weighted-overlay modelling and spatial interpretation. Figure 2 presents the workflow.

The approach follows the general principle of GIS-MCDA, whereby spatial criteria are standardised and combined using decision weights to produce a composite spatial decision surface (Malczewski & Rinner, 2015).

3.2 Data Acquisition and Characteristics

Table 1 presents the datasets used in this study together with their sources, characteristics, and analytical applications. Sentinel-2 satellite imagery was used to de-

rive the LULC information. The classified image represented the existing spatial distribution of developed and undeveloped surfaces and subsequently served as one of the criteria in the urban land suitability model. The classification procedure produced the LULC map presented in Figure 3.

Remote sensing-based LULC classification provides an efficient means of representing the spatial structure of urban environments and identifying developed and undeveloped areas (Zhang *et al.*, 2021).

The completed classification was assessed using independent reference observations and a confusion matrix. Overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient were calculated following established accuracy-assessment procedures (Congalton & Green, 2019).

3.3 Suitability criteria

Seven criteria were selected to represent the principal physical, environmental, socio-economic and accessibility dimensions of urban land suitability in Ilorin Metropolis (Table 2). Slope was included to capture terrain-related development constraints, while LULC and NDVI represented existing land-cover and vegetation conditions. LST introduced the thermal environment into the assessment, population density represented development pressure, proximity to roads represented accessibility, and proximity to water bodies represented an environmental planning constraint. The use of multiple criteria is consistent with GIS-based urban suitability studies, which demonstrate that urban development suitability is inherently multidimensional and cannot be adequately represented by a single spatial variable (Parry *et al.*, 2018; Ustaoglu *et al.*, 2021; Şahin *et al.*, 2024).

3.4 Slope

Slope was derived from the elevation dataset used in the study and represented the physical characteristics of the terrain. Slope influences construction feasibility, earthworks, drainage and infrastructure development. In the suitability model, gentle slopes received higher suitability scores, whereas steeper areas received lower scores.

This treatment is consistent with previous urban land suitability studies that identify terrain characteristics as important criteria in determining development potential (Parry *et al.*, 2018; Şahin *et al.*, 2024).

3.5 NDVI

The Normalised Difference Vegetation Index was used to represent vegetation conditions. NDVI was calculated as:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

where *NIR* represents near-infrared reflectance

and *Red* represents red-band reflectance.

The resulting NDVI surface was standardised according to its relationship with the urban development ob-

jective. Vegetation is an important environmental characteristic because it contributes to urban ecological quality and is associated with variations in the thermal environment.

3.6 Land surface temperature

LST was incorporated to represent the thermal characteristics of the land surface. The spatial LST layer provided an indication of the thermal conditions associated with different locations within the metropolis.

The inclusion of LST complements LULC and NDVI because surface thermal conditions vary according to land-cover composition, vegetation condition and the intensity of built development. Thus, LST provides an environmental dimension that would not be captured by land-cover classification alone.

3.7 Population density

Population density was incorporated as a socio-economic and development-pressure criterion. Areas with greater population concentration may experience stronger demand for housing, infrastructure, transportation and public services.

However, high population density may simultaneously indicate development pressure and existing limitations in land availability and infrastructure capacity. Consequently, its interpretation within suitability modelling depends on the specific planning objective and standardisation rule adopted.

3.8 Proximity to roads

Road proximity represents accessibility. The Euclidean distance from the road network was calculated and standardised so that locations closer to roads received higher suitability scores.

Transportation accessibility is commonly incorporated into urban suitability models because accessibility influences development potential and the spatial distribution of urban activities (Parry *et al.*, 2018; Şahin *et al.*, 2024).

3.9 Proximity to water bodies

Proximity to water bodies was included as an environmental constraint. Locations closer to water features were assigned lower suitability because inappropriate development around drainage and water systems may inter-

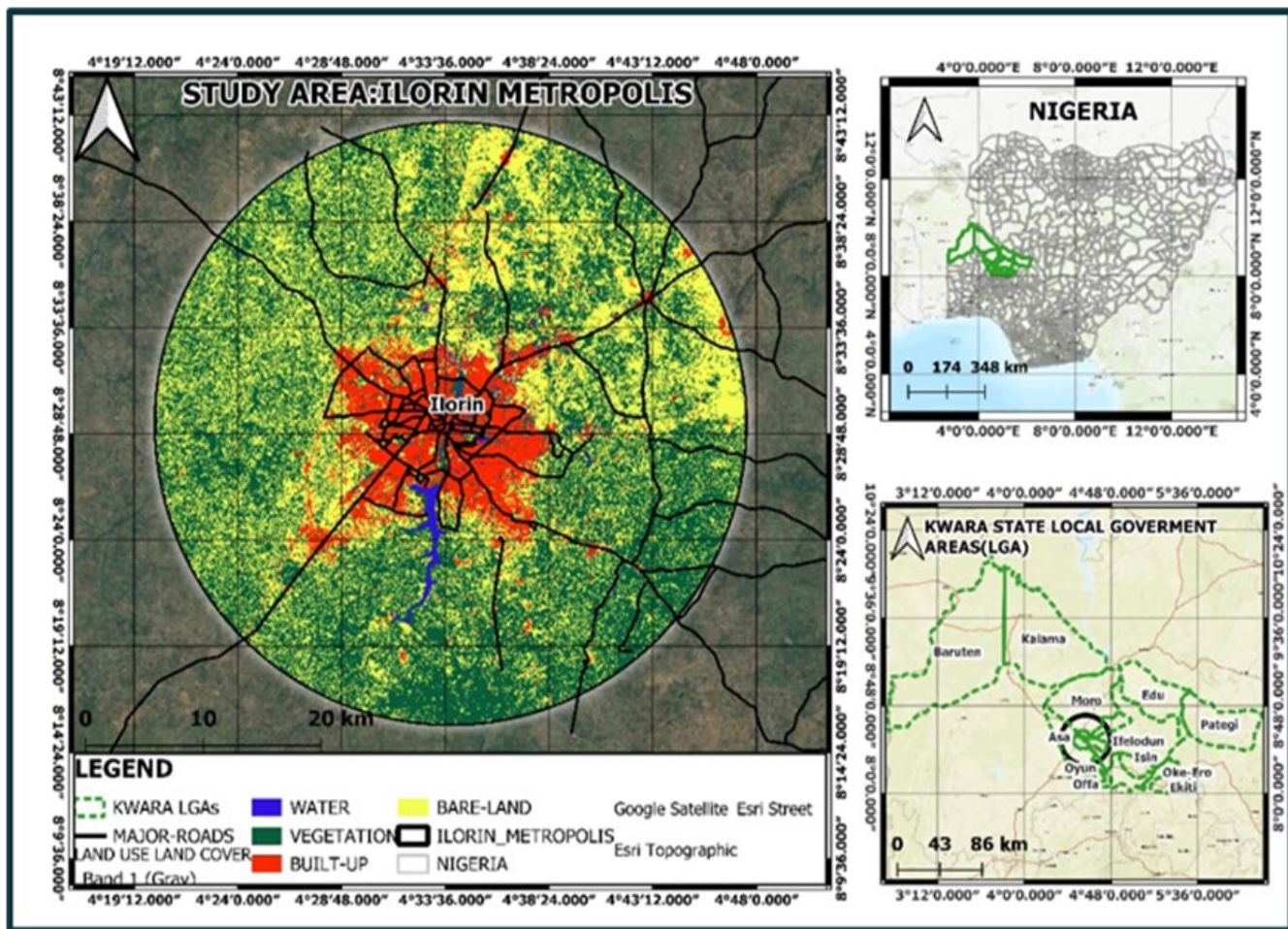


Figure 1. The boundary and major physical and infrastructural features of Ilorin Metropolis.

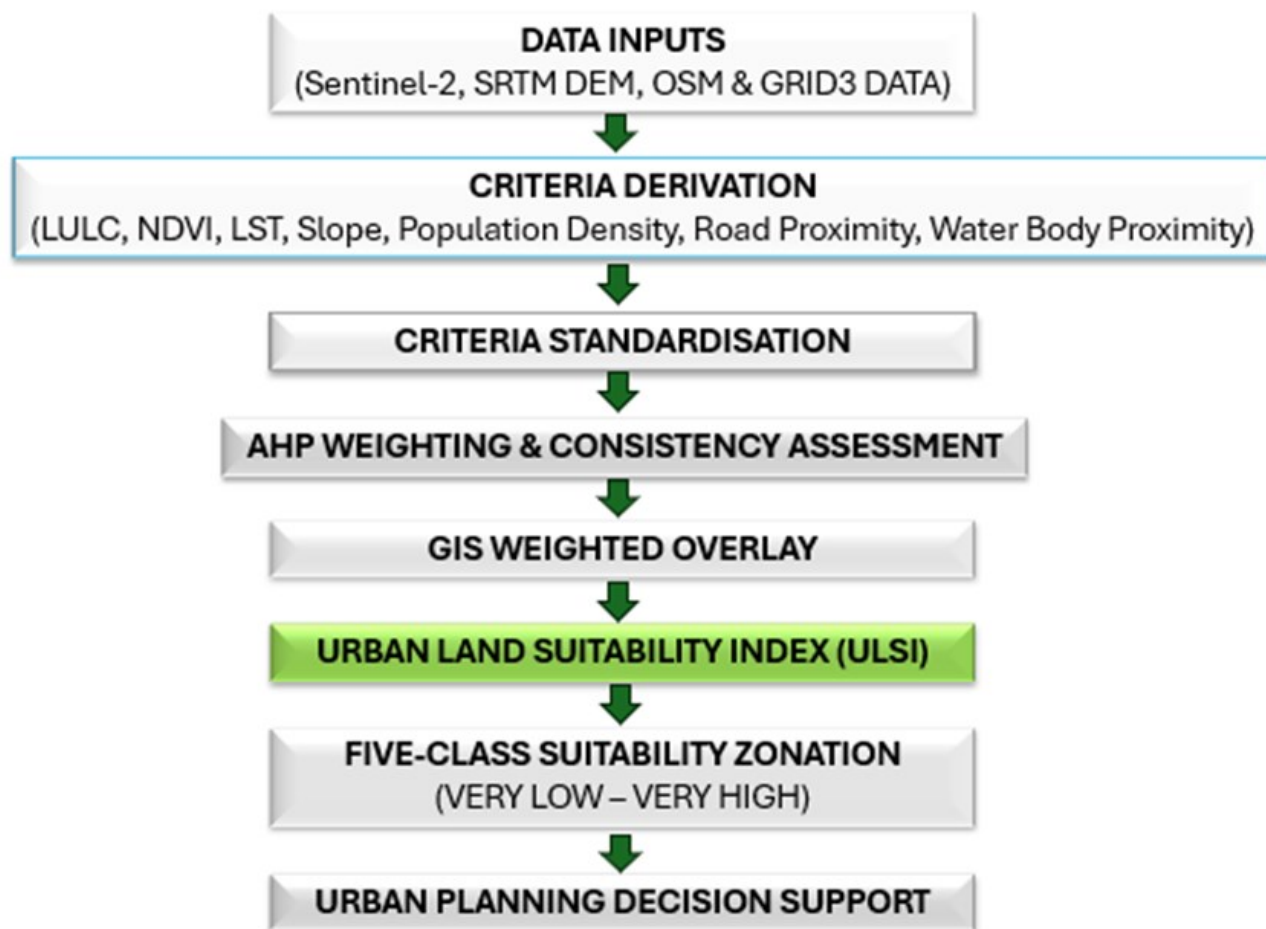


Figure 2. Methodological framework for the GIS-based Multi-Criteria Geospatial Evaluation of urban land suitability in Ilorin Metropolis.

ferre with natural drainage processes and increase environmental constraints.

The criterion was therefore not treated as a direct flood-risk model. Instead, it represented a spatial planning constraint associated with proximity to water features.

3.10 AHP weighting

The Analytic Hierarchy Process was used to determine the relative importance of the seven criteria. AHP provides a structured approach for pairwise comparison of criteria and conversion of qualitative judgements into quantitative weights (Saaty, 1980).

A seven-by-seven pairwise comparison matrix was constructed using Saaty's nine-point comparison scale. Reciprocal values were assigned to opposing comparisons. The comparison matrix was normalised by dividing each element by its corresponding column total. The criterion weight was then obtained from the mean of the normalised values in each row, following the AHP procedure (Saaty, 1980).

3.11 AHP consistency assessment

The consistency of the pairwise judgements was assessed using the Consistency Index (CI) and Consistency Ratio (CR):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

and

$$CR = \frac{CI}{RI} \quad (3)$$

where λ_{max} is the principal eigenvalue, n is the number of criteria, and RI is the Random Index.

A CR below 0.10 is conventionally considered acceptable (Saaty, 1980).

Table 1. Data Sources and Their Applications

S/N	Data Category	Data Type (Format)	Purpose in Study	Source	Resolution / Scale
1	Sentinel-2	Satellite imagery (Raster)	LULC classification	Sentinel-2 Land Cover Explorer	10m
2	Shuttle Radar Topography Mission (SRTM)	Elevation data (Raster)	Slope & terrain analysis	USGS Earth Explorer	30m (1 arc-second)
3	Road Network	Infrastructure (Polyline)	Network analysis	OpenStreetMap (Geofabrik)	Vector (Scale-independent)
4	Hospitals, Schools, Markets, and Police Stations	Service Location (Point)	Accessibility analysis	GRID3 Data Hub	Vector (Scale-independent)
5	Rivers/Streams	Infrastructure (Polyline)	Proximity to rivers	OpenStreetMap (Geofabrik)	Vector (Scale-independent)
6	Administrative boundary (STATES, LGA's, Wards)	Boundary (Polygon)	Study area clipping and mapping	GRID3 Data Hub	Vector (Scale-independent)
7	Population density	Socio-economic (CSV)	Demand and Planning pressure analysis	GRID3 Data Hub	100m (Base Grid) / Admin-level

Source: Author's compilation based on data obtained from Sentinel-2, USGS Earth Explorer, OpenStreetMap, and GRID3 (2026)

3.12 Standardisation, weighted overlay and suitability classification

Because the seven criteria were expressed in different units and scales, they were standardised to a common suitability scale before integration. This step is essential in GIS-MCDA because direct combination of variables measured in different units would produce inappropriate results (Malczewski, 2000, 2006).

The standardised criteria were combined using weighted linear combination:

$$ULSI = \sum_{i=1}^n w_i x_i \quad (4)$$

where $ULSI$ represents the Urban Land Suitability Index, w_i is the AHP-derived weight of criterion i , and x_i is the standardised suitability score of criterion i . Weighted linear combination allows each spatial criterion to contribute to the final suitability surface according to its relative importance (Malczewski & Rinner, 2015).

The continuous Urban Land Suitability Index (ULSI) was reclassified into five ordinal classes, Very Low, Low, Moderate, High and Very High, to facilitate spatial interpretation and communication of the continuous suitability surface. The five-level classification provides a graduated representation of increasing relative suitability, allowing areas with comparatively greater development constraints to be distinguished from areas with more favourable combinations of the evaluated criteria. Such classification is commonly used in GIS-based multi-criteria suitability assessment to transform continuous index outputs into interpretable spatial categories for planning and decision support (Malczewski & Rinner, 2015; Şahin *et al.*, 2024). Importantly, the classes represent relative suitability within the study area rather than absolute thresholds of development feasibility. Consequently, areas classified as High or Very High should be regarded as potentially favourable zones requiring further site-specific investigation and compliance with applicable planning and environmental regulations.

4. Results

Table 2. Criteria and rationale for urban land suitability assessment

Dimension	Criterion	Model representation
Physical	Slope	Terrain-related development constraints
Environmental	LULC	Existing land-cover conditions
Environmental	NDVI	Vegetation condition
Environmental	LST	Surface thermal conditions
Socio-economic	Population density	Development pressure
Accessibility	Proximity to roads	Transportation accessibility
Environmental constraint	Proximity to water bodies	Water-related environmental/planning constraints

Source: Author's framework, informed by previous GIS-based multi-criteria urban suitability studies (Parry *et al.*, 2018; Ustaoglu *et al.*, 2021; Şahin *et al.*, 2024).

4.1 Existing LULC structure

The LULC results indicate that Ilorin Metropolis was still predominantly characterised by semi-natural and peri-urban land-cover conditions, despite substantial recent urban expansion. Rangeland was the largest class, covering 1,277.58 km² (65.01%), followed by built-up land with 343.20 km² (17.46%), cropland with 207.03 km² (10.53%), and water-related features with 137.17 km² (6.98%).

The spatial distribution of built-up land indicates concentration around the central urban core, with development extending outward into surrounding areas. This pattern is consistent with the interpretation that existing development provides an indication of the direction and intensity of urban expansion.

The result is important for planning because LULC provides a spatial representation of the existing urban footprint but cannot independently determine where future development should occur. Urban land suitability requires the simultaneous consideration of other physical, environmental and socio-economic conditions.

4.2 Spatial characteristics of the suitability criteria

The seven criteria exhibited spatially heterogeneous distributions across the metropolis as shown in Figures 3(a-g).

Slope varied across the study area, with relatively gentle areas assigned higher development suitability and steeper areas assigned lower suitability. This reflects the practical influence of terrain on construction, drainage, earthworks and infrastructure.

NDVI showed spatial variation in vegetation condition. Its inclusion provided an environmental dimension to the suitability model and contributed substantially to the final decision structure.

LST also varied spatially across the metropolis. Areas experiencing relatively higher thermal conditions were represented as less favourable within the suitability standardisation adopted by the study.

Population density represented development pressure, while proximity to roads represented accessibility. Proximity to water bodies represented an environmental constraint, with locations closer to water features receiving lower suitability scores.

Together, the seven layers provided complementary information. No single criterion was sufficient to represent the complex spatial conditions influencing urban development suitability.

The accuracy assessment indicates a high level of agreement between the classified image and the independent reference observations. Importantly, this result validates the LULC input layer, rather than the entire suitability model. The distinction is necessary because classification accuracy and suitability-model validation address different analytical questions.

4.3 AHP-Derived Criterion Weights and Relative importance of suitability criteria

The AHP results revealed a clear ranking of the seven criteria. Figure 4 provides a graphical representation

of the criterion weights. Table 5 presents the pairwise comparison matrix.

The AHP results indicate that the seven criteria contributed unequally to the urban land suitability assessment (Figure 4). NDVI recorded the highest weight (24.72%), followed by LULC (19.19%), population density (16.22%), LST (15.39%), slope (13.98%), proximity to water bodies (6.22%), and proximity to roads (4.28%). Thus, vegetation condition and land-cover characteristics jointly accounted for 43.91% of the total decision weight, highlighting their substantial influence within the decision hierarchy.

The relatively high weight assigned to NDVI suggests that vegetation condition was considered the most influential criterion in determining urban land suitability in Ilorin. LULC and population density also made substantial contributions, reflecting the importance of existing land characteristics and the spatial distribution of development pressure. In contrast, proximity to roads received the lowest weight, indicating a comparatively smaller contribution to the overall suitability assessment. Similar GIS-AHP studies have demonstrated the value of assigning differentiated criterion weights to reflect their relative importance rather than assuming equal contributions among spatial variables (Mamo, 2019; Parry *et al.*, 2018).

The results should, however, be interpreted as relative preferences within the constructed decision hierarchy, rather than as evidence that lower-weighted criteria are unimportant. Each criterion contributes to the composite suitability index, with its influence determined by the AHP-derived weighting structure for the study area.

4.4 AHP consistency

The consistency assessment produced a CR of 0.055, which is below the conventional 0.10 threshold. The pairwise judgements can therefore be regarded as sufficiently consistent for use in the subsequent weighted-overlay analysis (Saaty, 1980). The obtained value of 0.055 therefore indicates an acceptable level of consistency in the pairwise judgements.

This result is important because AHP weights are partly dependent on judgement. Consistency testing provides a quantitative check on the internal coherence of the pairwise comparisons. Similar GIS-AHP applications have used the CR criterion to establish whether the derived weights are sufficiently consistent for subsequent spatial modelling (Mamo, 2019). Table 7 summarises the consistency assessment.

4.5 Urban Land Suitability Index and Spatial Distribution

The seven standardised criteria were integrated using their AHP-derived weights through weighted overlay to generate a continuous Urban Land Suitability Index (ULSI). This GIS-MCDA approach combines heterogeneous criteria on a common decision scale according to their relative importance (Malczewski, 2006; Malczewski & Rinner, 2015). The resulting ULSI ranged from 0.006

to 0.846 and was reclassified into five ordinal classes: Very Low, Low, Moderate, High and Very High

The spatial distribution in Figure 5 shows clear variation in relative suitability. High and Very High suitability zones are concentrated mainly around the existing urban core and major infrastructure corridors, particularly parts of Ilorin West and Ilorin South, reflecting the combined influence of land cover, population, environmental and accessibility conditions. Lower suitability is more evident around river corridors, relatively steeper terrain and areas with higher surface thermal conditions, consistent with the roles of water-body proximity, slope and LST in the model.

The Moderate class constituted the largest proportion (35%), followed by High and Low (20% each), Very Low (15%) and Very High (10%) (Table 8). Thus, 30% of the metropolis falls within High or Very High suitability, while 35% falls within Low or Very Low classes.

The Very High and High classes represent relatively favourable conditions within the adopted decision framework, not automatic development approval or future growth probability. Similarly, lower suitability around water bodies should not be interpreted as flood-hazard mapping, since no hydrological or hydraulic flood model was undertaken. The ULSI therefore provides a spatial decision-support basis for risk-sensitive urban planning and prioritisation of areas for further site-specific investigation (Parry *et al.*, 2018; Şahin *et al.*, 2024).

4.6 Suitability-model validation

ROC-AUC was considered as a possible validation approach for the suitability model. However, it was not implemented because an independent dataset containing observed suitable and unsuitable urban development locations was unavailable.

Consequently, the 92.5% overall LULC classification accuracy should not be interpreted as a 92.5% validation accuracy for the ULSI.

5. Discussion

The results reveal a spatially heterogeneous urban environment in Ilorin Metropolis, characterised by a concentrated built-up core surrounded by substantial rangeland, cropland and water-related features. Rangeland constituted 65.01% of the study area, while built-up land accounted for 17.46%, indicating that substantial semi-natural and peri-urban land conditions remain within the metropolitan landscape. The concentration of built-up development around the urban core suggests continuing pressure for outward expansion into surrounding undeveloped and agricultural areas. Such expansion requires spatially explicit planning because urbanisation interacts with land-use change, infrastructure provision and environmental conditions to influence urban sustainability and climate-related risks (Dodman *et al.*, 2023). Similar GIS-based suitability studies have demonstrated the value of integrating spatial criteria to identify areas with differing development potential (Parry *et al.*, 2018; Şahin *et al.*, 2024).

A key strength of the present assessment is the integration of seven complementary criteria: slope, LULC, NDVI, LST, population density, proximity to roads and proximity to water bodies, rather than relying on a single indicator. Each represents a different dimension of development suitability: terrain, existing land cover, vegetation condition, thermal environment, development pressure, accessibility and environmental constraint, respectively. GIS-MCDA is particularly appropriate for such problems because variables measured in different units and having different meanings can be standardised and integrated using explicit decision rules and weights (Malczewski & Rinner, 2015). The present framework therefore provides a more comprehensive representation of relative suitability than an assessment based solely on existing urban extent.

Table 3. LULC distribution of Ilorin Metropolis

LULC class	Area (km ²)	Percentage (%)
Rangeland	1,277.58	65.01
Built-up	343.20	17.46
Cropland	207.03	10.53
Water-related features	137.17	6.98
Total	1,965.00	100.00

Source: Author's analysis (2026)

The AHP results further demonstrate that the criteria did not contribute equally to the decision model. NDVI received the highest weight (24.72%), followed by LULC (19.19%), population density (16.22%), LST (15.39%), slope (13.98%), proximity to water bodies (6.22%) and proximity to roads (4.28%). The dominance of NDVI indicates that vegetation condition was considered the most influential criterion within the adopted decision hierarchy. This should not be interpreted as vegetation alone determining suitability; rather, its weighting reflects its greater relative contribution within the expert-derived decision structure. The remaining 75.28% was distributed among the other six criteria, demonstrating the multi-dimensional nature of the assessment. The consistency ratio of 0.055, below the conventional 0.10 threshold, further indicates acceptable consistency in the pairwise judgements (Saaty, 1980).

The relatively high weights assigned to LULC and NDVI emphasise the importance of land-cover and vegetation conditions in the Ilorin suitability structure. This is particularly relevant in an expanding city where conversion of vegetated and agricultural surfaces can alter environmental conditions. The 15.39% weight assigned to LST additionally introduces a thermal dimension to land suitability. Its inclusion is justified by growing concern regarding urban heat under changing climatic conditions (Dodman et al., 2023; Nunes, 2021). However, LST represents land-surface

thermal conditions and should not be interpreted directly as human thermal comfort or heat-health risk. Its role here is therefore as an environmental indicator contributing to relative suitability. The combined use of LST, NDVI and LULC provides a more defensible environmental representation than treating any one of these variables independently.

Slope and proximity to water bodies provide complementary physical and environmental constraints. The 13.98% weight for slope indicates that terrain contributes meaningfully to the suitability assessment, consistent with previous GIS-AHP applications that incorporate physical characteristics into urban planning decisions (Parry *et al.*, 2018). Water-body proximity received a lower weight of 6.22%, but its inclusion remains important because development close to water features may require greater consideration of drainage, environmental protection and flood-sensitive planning. Nevertheless, proximity to water bodies in this study is a planning constraint rather than a flood-hazard model; it does not quantify flood probability, depth or hydraulic behaviour.

Proximity to roads received the lowest weight (4.28%). This does not imply that accessibility is unimportant, but rather that it had the smallest relative influence within this decision structure. This illustrates the value of locally defined AHP weights, since criteri-

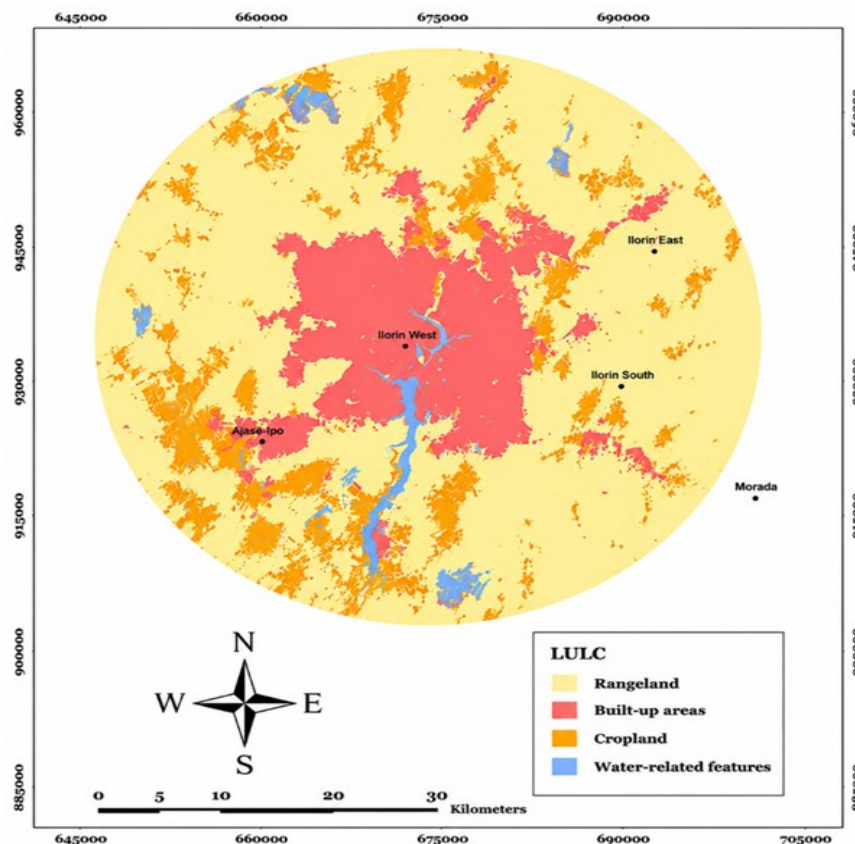


Figure 3a. Land-use/land-cover classification of Ilorin Metropolis derived from Sentinel-2 imagery.

Source: Author's analysis of Sentinel-2 imagery, 2026.

The LULC classification achieved an Overall Accuracy of 92.5% and a Kappa coefficient of 0.89. Producer's accuracy ranged from 85.0% to 96.2%, while user's accuracy ranged from 87.5% to 95.8%.

Table 4. Accuracy assessment of the LULC classification

Accuracy measure	Result
Overall Accuracy	92.5%
Producer's Accuracy	85.0–96.2%
User's Accuracy	87.5–95.8%
Kappa coefficient	0.89

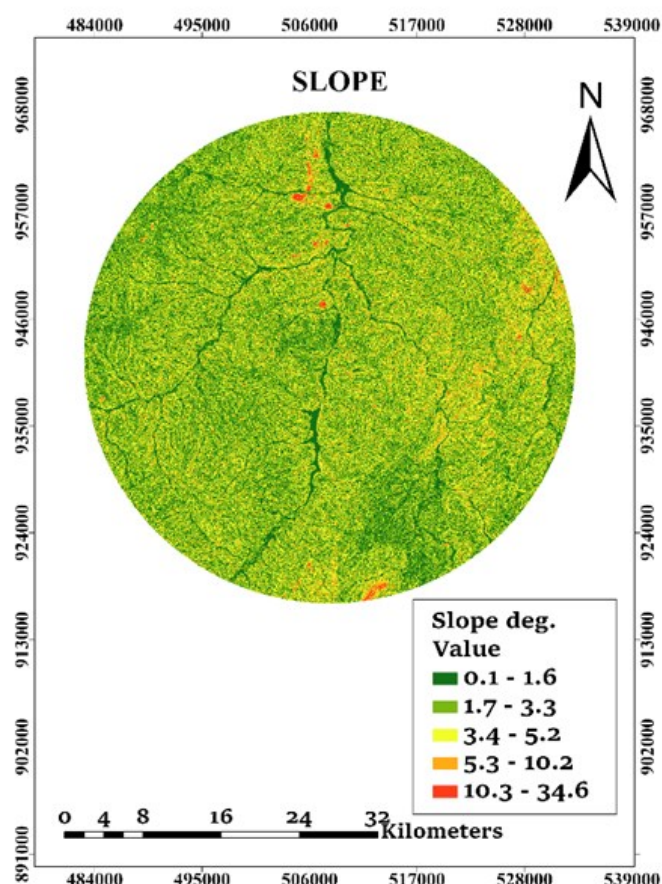


Figure 3c. Spatial distribution of NDVI in Ilorin Metropolis.

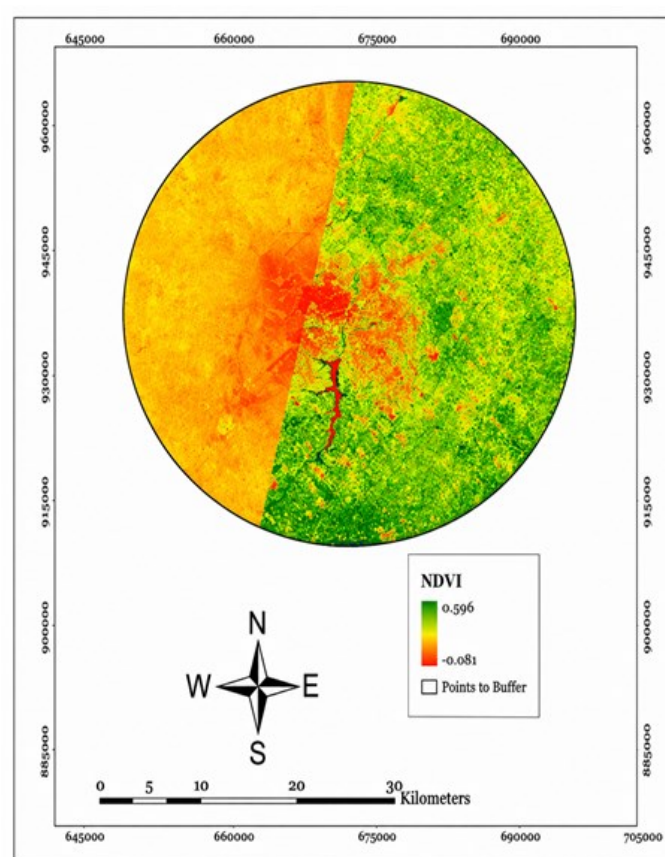


Figure 3b. Spatial distribution of slope in Ilorin metropolis

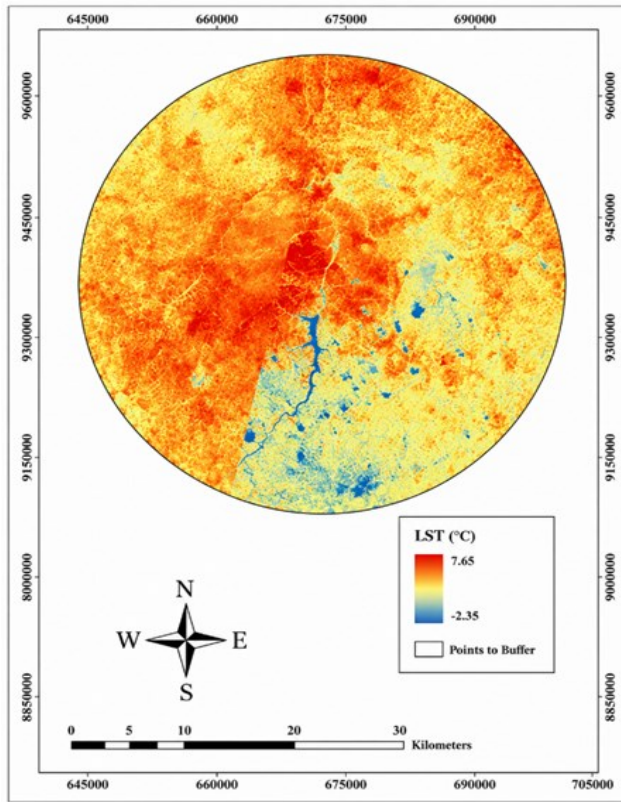


Figure 3d. Spatial distribution of land surface temperature in Ilorin metropolis

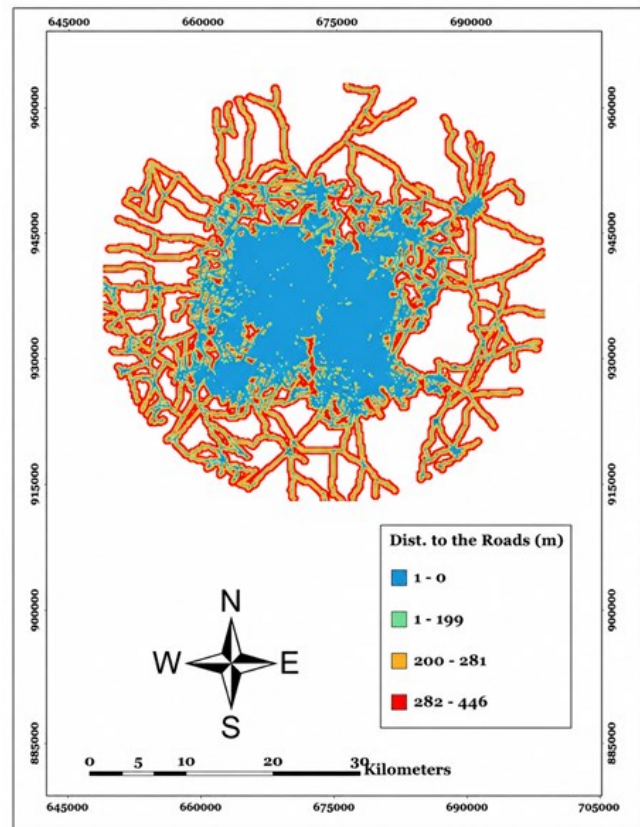
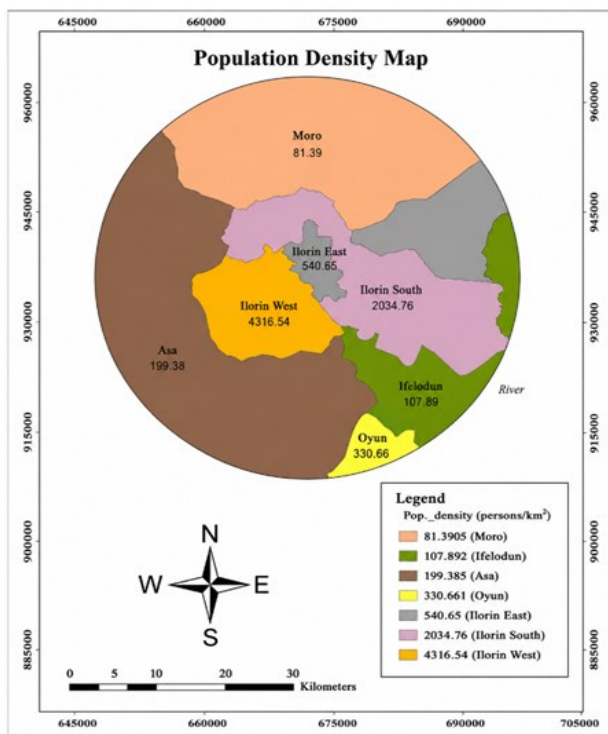
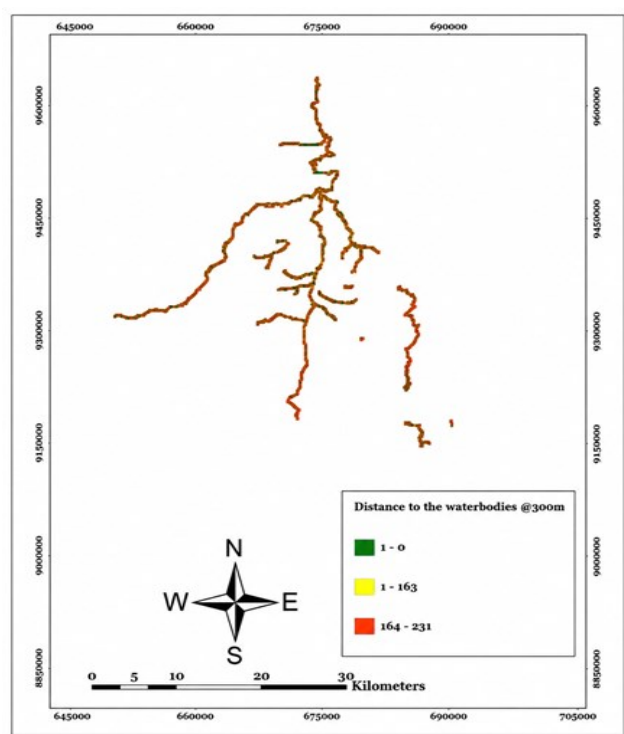


Figure 3f. Spatial distribution of proximity to roads in Ilorin Metropolis.



**Figure 3e. Spatial distribution of population density
In Ilorin metropolis**



**Figure 3g. Spatial distribution of proximity to
in Ilorin Metropolis**

Table 5. Pairwise comparison matrix used in the AHP

Criteria	Slope	NDVI	LULC	Water bodies	Population density	Roads	LST
Slope	1	1/3	1	3	1	3	1
NDVI	3	1	2	4	1	6	1
LULC	1	1/2	1	7	1	6	1
Water bodies	1/3	1/4	1/7	1	1/3	1	1
Population density	1	1	1	3	1	3	1
Roads	1/3	1/6	1/6	1	1/3	1	1/4
LST	1	1	1	1	1	4	1

Source: Author's computation based on the AHP procedure of Saaty (1980).

The resulting derived criterion weights for the urban land suitability are presented in Table 6.

Table 6. AHP-derived weights of urban land suitability criteria

Rank	Criterion	Weight	Percentage
1	NDVI	0.247	24.72
2	LULC	0.192	19.19
3	Population density	0.162	16.22
4	LST	0.154	15.39
5	Slope	0.140	13.98
6	Proximity to water bodies	0.062	6.22
7	Proximity to roads	0.043	4.28
Total		1.000	100.00

Source: Author's computation based on Saaty (1980)

on importance depends on the planning objective and decision context (Malczewski & Rinner, 2015).

The weighted overlay produced a continuous ULSI ranging from 0.006 to 0.846, subsequently classified into five ordinal categories. Moderate suitability constituted the largest class (35%), followed by Low and High suitability (20% each), Very Low (15%) and Very High (10%). The predominance of the Moderate class indicates that much of Ilorin exhibits intermediate combinations of the evaluated conditions rather than uniformly favourable or constrained characteristics. High and Very High suitability were concentrated mainly around the existing urban core and major infrastructure corridors, particularly parts of Ilorin West and Ilorin South, whereas lower suitability was more evident around river corridors, steeper terrain and areas with higher thermal conditions. This pattern is broadly consistent with GIS-AHP studies demonstrating that composite suitability modelling can reveal spatial differences in development potential (Parry *et al.*, 2018; Şahin *et al.*, 2024).

The findings have implications for risk-sensitive urban planning, although the framework should not be interpreted as a formal multi-hazard risk assessment. The integration of thermal conditions, terrain, population pressure and water-related constraints provides spatial information relevant to climate-sensitive planning. Green infrastructure and vegetation-based interventions can further contribute to urban environmental quality and heat mitigation (Herath & Bai, 2024; Pereira *et al.*,

2024). Accordingly, High and Very High zones should be regarded as potentially favourable areas for further investigation, not automatic development zones. Conversely, Low and Very Low areas warrant greater environmental and planning scrutiny. Detailed site investigation, statutory planning requirements and hazard-specific assessments remain necessary before implementation.

Finally, the LULC classification achieved an overall accuracy of 92.5% and Kappa of 0.89, providing reliable thematic input to the suitability model; however, an independent dataset for validating the ULSI itself was unavailable. Thus, the ULSI should be interpreted as a model-derived relative suitability surface and strategic decision-support product, rather than a statistically validated prediction of development success. Overall, the study demonstrates the usefulness of integrating Remote Sensing, GIS and AHP to support spatially differentiated and environmentally informed urban land-use planning in Ilorin Metropolis.

6. Implications for Risk-Sensitive Urban Planning

Although the present study does not constitute a formal multi-hazard or climate-risk assessment, its integrated suitability framework provides spatially explicit information that can strengthen risk-sensitive urban planning in Ilorin Metropolis. By combining environmental, physical, socio-economic and accessibility criteria, the study moves beyond conventional land suitability assessment towards a planning approach that recognises that

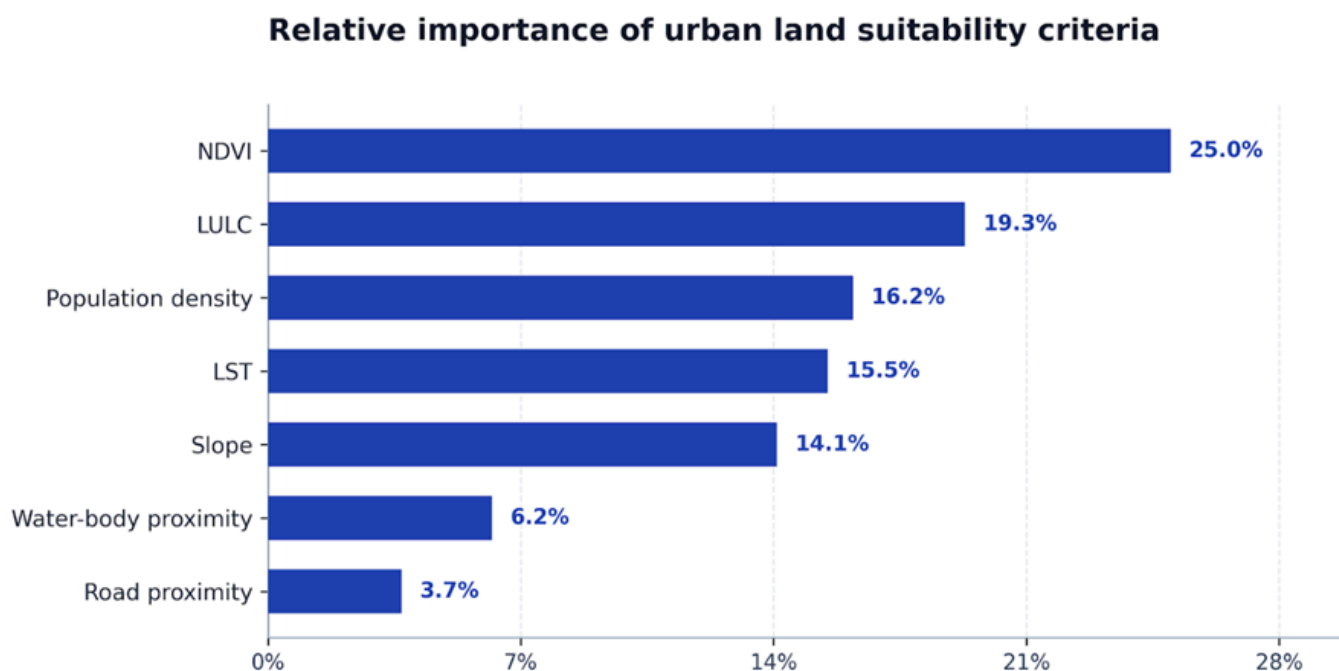


Figure 4. Relative importance of the AHP-derived weights of the seven criteria used in the urban land suitability model.

Source: Author's AHP analysis

development potential varies according to prevailing environmental conditions.

The inclusion of LST (15.39%) and NDVI (24.72%) is particularly relevant to climate-sensitive planning because it incorporates thermal conditions and vegetation characteristics into decisions concerning urban development. This is important in rapidly urbanising environments where vegetation loss and increasing impervious surfaces can intensify urban heat and reduce environmental resilience (Nunes, 2021; Herath & Bai, 2024). Similarly, slope (13.98%) and proximity to water bodies (6.22%) introduce physical and environmental constraints that can guide planners towards locations requiring fewer terrain-related interventions and away from environmentally sensitive areas. However, water-body proximity should be interpreted as a planning constraint rather than a substitute for flood-hazard modelling.

The resulting ULSI therefore provides a decision-support layer for differentiated urban planning. The concentration of High and Very High suitability zones around existing urban areas and infrastructure corridors suggests opportunities for more controlled and efficient development, while Low and Very Low zones warrant greater environmental scrutiny. Such spatial differentiation is consistent with the broader principle of integrating environmental conditions and risk considerations into urban development decisions (Dodman et al., 2023).

Importantly, the framework should inform rather than replace statutory planning, site-specific engineering investigations and hazard-specific assessments. Its principal contribution is the provision of a transparent GIS-AHP basis for identifying relatively favourable and constrained areas, thereby supporting more environmentally informed and risk-sensitive urban expansion in Ilorin.

7. Strengths and Limitations of the study.

The principal strength of the study is its integration of remote sensing and GIS with AHP-based multi-criteria evaluation. The approach converts heterogeneous spatial information into a transparent decision-support framework.

The LULC classification also demonstrated good thematic performance, with an overall accuracy of 92.5% and a Kappa coefficient of 0.89. This provides confidence in the LULC layer used within the suitability model.

The AHP consistency ratio of 0.055 provides additional evidence that the pairwise comparisons were sufficiently coherent for the derived weights to be used in the overlay analysis. Several limitations nevertheless require acknowledgement.

First, AHP depends partly on expert judgement, and criterion weights may therefore contain subjectivity. This is a recognised limitation of AHP-based spatial decision analysis (Saaty, 1980; Malczewski & Rinner, 2015).

Second, the quality of the final suitability map depends on the quality, resolution and compatibility of the input datasets.

Third, the suitability model was not independently validated using ROC-AUC because an independent dataset of observed suitable and unsuitable development locations was unavailable.

Fourth, the LULC classification accuracy should not be interpreted as validation of the entire ULSI. The 92.5% OA and 0.89 Kappa establish the reliability of the classification input, not the predictive performance of the MCDA output.

Finally, the LULC results in the current thesis contain an internal numerical inconsistency between Table 4.1 and the later Discussion/Conclusion. This must be resolved against the original GIS outputs before journal submission. The manuscript should contain only one verified LULC dataset.

8. Conclusions

This study developed and applied a GIS-based Multi-Criteria Geospatial Evaluation framework for urban land suitability assessment in Ilorin Metropolis, Nigeria. The framework integrated remote sensing-derived LULC and environmental information with physical, socio-economic and accessibility criteria through AHP and weighted overlay.

The completed results demonstrate substantial spatial variation in development suitability across Ilorin. The final reported LULC assessment showed a predominantly semi-natural and peri-urban landscape, with rangeland representing the largest reported class at 65.01%, followed by built-up land at 17.46%, cropland at 10.53% and water-related features at 6.98%. Built-up areas were concentrated around the urban core, indicating an established pattern of urban development and continuing pressure for expansion.

Seven criteria were successfully incorporated into the suitability model: slope, LULC, NDVI, LST, population density, proximity to roads and proximity to water bodies. AHP assigned the greatest relative importance to NDVI (24.72%), followed by LULC (19.19%), population density (16.22%), LST (15.39%), slope (13.98%), water-body proximity (6.22%) and road proximity (4.28%). The consistency ratio of 0.055 confirmed acceptable consistency in the pairwise judgements.

The weighted-overlay model produced a continuous Urban Land Suitability Index that was classified into five categories. Moderate suitability represented the largest proportion of the study area (35%), followed by Low and High suitability (20% each), Very Low suitability (15%) and Very High suitability (10%). High and Very High suitability areas were principally concentrated around the established urban core and major infrastructure corridors, while lower suitability was associated more strongly with river corridors, steeper terrain and areas with higher thermal conditions.

The principal contribution of the study is therefore the development of a transparent, spatially referenced decision-support framework capable of integrating heterogeneous urban planning criteria into a single suitability assessment. The framework can assist planning authorities in screening potential areas for future development, identifying

Table 7. AHP consistency assessment

Measure	Value
Number of criteria	7
Principal eigenvalue (λ_{max})	7.44
Consistency Index (CI)	0.073
Random Index (RI)	1.32
Consistency Ratio (CR)	0.055
Decision	Consistent

Table 8. Distribution of Urban Land Suitability Classes

Suitability class	Percentage (%)
Very Low	15
Low	20
Moderate	35
High	20
Very High	10
Total	100

Source: Authors' analysis (2026).

environmentally constrained locations and supporting more evidence-based land-use decisions.

The suitability map should, however, be regarded as a decision-support instrument rather than a replacement for statutory planning procedures, field verification, detailed engineering assessment or formal hazard modelling.

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Disclosure Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper. The research was conducted solely for academic and scientific purposes as part of the doctoral research activities

of the first author within the Department of Surveying and Geoinformatics.

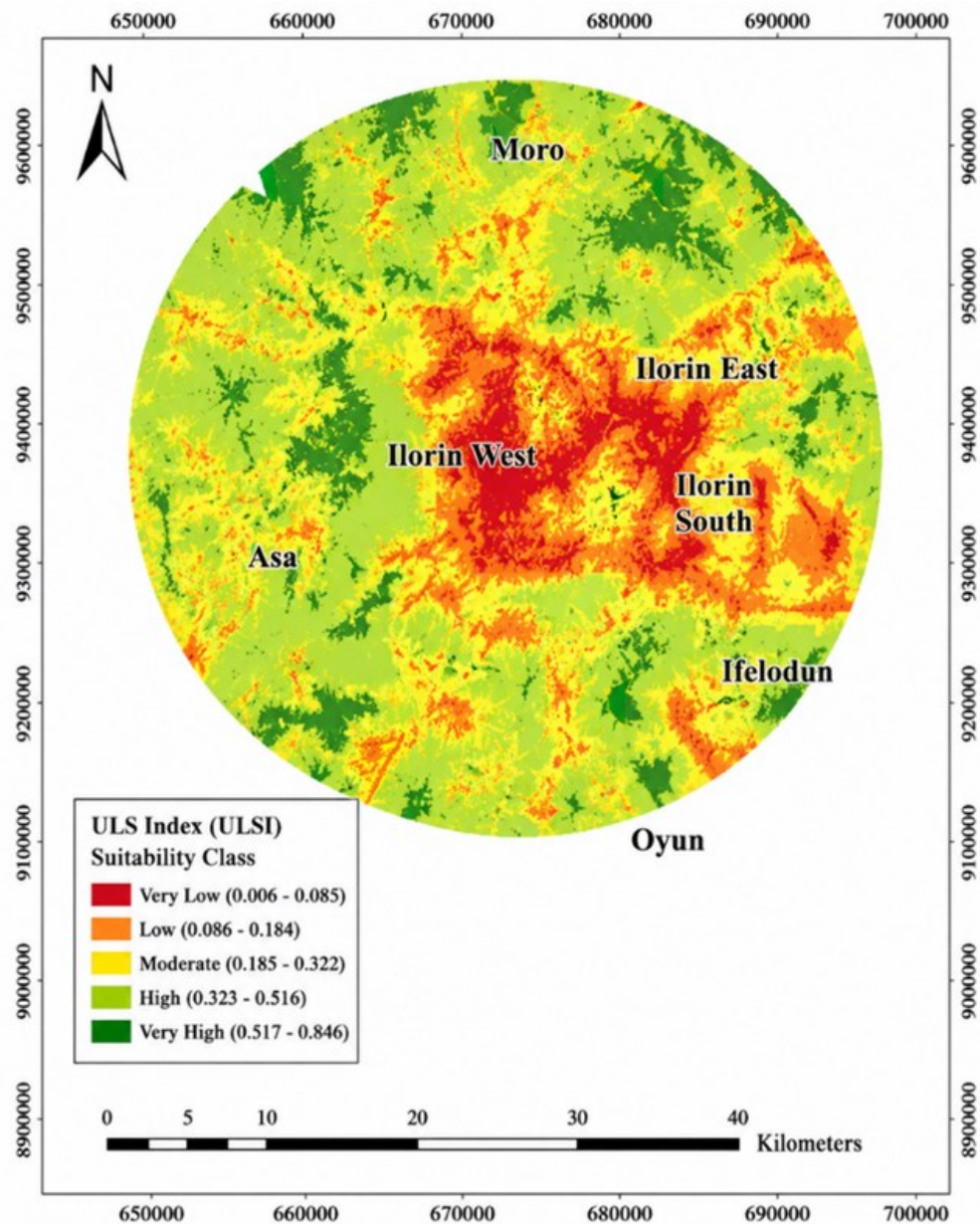


Figure 5. Urban Land Suitability Index and classified suitability zones of Ilorin Metropolis.

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