A GIS-based analytical hierarchy process modeling for agricultural-land suitability in Awka South local government area

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Abstract: This study aimed at performing a GIS-based analytical hierarchy process modeling for agricultural land suitability in Awka South L.G.A. The objectives of the study were to: establish the factors for agricultural land suitability in Awka South L.G.A; reclassify and standardize the factors for agricultural suitability; calculate the weights and consistency of the classified factors; and determine the most suitable areas for agriculture practices in the Awka South L.G.A. The methodological approach employed the assessment of factors in modelling and mapping agricultural suitability in Awka South L.G.A. This assessment was based on a wide range of criteria, including slope, elevation, soil, temperature, precipitation, drainage network, and landcover/landuse. The analytic hierarchy process (AHP) was used to compare and determine the relative importance of these criteria through matrix comparisons. Subsequently, these criteria were assigned relative weights. To generate the final suitability map, a Weighted Overlay technique was applied, integrating the various suitability criteria maps. The findings revealed three distinct suitability zones for the area under study: high suitability, moderate suitability, and low suitability. High suitability encompassed an area of 33.324 km^2, constituting 20.23% of the total coverage. The moderate suitability zone extended over 89.294 km^2, representing a substantial 54.23% coverage. The low suitability zone covered 42.032 km^2, accounting for 25.52% of the whole area. These delineations provide a comprehensive understanding of the distribution and extent of suitability within the study area. It was recommended that priority should be given to the development and intensification of agricultural activities in areas identified as high-suitability zones. This zone represents prime agricultural land, and efforts should be directed towards maximizing productivity while implementing sustainable farming practices

Keywords: agricultural land suitability, remote sensing, site selection, sustainable agriculture, Awka South LGA

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1 Introduction

Evaluation of the suitability of agricultural land plays a crucial and pivotal role in ensuring sustainable land management and agricultural development. It involves assessing the suitability of land for specific agricultural activities based on various factors such as soil, climate conditions, topography, and water availability. Accurate

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evaluation of land suitability helps farmers and policymakers make informed decisions regarding land use planning, crop selection, and resource allocation.

It is commonly known that one of the significant markers of economic growth is the prudent and sustained use of nonreproducible natural resources, such as land. The World Commission on Environment and Development defined sustainable development as meeting present needs without jeopardizing future generations' ability to meet their own needs, and they linked land suitability with sustainable development (FAO, 2007). Furthermore, especially in metropolises, the fast migration and population growth necessitate the creation of new areas to meet basic needs. As a result, natural resources like wetlands, forests, pastures, and agricultural lands are used inappropriately for their potential and are converted into industrial areas or settlements (Rawat and Kumar, 2015; Khawalda, 2016). Because of this, it is crucial to create land use plans that allow for the sustained use of natural resources in a way that maximises their potential while also allowing for their transfer to future generations. An evaluation of the land's suitability is a requirement for land use planning. By offering details on the opportunities and limitations associated with using a specific land area, the assessment facilitates the best use of land (Abdel-kawy et al., 2010). It also entails allocating resources according to their estimated potential (Omran, 2012). Land suitability analyses that take into account land properties and user needs are the first step in determining the most appropriate land use type for this assessment (Mazahreh et al., 2018; Elsheik et al., 2010). As previously mentioned, a variety of factors is taken into account in order to determine whether a particular plot of land is suitable for agricultural production. Different techniques are employed to ascertain the weights of these criteria and the scores of the sub-criteria because not all criteria impacting land suitability have equal levels of significance (Joerin et al., 2001).

GIS-based analytical hierarchy process (AHP) modeling for agricultural land suitability involves using GIS technology and AHP methodology to assess and figure different factors influencing agricultural land suitability. AHP will help this research in breaking down a complex problem, such as land suitability, into a hierarchy of criteria and sub-criteria. In the context of agriculture, these criteria include soil type, climate, slope, water availability, and land use constraints. GIS is then used to spatially represent and analyze these criteria, creating maps that highlight areas with different degrees of suitability for agriculture.

The agricultural situation in Awka South Local Government Area faces significant challenges that require a well-thought-out solution. One major issue is the lack of a clear method for deciding which areas are best for farming. This leads to poor decisions about how to use the land and allocate resources. The current methods don't fully consider all the factors that affect how well crops can grow, making it hard for both farmers and policymakers to make smart choices. A big part of the problem is that there isn't a good way to look at all the different factors that affect how good the land is for farming. The usual methods don't consider things like the type of soil, the weather, and the environment, which are all important for successful farming. This lack of understanding makes it tough to create sustainable and strong farming systems. It also makes the region vulnerable to challenges like changes in the climate and the environment.

Another problem making things worse is that more and more land that's perfect for farming is being used for development and other non-farming purposes. The fast rate of development is taking away land that could be used for growing crops. This means there's less land available for farming, making it harder to grow enough food.

To address these issues, this study aims to employ an analytical method for deciding which areas are best for farming. By using advanced technology and analysis methods, the study wants to provide a tool that helps evaluate how suitable the land is for agriculture. The goal is to fill the gaps in our knowledge; especially about how space and different factors affect farming decisions in Awka South L.G.A. The study hopes to give valuable information to people involved in farming so they can make better decisions and use the land more efficiently, ultimately making agriculture in the area more sustainable and resilient.

2 Materials and methods

2.1 Area of study

Awka South is a local government area in Anambra State, Nigeria. It is located in the southeastern part of the country. The local government area is situated in the capital city of Anambra State, which is Awka. Awka South is bordered by other local government areas such as Awka North, Njikoka, and Dunukofia. Geographically, Awka South is positioned at approximately 6.2100° N latitude and 7.0700° E longitude. It covers a land area of about 73 square kilometers. The area is predominantly urban, with a growing population and various infrastructural developments, Figure 1 shows the map of the study area.

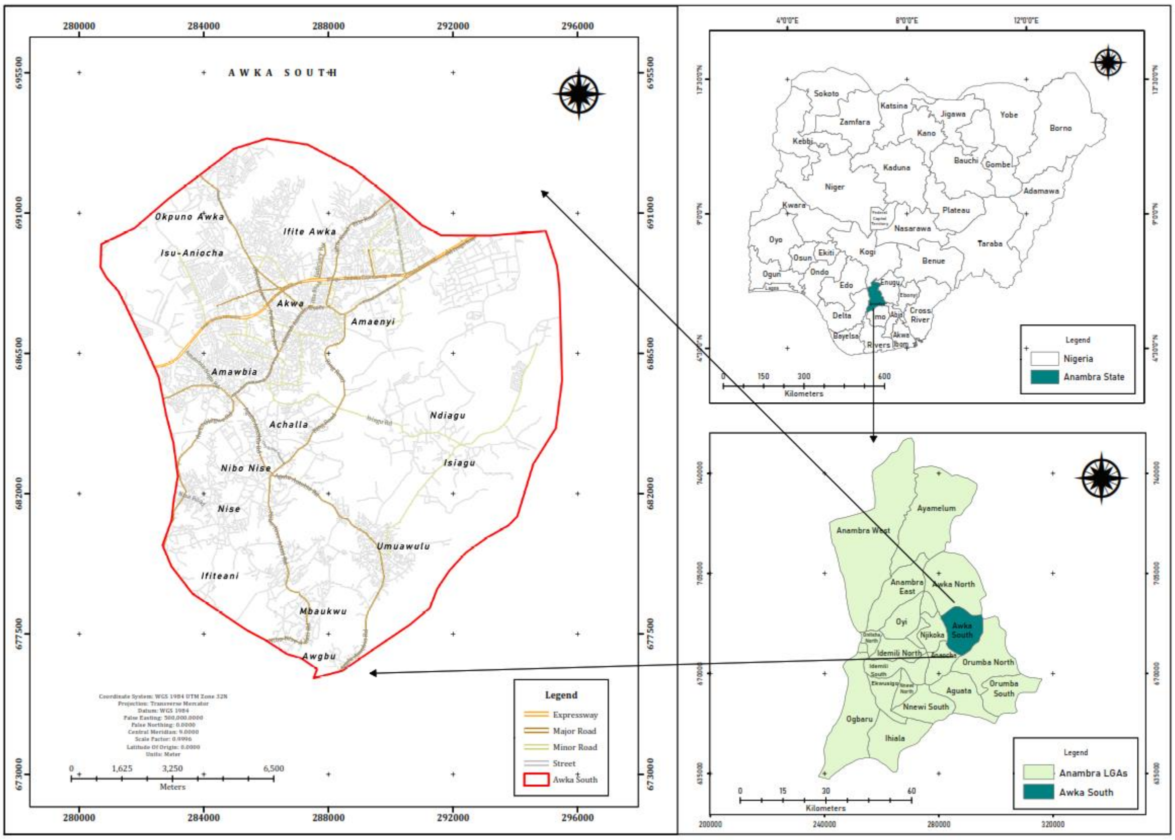


Figure 1 Map of the study area

2.2 Data collection and analysis

This study utilized both primary and secondary data sources to assess agricultural land suitability. The primary data included Global Positioning System (GPS) coordinates of farms and non-spatial attributes describing the on-ground characteristics of the study area, which were collected in 2023. The secondary data were obtained from multiple sources. Sentinel-2 imagery from 2023, with a 10-meter resolution, was sourced from the European Space Agency (ESA) Copernicus Open Access Hub and used for land cover and land use classification. This imagery, captured by the Multispectral Instrument (MSI) sensor at Level-2A, provided multispectral data with atmospheric correction. The Phased Array L-band Synthetic Aperture Radar Sensor (ALOS PALSAR) data from 2022, with a 12.5-meter resolution and L-band SAR technology, were obtained from the Japan Aerospace

Exploration Agency (JAXA) and supplied detailed information on slope, elevation, and drainage characteristics, ensuring high-precision topographic analysis. Meteorological data on temperature and precipitation, covering the period from 2000 to 2023, were acquired from the National Climatic Data Center (NOAA) to analyze long-term climatic trends. Additionally, administrative boundary maps, road network data, and waterbody information were sourced from the Department of Surveying and Geoinformatics at Nnamdi Azikiwe University.

2.3 Image sub-mapping

The process of image sub-mapping was conducted to extract the study area from the larger datasets. Using the administrative boundary shapefile of Awka South and Anambra State, the relevant portions of the Sentinel-2 and ALOS PALSAR images were clipped. This ensured that all subsequent analyses were confined to the area of interest, facilitating more precise and focused examination.

2.4 Image classification and ALOS PALSAR processing

Image classification was performed using a supervised classification method, which involved training the classification algorithm on known landcover types identified during field visits. The Sentinel-2 data were classified to distinguish various landuse/landcover types. Meanwhile, ALOS PALSAR data were processed to extract elevation, slope, and drainage networks, crucial for the suitability analysis. Sink filling was carried out on the DEM data to correct any depressions, ensuring accurate topographical representation.

2.5 Pairwise comparism matrix

To determine the relative importance of the various factors influencing agricultural suitability, a pairwise comparison matrix was developed using the AHP. Each factor—soil, temperature, precipitation, landuse/landcover, slope, drainage, and elevation—was compared against the others to assign weights. The pairwise comparison facilitated the creation of a normalized matrix, from which the relative weights were computed, reflecting the importance of each factor in the overall suitability assessment.

2.6 Consistency ratio

The consistency ratio (CR) was determined to ensure the reliability of the judgments made during the pairwise comparisons. A CR value below 0.1 indicated a reasonable level of consistency in the comparisons, confirming the validity of the computed weights. If the CR exceeded this threshold, the pairwise comparison process was revisited to correct any inconsistencies and ensure that the final weights accurately represented the importance of the criteria.

2.7 Dataset overlay

The final step involved overlaying the weighted datasets to produce a suitability map. Each criterion, weighted according to the results of the pairwise comparison matrix, was combined using the weighted linear combination (WLC) method. This analysis resulted in a suitability index, categorizing the study area into zones of high, moderate, and low suitability for agriculture. The overlay was executed in the ArcGIS environment, providing a visual and analytical framework for assessing land suitability in the region.

3 Results and discussion

Agricultural land suitability in Awka South L.G.A. was assessed through a comprehensive analysis of several factors. Land Cover/Land Use (LULC), derived from Sentinel-2 satellite imagery at a 10-meter resolution, helped identify areas currently used for agriculture and those that could be converted, considering the environmental impact and transformation costs. Temperature, sourced from NCDC data at a 100-meter resolution, was vital for selecting areas that was suited to warm climates, ensuring optimal growth conditions. Precipitation, also from NCDC at a 100-meter resolution, was crucial for determining water availability, with adequate rainfall necessary to prevent water stress or waterlogging, thereby supporting sustainable agriculture. Slope, extracted from ALOS Palsar DEM at a 12.5-meter resolution, influences water drainage, erosion potential, and sunlight exposure, with gentle slopes preferred for farming to minimize soil erosion and maximize crop growth. Elevation, impacting temperature, atmospheric pressure, and oxygen levels, was assessed using ALOS Palsar DEM at a 12.5-meter resolution to identify low-lying areas conducive to agriculture, ensuring crops are planted in suitable climatic conditions. Drainage, essential for preventing waterlogging and ensuring root oxygen availability, was evaluated using proximity to natural drainage networks from ALOS Palsar DEM, providing an advantage for irrigation. Soil type, analyzed from FAO data at a 100-meter resolution, was critical for determining the suitability of land for specific crops, Figure 2 shows the collective factors that were used in map form. These criteria were selected based on empirical data, and validation from current literature, ensuring that evaluation decisions are grounded in reliable and scientifically supported methodologies, Table 1 shows further details.

Table 1 Criteria and requirements for agricultural land suitability

Criteria	Data source	Requirement for suitability	Original data structure	Resolution / feature type
Land use land cover (LULC)	Sentinel-2 (European Space Agency Copernicus Open Access Hub)	Should be in agricultural zones. Accurate LULC mapping is essential for identifying suitable agricultural areas, as it reflects current land utilization and potential for crop production (Giannarakis et al., 2022).	Raster	10 m
Temperature	National Climatic Data Center (NCDC) (ncdc.noaa.gov)	Should be in warm climates. Optimal temperature ranges are crucial for crop growth and yield; deviations can adversely affect agricultural productivity (Shevchenko et al., 2023).	Raster	100 m
Precipitation	National Climatic Data Center (NCDC) (ncdc.noaa.gov)	Best suited in areas with adequate precipitation. Sufficient rainfall is vital for crop development, influencing soil moisture and irrigation needs (Haris et al., 2024).	Raster	100 m
Slope	ALOS PALSAR DEM (Japan Aerospace Exploration Agency)	Should be on gentle slopes. Gentle slopes facilitate mechanized farming and reduce soil erosion, enhancing land suitability for agriculture (Sugumaran and Degroote, 2011).	Raster	12.5 m
Elevation	ALOS PALSAR DEM (Japan Aerospace Exploration Agency)	Should be at suitable elevations. Elevation affects microclimates and, consequently, crop suitability and potential yields (Sugumaran and Degroote, 2011)	Raster	12.5 m
Drainage	ALOS PALSAR DEM (Japan Aerospace Exploration Agency)	Should be near drainage networks for irrigation advantages. Proximity to drainage systems ensures efficient water management, crucial for crop health (Boonsuk and Harding, 2014).	Raster	12.5 m
Soil	Food and Agriculture Organization (FAO) (fao.org)	Should have fertile soil types. Soil fertility directly influences crop growth, yield, and overall land productivity (Hengl, 2017).	Raster	100 m

The development of the ranking system in Table 2 was guided by the implementation of the AHP and the WLC model. The process began with the reclassification and standardization of criteria, which involved assigning numerical values to each dataset to facilitate meaningful analysis. Given that the datasets contained variables measured in different units, direct integration was not feasible. For example, slope values in degrees could not be directly merged with distance values in meters. To address this challenge, all datasets were transformed onto a common measurement scale, enabling relative weighting and comparison of criteria.

The standardization process involved reclassifying the datasets into three suitability classes: high suitability (1), moderate suitability (2), and low suitability (3). This transformation converted continuous values, such as temperature, precipitation, and slope, into discrete integer values to align with the required measurement scale for weighted overlay analysis. The classification thresholds for each factor were established based on natural breaks in the data distribution and supported by relevant literature on agricultural land suitability.

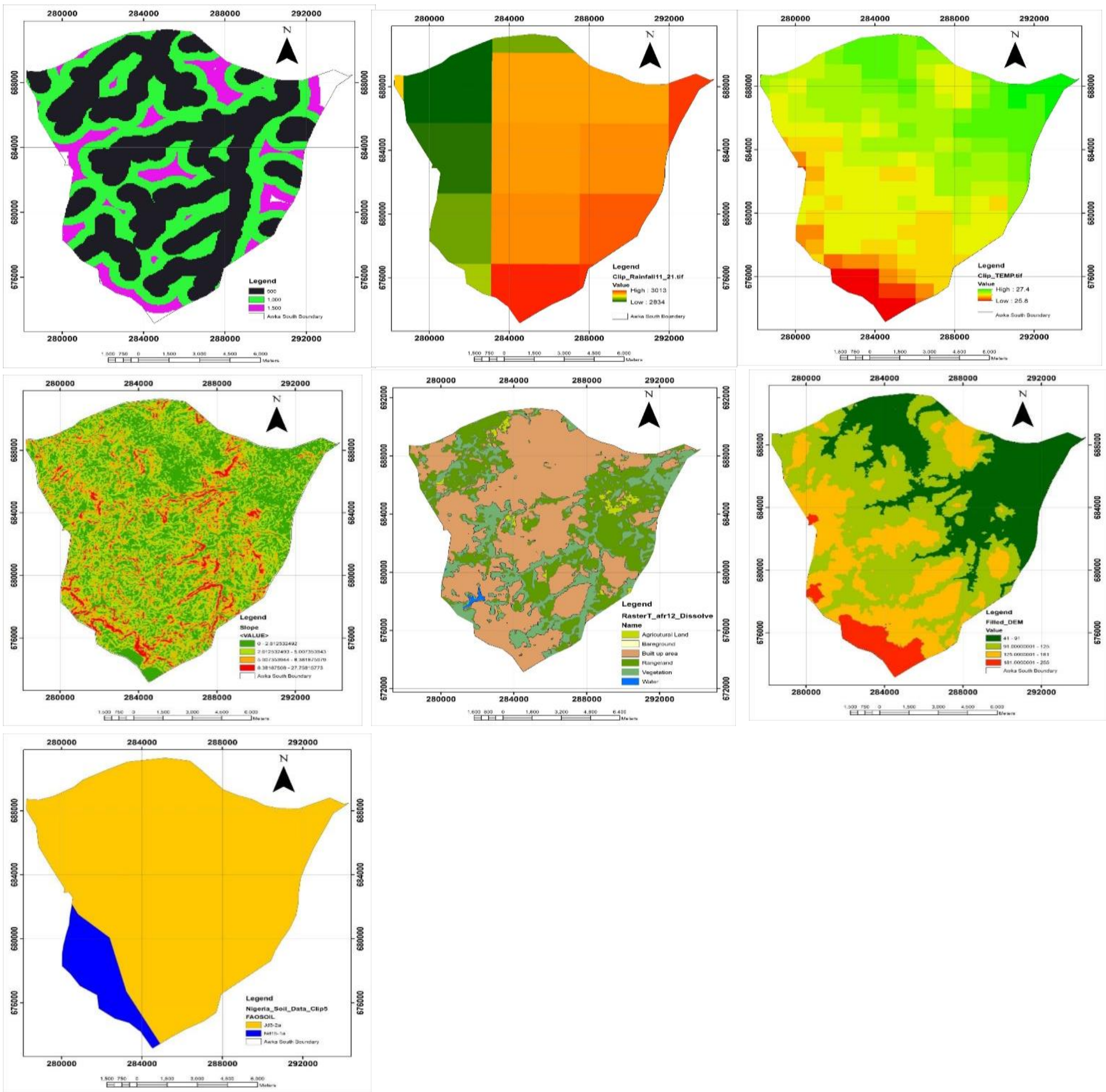


Figure 2 Factors used for agricultural suitability

For land use land cover (LULC), agricultural land was ranked as the most suitable (1), while mixed forest and built-up/open space were assigned lower suitability rankings (2 and 3, respectively) due to constraints on agricultural activities. Temperature was categorized based on optimal growing conditions, with lower temperatures (25.79°C–26.49°C) ranked least suitable (3) and higher temperatures (26.99°C–27.39°C) ranked most suitable (1) for agricultural productivity. Precipitation followed a similar approach, where areas with lower rainfall (2834–2874.71 mm) were considered least suitable (3), while regions receiving higher rainfall (2973.69–3013 mm) were ranked most suitable (1).

For topographical factors, slope values were classified with gentle slopes (0–3.26°) receiving the highest suitability ranking (1) due to ease of mechanization and reduced erosion risk, whereas steeper slopes (6.74–27.75°) were considered least suitable (3). Similarly, elevation was ranked based on agricultural feasibility, where lower elevations (41–103 m) were deemed most suitable (1) and higher elevations (168–255 m) least suitable (3) due to harsher climatic conditions. Drainage suitability was determined by proximity to water sources, with areas closer than 500 m to drainage networks ranked highest (1), while those farther than 1.5 km were ranked lowest (3) due to reduced irrigation potential. Soil types were ranked based on fertility, with Dystric Fluvisols, known for higher agricultural productivity, assigned the highest suitability score (1), while Dystric Nitosols were given moderate suitability (2), and areas with undefined soil characteristics received the lowest ranking (3).

The final ranking structure was established through expert judgment, field observations, and literature review, ensuring that each factor was appropriately weighted to reflect its influence on agricultural suitability. The reclassified and standardized criteria, as illustrated in Table 2 and Figure 3 provided a structured foundation for the weighted overlay analysis used in the land suitability assessment.

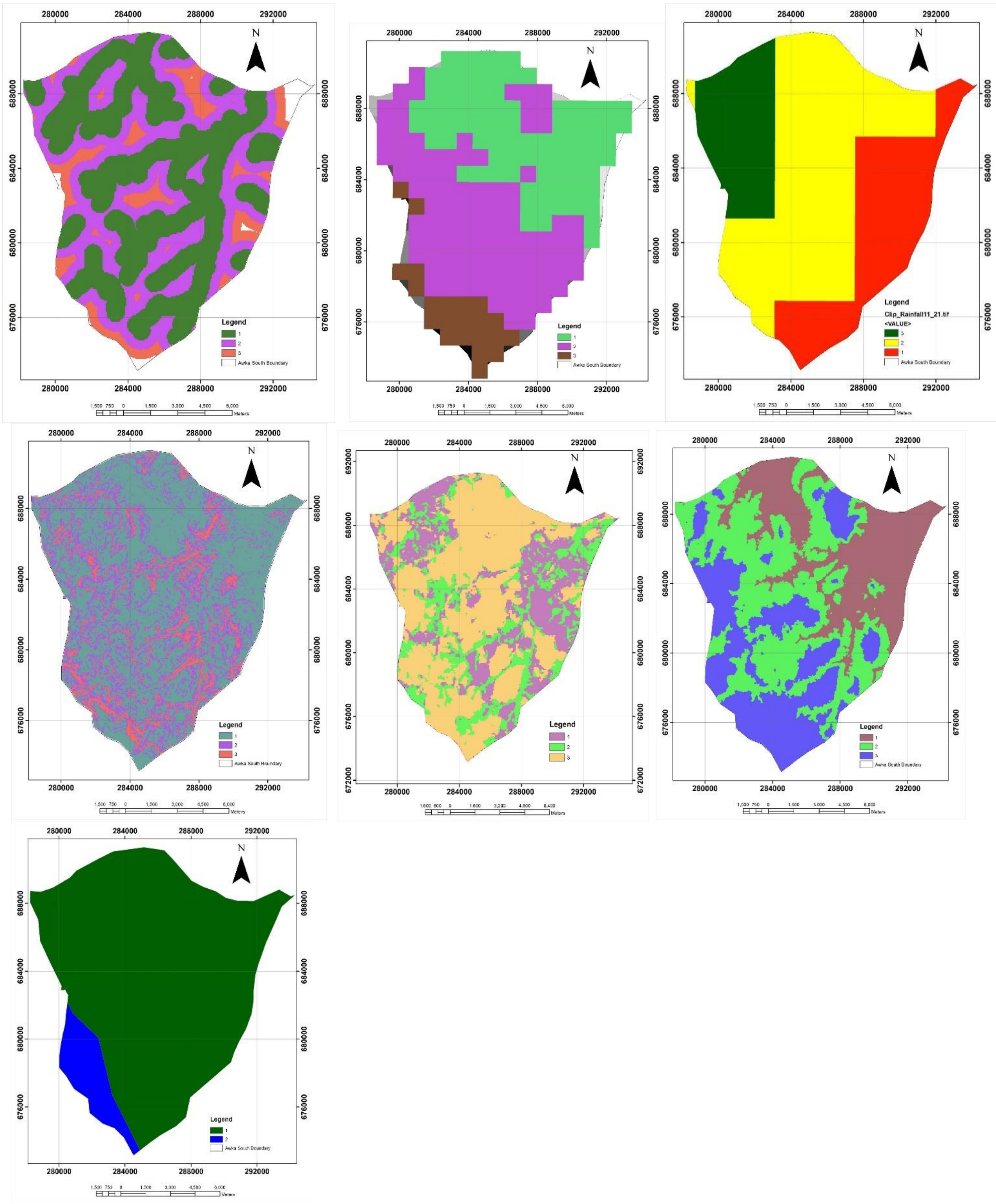


Figure 3 Standardized factors

Table 2 Criteria and requirements for agricultural land suitability

Factor	Value	Ranking
	Built up, open space	3
LULC	Mixed forest	2
	Agricultural land	1
	25.79 – 26.49	3
Temperature	26.49 – 26.99	2
	26.99 – 27.39	1
	2834 – 2874.71	3
Precipitation	2874.71 – 2973.69	2
	2973.69 - 3013	1
	6.74 – 27.75	3
Slope	3.26 – 6.74	2
	0 - 3.26	1
	168 m – 255 m	3
Elevation	103 m – 168 m	2
	41m – 103 m	1
	< 1.5 km	3
Drainage	< 1 km	2
	< 500 m	1
	-	3
Soil	Dystric nitosols	2
	Dystric fluvisols	1

The AHP uses the Eigenvector method to create a ratio matrix for comparing criteria. Table 3 presents the Relative Importance Scale for Pairwise Comparison, which was established based on the recommendations of Saaty (2008) in the AHP. This scale provides a numerical representation of qualitative judgments when comparing two criteria. The assigned values range from 1 to 9, where 1 represents equal importance, 3 indicates moderate importance, 5 denotes strong importance, 7 signifies very strong importance, and 9 represents extreme importance. Intermediate values allow for finer distinctions between levels of importance. These constants serve as the foundation for structuring comparisons between criteria in multi-criteria decision analysis, ensuring consistency in the weighting process.

The development of the pairwise comparison matrix, as presented in Table 4, involved assigning values based on expert judgment and the Saaty (2008) scale. Each criterion, including LULC, temperature, precipitation, slope, elevation, drainage, and soil, was systematically compared against the others to establish their relative importance in determining agricultural land suitability. Higher values were assigned to criteria with a more significant impact on agricultural productivity. For instance, LULC received a higher ranking over elevation and drainage, given its direct influence on the availability of arable land. Similarly, precipitation and temperature were given strong importance over slope, as climatic factors are crucial for crop growth and yield. The lower triangular portion of the matrix contains reciprocal values of the upper triangular entries, ensuring consistency in the comparison process. The column totals at the bottom of Table 4 were used to normalize the values for further analysis.

The Prioritization Weight Matrix, displayed in Table 5, was derived from the normalized values of the pairwise comparison matrix in Table 4. To compute the normalized values, each entry in the pairwise comparison matrix was divided by the respective column total. The mean of the normalized values for each criterion was then calculated, yielding the relative weight percentage (W%), which indicates each criterion's contribution to agricultural land suitability.

The results from the prioritization process revealed that LULC had the highest weight at 32.20%, emphasizing its dominant role in determining agricultural suitability. Temperature and precipitation followed closely, with weights of 27.27% and 20.18%, respectively, underscoring the significant influence of climatic conditions on agricultural viability. Slope, elevation, drainage, and soil had lower weights, indicating that while they contribute to land suitability, their impact is less pronounced than LULC and climatic factors.

The final weighted scores derived from Table 5 were subsequently incorporated into the WLC model, which was used to generate the agricultural land suitability map. By ensuring that criteria with the most substantial influence were assigned higher weights, this method provided a systematic and data-driven approach to assessing agricultural suitability.

Table 3 Relative importance in pairwise comparison (Saaty, 2008)

Judgment value	Description
1	Equal importance
3	Moderate importance
5	Strong Importance
7	Very strong importance
9	Extreme importance

Table 4 Pair-wise comparison matrix for agricultural land suitability

Criterion	LULC	Temperature	Precipitation	Slope	Elevation	Drainage	Soil
LULC	1	2	3	4	5	5	9
Temperature	0.5	1	3	5	6	6	7
Precipitation	0.33	0.33	1	5	6	6	7
Slope	0.25	0.2	0.16	1	2	3	4
Elevation	0.2	0.16	0.16	0.5	1	2	3
Drainage	0.2	0.16	0.16	0.33	0.5	1	4
Soil	0.11	0.14	0.14	0.25	0.33	0.25	1
Total	2.59	3.99	7.62	16.08	20.83	23.25	35

Table 5 Prioritization weight matrix for agricultural land suitability

Criterion	LULC	Temperature	Precipitation	Slope	Elevation	Drainage	Soil	Mean	W%	row total of normalized matrix
LULC	0.39	0.50	0.39	0.25	0.25	0.22	0.26	0.32	32.20	2.25
Temperature	0.19	0.25	0.39	0.31	0.30	0.26	0.20	0.27	27.27	1.91
Precipitation	0.13	0.08	0.13	0.31	0.30	0.26	0.20	0.20	20.18	1.41
Slope	0.10	0.05	0.02	0.06	0.10	0.13	0.11	0.08	8.20	0.57
Elevation	0.08	0.04	0.02	0.03	0.05	0.09	0.09	0.06	5.59	0.39
Drainage	0.08	0.04	0.02	0.02	0.03	0.04	0.11	0.05	4.88	0.34
Soil	0.04	0.04	0.02	0.02	0.02	0.01	0.03	0.02	2.39	0.17
Total	1	1	1	1	1	1	1	1	100	7

In this study, the calculated CR for agricultural land suitability was 0.09. This value is below the threshold of 0.10, which signifies that the pairwise comparisons are reasonably consistent and the judgments are acceptable.

The agricultural land suitability analysis for Awka South L.G.A. identified three distinct suitability zones: High suitability, Moderate suitability, and Low suitability, as depicted in Figures 4 and 5. The high suitability zone covers 33.324 km² (20.23% of the total area) and is primarily influenced by LULC at 32.20%, temperature at 27.27%, and precipitation at 20.18%. This suggests that areas classified as highly suitable benefit mainly from favourable land cover types, optimal temperature conditions, and adequate rainfall.

The Moderate suitability zone spans 89.294 km^2 (54.23% of the total area) and reflects a balance of these factors, though certain limitations such as less favourable temperature variations or suboptimal precipitation may lower suitability.

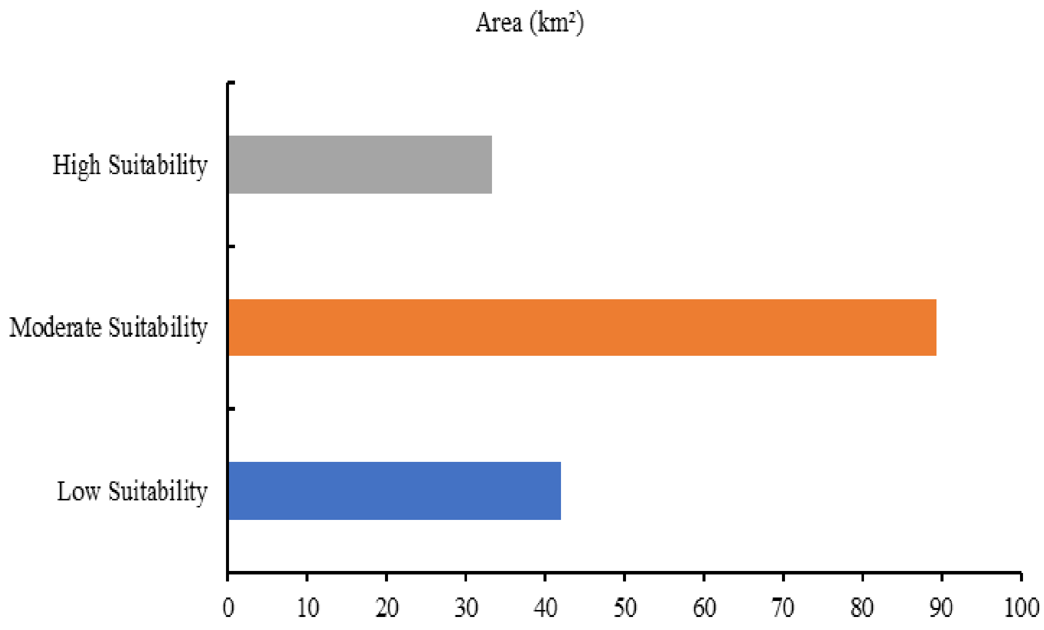
The Low suitability zone, covering 42.032 km^2 (25.52% of the total area), is largely influenced by constraints related to slope (8.20%), elevation (5.59%), drainage (4.88%), and soil quality (2.39%). These areas likely exhibit steeper slopes, poorer drainage, or less fertile soils, making them less viable for agriculture.

This analysis highlights the dominant role of LULC, temperature, and precipitation in determining suitability while also acknowledging the secondary impact of topographic and soil-related factors in marginal areas.

The delineation of these suitability zones is crucial for agricultural sustainability. The High suitability zone, which comprises 20.23% of the area, indicates land that is particularly well-suited for cultivation, offering an opportunity to enhance agricultural productivity through sustainable practices. The Moderate suitability zone, covering 54.23% of the area, represents land that, while less inherently fertile than the High suitability zone, still holds potential for productive use with appropriate agricultural interventions.

In contrast, the Low suitability zone, making up 25.52% of the area, highlights regions where agricultural productivity may be limited by inherent challenges. This requires careful consideration of alternative land uses or the implementation of targeted soil improvement strategies to promote sustainability.

The zoning analysis provides a strategic framework for agricultural development, enabling stakeholders—such as farmers and land planners—to make informed decisions regarding land use, resource allocation, and sustainable practices. By aligning agricultural activities with the land's natural suitability, this study lays the groundwork for a more resilient and environmentally friendly agricultural system, contributing to long-term sustainability in the region, see Figures 4 and 5 for more details.



	Low Suitability	Moderate Suitability	High Suitability
Area	42.032	89.294	33.324

Figure 4 Agricultural land suitability distribution

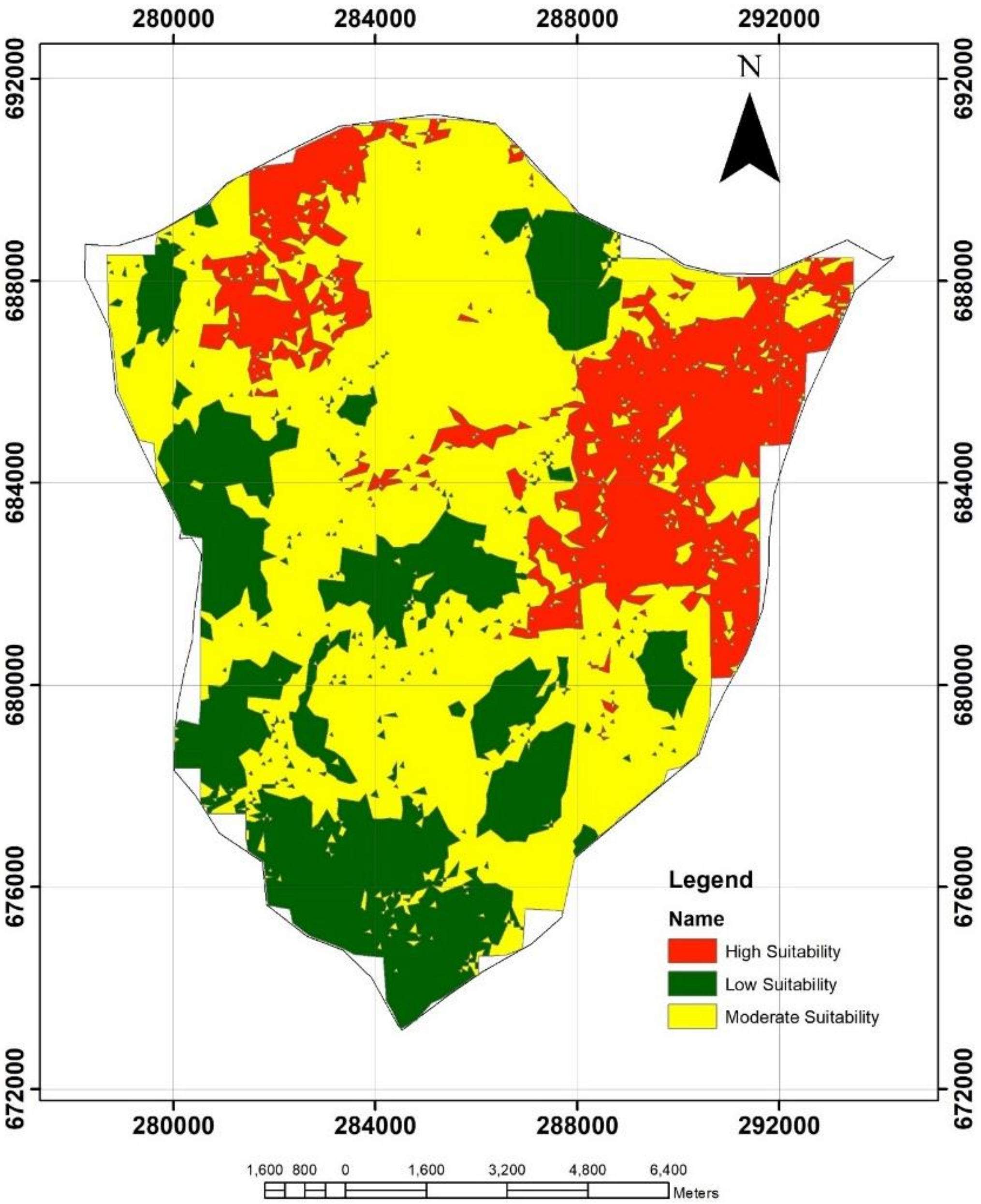


Figure 5 Agricultural land suitability map

4 Conclusion

The in-depth study conducted in Awka South Local Government Area has significantly contributed to the understanding of agricultural land suitability and sustainability in the study area. The research spanning from criteria selection to the assessment of suitability zones, have provided a comprehensive framework for informed decision-making in agriculture.

The selection of criteria laid the groundwork, recognizing the factors influencing agricultural land suitability. These criteria, including land cover, temperature, precipitation, slope, elevation, drainage, and soil properties, formed the basis for subsequent analyses.

The successful application of reclassification and standardization of criteria set the stage for a comprehensive evaluation, allowing for an understanding of the land's inherent capabilities.

The study introduced AHP to calculate weights and ensure consistency in decision-making. The achieved CR of 0.09 demonstrated the reliability of the judgments made during the pairwise comparisons, enhancing the credibility of the subsequent analyses.

The application of the WLC model provided a detailed assessment of agricultural land suitability. The delineation of three distinct suitability zones—

High, Moderate, and Low—offered valuable insights for stakeholders. These findings have practical implications for sustainable agriculture, guiding decisions related to land use, resource allocation, and the adoption of eco-friendly practices.

This study not only enhances our understanding of the agricultural landscape in Awka South L.G.A but also provides actionable insights for stakeholders involved in land management, agriculture development, and environmental conservation. The strategic and tailored approach outlined in this research contributes to the long-term sustainability of agriculture in the region, promoting optimal land utilization while minimizing environmental impact. As the agricultural sector continues to evolve, these findings serve as a valuable resource for informed decision-making and resilient agricultural practices.

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