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Analysis of suitable criteria for siting grazing reserves in Zuru Emirate, Kebbi State, Nigeria

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ABSTRACT

As urbanization and land use changes are continuous in Zuru Emirate, struggle for common resources has led to violent conflicts between herders and crop farmers. It is therefore, critical to identify suitable grazing areas to ensure peaceful coexistence between farmers and herders in the area. This study used geospatial techniques and Multi-Criteria Decision Analysis tools to analyze criteria for sitting grazing reserves in Zuru Emirate, Kebbi State. Eleven biophysical and environmental criteria were used, including water, road, settlement, soil organic carbon, soil pH and soil depth. The criteria were standardized and weighted using AHP in ArcGIS 10.8. To validate the land suitability map, zonal statistical analysis was used to calculate the mean NDVI value of each land suitability map. Results of AHP weighted analysis of the criteria revealed that land use was the most influential criterion, with a weight of 0.22 (22%), while soil depth and soil pH have the lowest weight of 0.04 (4%), while 0.92% of the study area indicated less suitable, 83.13% is moderately suitable, 16.48% is suitable, and 0.46% of the study area is suitable for sitting grazing reserves. Validation of the land suitability map revealed that the high suitability category has the highest mean NDVI value of 0.05057, while the less suitable class has lowest of 0.04114. Zuru Emirate is moderately suitable for siting grazing reserves. Office of the Surveyor General of the Federation is recommended to collaborate with consenting states to survey and document grazing reserves to prevent future conflicts between farmers and herders.

KEY WORDS: *Analytical hierarchy process*; *Consistency ratio*; *Grazing reserves*; *Multi-Criteria analysis*

1. Introduction

Pastoralism is facing global crisis due to man-made activities, natural constraints, internal and external influences (Martin, *et al.*, 2020). The expansion of human settlements in both developed and developing countries in the 21st century has led to the depletion of land resources. (Nhim *et al.*, 2019). The high demand for pastoral facilities like grazing reserves has led to ongoing conflicts and disputes, resulting in the loss of lives and properties (Mahdi, 2018).

According to Cécile *et al.* (2018), "site suitability considers the appropriateness of livestock grazing for a particular land area, based on the economic, social and environmental considerations that may be affected by livestock grazing". Land suitability

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modelling aids in determining the most suitable spatial pattern for future land use based on specific requirements, preferences, and activity predictors, crucial for locational and siting decisions (Obsa, 2021).

Land suitability classification evaluates specific land areas based on crop requirements and soil/land characteristics, determining their suitability for a defined use. Suitability is also a measure of how well the qualities of a land unit match the requirements of a particular form of land use (Aymen *et al.*, 2021).

Nigerians, ranging from 50% to 80%, are involved in crop or livestock farming, which are vital aspects of their daily lives. Agricultural sector is evolving, with farmers transitioning from traditional crop production to crop-livestock farming (Akinola *et al.*, 2015). Conflicts are common in West Africa and Nigeria, especially due to nomad activities and farmer-herder conflicts, a trend that is not new in the region (Egbuta, 2018).

Conflicts between herders and farmers in Zuru Emirate have escalated due to a struggle for common resources (Sanchi *et al.*, 2021). The encroachment of grazing reserves due to increased population has reduced grazing space for livestock, causing crisis between the two groups (Ibrahim *et al.*, 2017). Traditional transhumance practices, which require free movement for pasture access have led to violent conflicts between herders and crop farmers (Mahdi, 2018).

Many studies have used Multi-Criteria Decision Analysis (MCDA) techniques such as Analytical Hierarchy Process (AHP) to evaluate land suitability for crop production with encouraging results (Ujoh *et al.*, 2019; Ozsahin and Ozdes, 2021; Aina, 2022), and for siting grazing reserves (Akomolafe, 2015; Samuel *et al.*, 2020; Zumo *et al.*, 2020). For the application of MCDA in siting grazing reserves, Akomolafe, 2015 conducted mapping and analysis of sites for grazing reserves in Niger and Kaduna states of Northern Nigeria; Zumo *et al.*, 2020 carried out suitability analysis of grazing reserves in suitability site selection analysis for grazing areas in Yobe State of Northern Nigeria; Samuel *et al*., 2020 also carried out suitability mapping of Girei LGA for Grazing Reserve in Adamawa State of Northern Nigeria. Likewise, Amiri, 2009 carried out a geospatial model for the optimization of grazing management in semi-arid rangeland of Iran; Rouhi-Moghaddam *et al.*, 2017 determined range Suitability of Bagheran Birj and watershed, South Khorasan province, Iran. The reviewed studies mostly used MCDA and Fuzzy Logic; however, they did not consider biophysical factors related to soil namely: soil pH, soil organic carbon, and soil depth. The quality of soil directly impacts the carrying capacity and sustainability of grazing reserves, highlighting the importance of considering soil-related factors in land suitability assessments.

Based on the identified gaps in the reviewed studies, this study aims to analyze suitable areas for siting grazing reserves in Zuru Emirate, considering soil-related factors like pH, depth, and organic carbon. The objectives used to achieve the aim are to: identify and map LULC; analyze the suitability of each criterion; model suitable areas; and validate the land suitability map for siting grazing reserves in Zuru Emirate.

Remote sensing technology and GIS can be used to identify suitable grazing areas in Zuru emirate, enhancing understanding of the complex biophysical and socio-economic components of the landscape and reducing issues faced by nomads and farmers. The study explores biophysical and socioeconomic factors such as land use, slope, temperature, precipitation, elevation, distance from water, road, settlement, soil organic carbon, pH, and depth, using a descriptive and exploratory approach.

2. Material and Methods

2.1 Study area

The area of study is Zuru Emirate. It is located in the Southern part of Kebbi State Nigeria. It lies between Latitudes 10°01'14" and 11°01'14" North of the Equator and Longitudes 04°01'14" and 06°00'00" East of the Central Meridian. It occupies a total land mass of about 9,000 sq.km. The headquarters of Zuru Emirate is in the town of Zuru, which comprises four Local Government Areas namely: Danko/Wasagu, Fakai, Sakaba and Zuru (Zaka, 2018). It is bordered by Bukkuyum LGA, Zamfara State in the North, while in the East it shares boarder with Kuyanbana, Kaduna State (**Fig. 1**), and to the South is Niger State (Alhassan, 2019).

It has an estimated population of about 1,011,309 (National Bureau of Statistics, 2019). The choice of Zuru Emirate for this study is because it is an agrarian community in Nigeria, with a majority engaged in crop cultivation and livestock farming which requires vast expanse of open land for grazing (Gaddafi *et al.*, 2021).

The techniques used for the study, which cut across data collection (**Fig. 2**), reclassification (standardisation), calculation of weight, weighted overlay, production of suitability map and validation of suitability map.

2.2 Datasets and sources

This research utilized data from remote sensing and other secondary sources, which are succinctly sources as documented in **Table 1**.

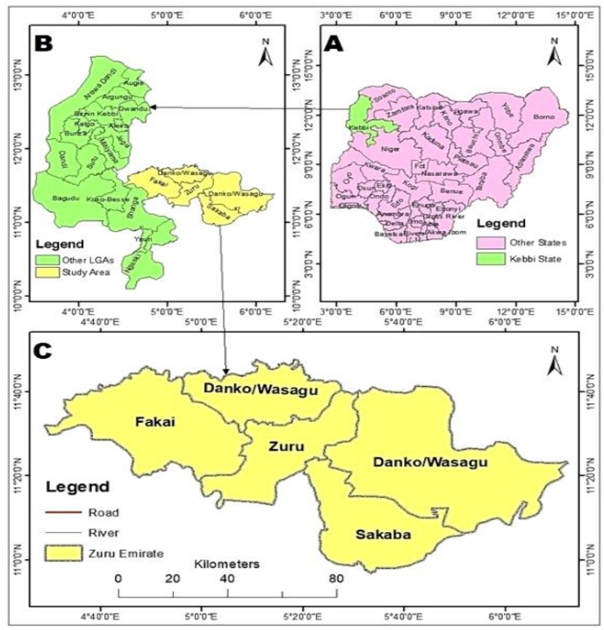

Fig. 1: Inset map of the study area (A, B & C).

A. Indicates the map of Nigeria and its States,
B. The administrative boundary of Zuru Emirate within the border of Kebbi State,
C. Administrative boundary of Zuru Chiefdoms.

2.3 Data processing

2021 Landsat 8 image of the study area was classified into five land use land cover types using supervised maximum likelihood classification algorithm in ArcGIS 10.8. Soil and climate data were extracted using the clipping tool and data with 90m or 250 m resolution was projected to UTM Zone 31N and resampled to 30m spatial resolution for overlay using the project raster and resample tools in the ArcGIS data management extension.

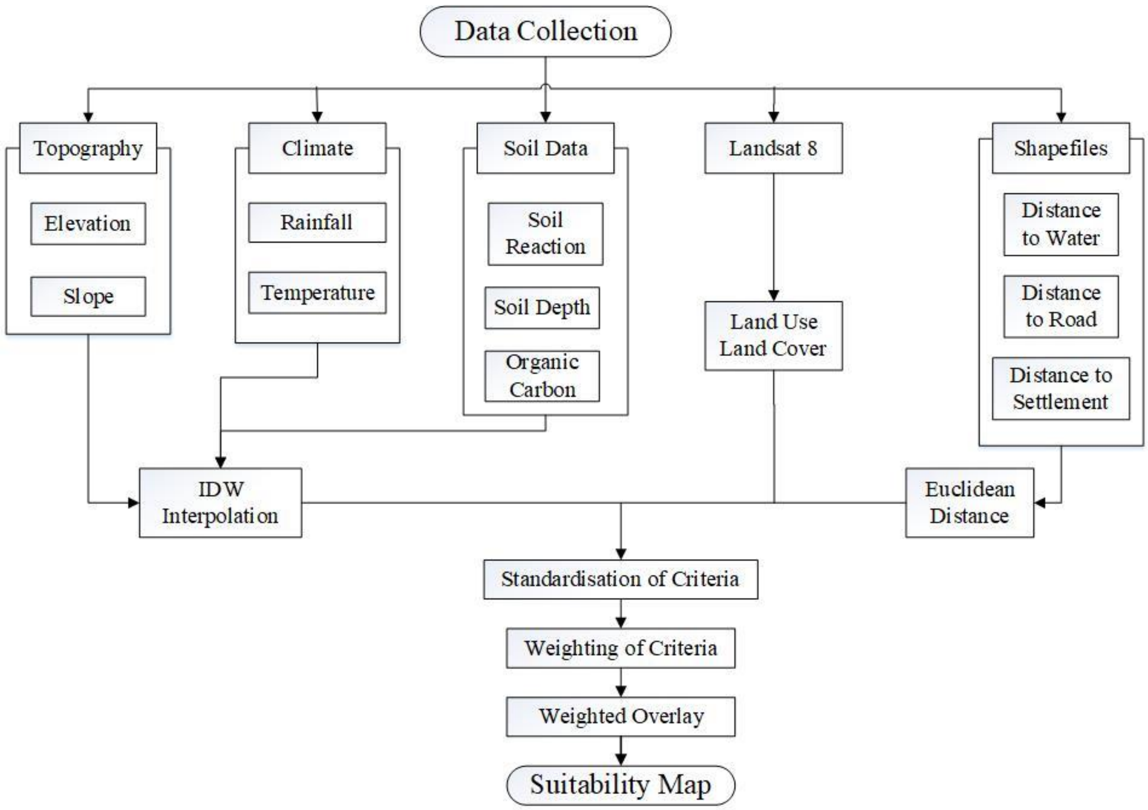

Fig. 2: Workflow diagram of the study

2.4 Generation of criterion maps

This stage focused on utilizing GIS to collaborate with spatial data input to evaluate parameters for grazing reserves. Each parameter was represented as a map layer in GIS, generating criterion maps for a visual representation of land suitability maps for grazing reserves.

Table 1: Datasets and their characteristics

Sl. No.	Data Type	Resolution	Source	Purpose
1	Landsat 8 image of 2021	30m	Downloaded from the United State Geological Survey (USGS); (http://glovis.usgs.gov)	For LULC and NDVI maps
2	Shuttle Radar Topographic Mission, (SRTM) (2000)	90m	Downloaded from the United State Geological Survey (USGS); (http://glovis.usgs.gov)	For creation of slope map
3	Soil data (soil pH, soil depth and soil organic carbon)	250m	Downloaded from www.isric.org	For suitability maps
4	Climate data (Temperature and Rainfall)		https://app.climateengine.org/climateEngine	For suitability maps
5	Road, waterway and settlement shape files		grid3.gov.ng	For proximity maps

2.5 Criteria standardization and rating

The study used a standardized scale for consistency and accuracy, with a range of 0 to 1 or 0 to 100 on a real number scale, depending on the user's choice. On a scale of 1 to 9, using Saatys' scale (Saaty, 1980), The reclassify spatial analyst tool in ArcGIS 10.8 was used to rank attributes based on their impact on land suitability for grazing reserve as shown in **Table 2**. The process ensured consistent evaluation and ranking of criteria using a standardized scale for land suitability analysis, providing a comprehensive map for decision-making in land use planning and management. Overall, the standardisation of criteria on a common scale is crucial for accurate and reliable land suitability analysis (Hoque *et al.*, 2019).

2.6 Determination of criterion weights using AHP

For decision-making, the Analytic Hierarchy Process was utilized. The method assigns value to criteria based on their importance, involving expert opinions, indigenous knowledge, and comparing land use with location-specific characteristics. To create a pairwise comparison matrix, a range of values to indicate the importance of each criterion was used. Larger values indicate greater importance, while 1 indicates equal importance. A value of 9 signifies absolute importance, while 1/9 indicates absolute triviality. The normalization of a pairwise comparison matrix involves dividing each column's number by the sum of the columns, and then calculating the weight for each criterion by calculating the average of each row. This enables decision-maker to prioritize criteria based on their relative importance. The decision-making process is sensitive to local contexts and factors by utilizing expert opinions and indigenous knowledge (Malek and Verburg, 2020).

Saaty (1980) has proposed a measure of consistency in pair-wise comparison, the consistency ratio (CR), which ranges from 0 to 1. A CR of 0 indicates perfect consistency, while a CR of 1 implies complete inconsistency. According to Lamidi and Ijaware (2022), a CR of less than 0.1 is deemed acceptable, whereas values exceeding 0.1 indicate considerable inconsistency and unreliability in the pair-wise comparison.

2.7 Generation of suitability map

Thematic layers like soil, slope, nitrogen, phosphorus, potassium, and soil texture were grouped into five classes based on their impact on land suitability for grazing reserves. Data formats were converted to raster at 30m resolution and reclassified into a common evaluation scale of 1-9. The highest score was highly suitable, while the lowest score was unsuitable. A suitability map was generated using the weighted overlay tool in ArcGIS 10.8.

2.8 Validation of land suitability map for grazing reserve

Normalized Difference Vegetation Index (NDVI) was computed in ArcGIS 10.8 using the raster calculator. The following formula was used to calculate the (NDVI) map of the study area:

$$\text{NDVI} = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)} \quad \text{----------------------(1)}$$

The zonal statistics tool in ArcGIS 10.8 was used to calculate the mean (NDVI) value of land suitability classes, with areas with higher NDVI values being more suitable for grazing reserves.

Table 2: Criteria for grazing reserve suitability analysis

Criteria	Category	Rank	Level of Suitability	Source
Distance to water (m)	0-500	9	Highly Suitable	Adapted from Holechek *et al.* (1998)
	500-1000	7	Suitable	
	1000-3000	5	Moderately Suitable	
	3000-5000	3	Less Suitable	
	>5000	1	Not Suitable	
Slope (%)	0-8	9	Highly Suitable	Guenther *et al.* (2000)
	8-16	7	Suitable	
	16-30	5	Moderately Suitable	
	30-50	3	Less Suitable	
	>50	1	Not Suitable	
Distance to Road (Km)	>10	9	Highly Suitable	Adapted from Vázquez-Quintero *et al.* (2020)
	5-10	7	Suitable	
	2-5	5	Moderately Suitable	
	0.5-2	3	Less Suitable	
	<0.5	1	Not Suitable	
Land use and Land Cover	Bareland	7	Highly Suitable	Lemmessa (2011)
	Forest	9	Moderately Suitable	
	Farmland	5	Not Suitable	
	Built up	1	Not Suitable	
	Water	1	Not Suitable	
pH	6.5-7	9	Highly Suitable	Sys *et al.* (1991)
	6-6.5	7	Suitable	
	5.5-6	5	Moderately Suitable	
Rainfall (mm)	400-900	9	Highly Suitable	Adapted from Kau *et al.* (2023)
	900-1200	7	Suitable	
Distance to Settlement (Km)	>10	9	Highly Suitable	Vázquez-Quintero *et al.*, (2020)
	10-5	7	Suitable	
	3-5	5	Moderately Suitable	
	1-3	3	Less Suitable	
	<1	1	Not Suitable	
Temperature (ºC)	25-27	7	Suitable	Sys *et al.* (1991)
	27-30	5	Moderately Suitable	
Elevation (m)	<400	9	Highly Suitable	Ostovari *et al.* (2019)
	400-500	7	Suitable	
	500-600	5	Moderately Suitable	
	>600	3	Less Suitable	
Soil Depth (cm)	>50	9	Highly Suitable	Adapted from Mazahreh *et al.* (2019)
Organic carbon	>2	9	Highly Suitable	Sys *et al.* (1991)
	2-1.2	7	Suitable	
	1.2-0.8	5	Moderately Suitable	
	<0.8	3	Less Suitable	

3. Results and Discussion

3.1 Land use and land cover

The land use/land cover analysis revealed that bareland is the dominant land cover type in the study area (**Table 3** and **Fig. 3**), occupying 8,054.74 km² (91.09%) of the total area. Farmland represents the second-largest land use category, covering 497.00 km² (5.62%), indicating limited agricultural land availability. Vegetation covers 231.45 km² (2.62%), suggesting relatively sparse vegetative cover across the landscape.

The built-up area accounts for only 51.61 km² (0.58%), reflecting a low level of urban development, while water bodies occupy a negligible proportion of the study area (8.23 km²; 0.09%). Overall, the predominance of bareland indicates that the study area is characterized by extensive open land with limited vegetation, agricultural activities, and surface water resources, which may influence land suitability, ecological stability, and resource management strategies.

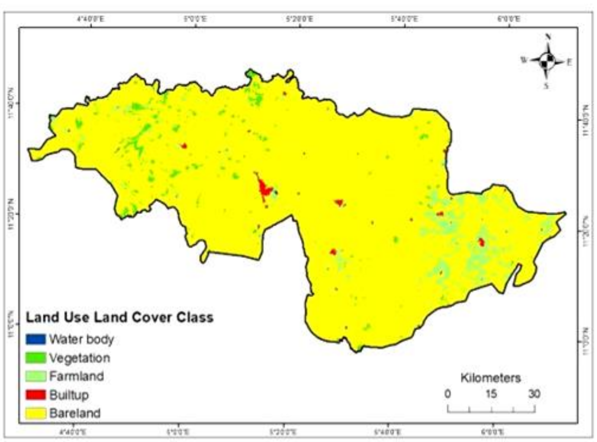

Fig. 3: Land use and land cover of Zuru Emirate in 2021

Table 3: Land Use/Land Cover (LULC) statistics of the study areas

LULC Class	Area (sq. km)	Percentage (%)
Vegetation	231.45	2.62
Bareland	8054.74	91.09
Farmland	497.00	5.62
Built-up	51.61	0.58
Water body	8.23	0.09
Total	8843.04	100.00

3.2 Suitability analysis of criteria

Suitability analysis of criteria for establishing grazing reserves of the study area are generated as shown in **Table 4a – 4k** and **Fig. 4a – 4k** respectively. From **Table 4a** and **Fig. 4a**, the study found that vegetation is moderately suitable for siting grazing reserve, covering 23.25 sq.km (2.62%) of the total area. The largest is bare land, covering 8054.74 sq.km (91.09%) of the total area, deemed highly suitable. Farmland, covering 5.62%, is moderately suitable. Areas occupied by built-up covers 51.61 sq.km (0.58%), while majority of land is highly suitable for siting grazing reserve, with livestock preferring vegetation types that meet their nutritional requirements, despite water covering 8.23 sq.km (0.09%) and not suitable for sitting grazing reserves (Lemmessa, 2011).

Table 4a: Suitability analysis of criteria for establishing grazing reserves (LULC)
a: LULC

Criterion (a)	Name	Rank	%	Level of Suitability
LULC	Vegetation	9	2.62	Highly Suitable
	Bareland	7	91.09	Suitable
	Farmland	5	5.62	Moderately Suitable
	Built up	1	0.58	Not Suitable
	Water	1	0.09	Not Suitable
	Total		100	

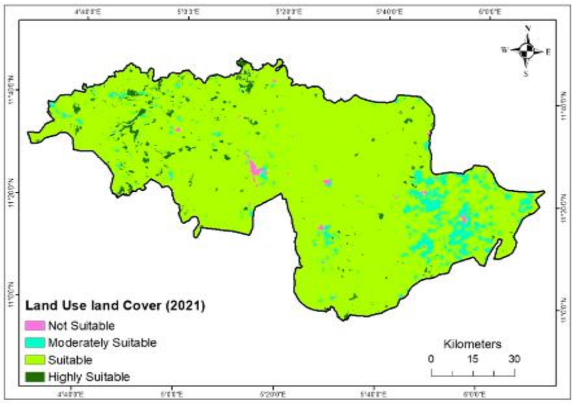

Fig. 4a: Suitability analysis of criteria for establishing grazing reserves - LULC

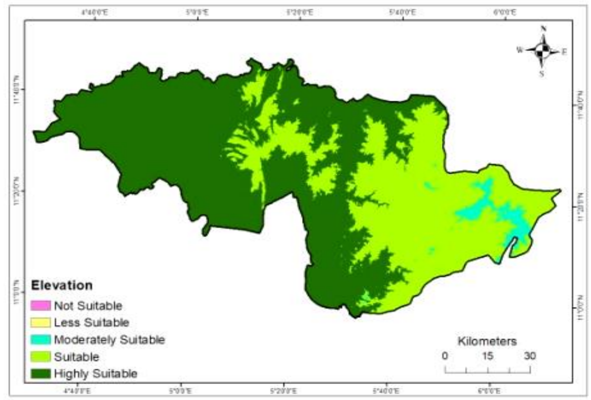

Fig. 4b: Suitability analysis of criteria for establishing grazing reserves - Elevation

Table 4b and **Fig. 4b** presents results of elevation. Majority of the study area has elevation values below 400m accounting for 5424.45 sq.km (61.34%) which are highly suitable for siting grazing reserves. Elevation values ranging from 400m to 500m are suitable for establishing grazing reserves, covering 36.27%. Areas within 500m to 600m range are moderately suitable, covering 2.39%. Areas with elevation values greater than 600m cover the smallest area 0.31 sq.km, thus, less suitable for grazing reserves. Changes in altitude are linked to alterations in climatic and site conditions, which significantly impact plant communities (Kharkwal *et al.*, 2005).

Table 4b: Suitability analysis of criteria for establishing grazing reserves
b: Elevation

Criterion (b)	Category	Rank	%	Level of Suitability
	<400	9	61.34	Highly Suitable
	400-500	7	36.27	Suitable
Elevation	500-600	5	2.39	Moderately Suitable
	>600	3	0.00	Less Suitable
	Total		100	

From **Table 4c** and **Fig. 4c**, the area covering 8560.68 sq.km is highly suitable for establishing grazing reserves due to its slope categories. 0-8% slope covers 96.81%, while 8-16% slope covers 215.97 sq.km. 16-30% slope covers 62.19 sq.km, 0.70%, and the 30-50% covers only 0.05%. Poor livestock distribution on rangelands is largely due to rugged topography, which can cause soil erosion and runoff, affecting forage growth (Amiri *et al.*, 2014).

Table 4c: Suitability analysis of criteria for establishing grazing reserves
c: Slope

Criterion (c)	Category	Rank	%	Level of Suitability
	0-8	9	96.81	Highly Suitable
	8-16	7	2.44	Suitable
Slope	16-30	5	0.70	Moderately Suitability
	30-50	3	0.05	Less Suitable
	Total		100	

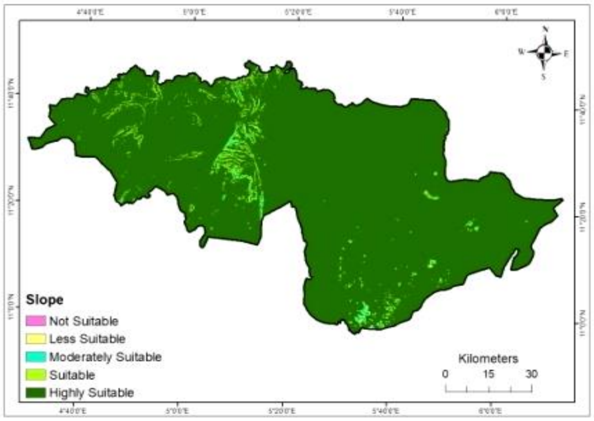

Fig. 4c: Suitability analysis of criteria for establishing grazing reserves - Slope

Table 4d and **Fig. 4d** shows the suitability of rainfall. The study area has 24.45% of land with suitable rainfall levels (400-900mm) covering 2161.81sq.km, while 75.55% falls within the suitable rainfall range (900-1200mm) covering 6681.23 sq.km.

Rainfall significantly influences grazing land and rangeland suitability by regulating water availability for plant development and enhancing greenness in rangelands (Terfa and Suryabhagayan, 2015).

Table 4d: Suitability analysis of criteria for establishing grazing reserves
d: Rainfall

Criterion (d)	Category mm	Rank	%	Level of Suitability
	400-900	9	24.45	Highly Suitable
Rainfall	900-1200	7	75.55	Suitable
	Total		100	

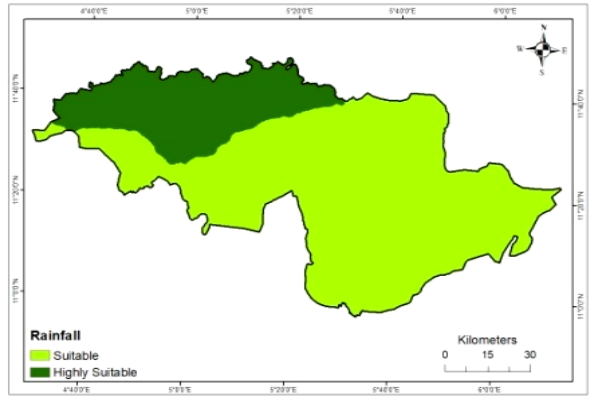

Fig. 4d: Suitability analysis of criteria for establishing grazing reserves - Rainfall

The study evaluates the effectiveness of various temperature ranges in establishing grazing reserves and their corresponding levels of suitability (**Table 4e** and **Fig. 4e**). It shows that 25-27°C is suitable covering 7803.18sq.km (88.24%) of the total area. The slightly higher temperature range of 27-30°C (11.6%) is moderately suitable. Temperature impacts plant growth, affecting land suitability for grazing. Three significant effects include growth cessation below critical temperatures, variations in growth rates with moderate temperature, and negative effects at extremely high temperatures (FAO, 1990).

Table 4e: Suitability analysis of criteria for establishing grazing reserves
e: Temperature

Criterion (e)	Category (°C)	Rank	%	Level of Suitability
	25-27	7	88.24	Suitable
Temperature	27-30	5	11.76	Moderately Suitable
	Total		100	

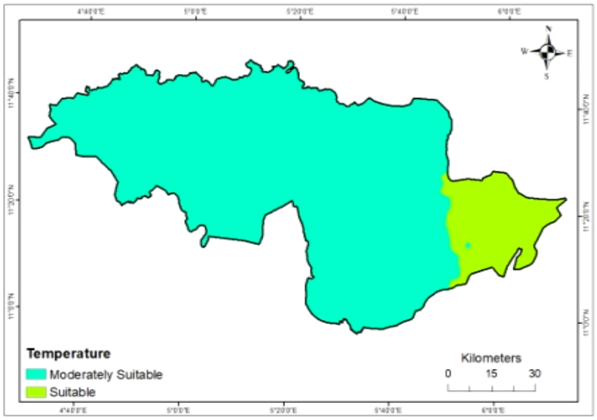

Fig. 4e: Suitability analysis of criteria for establishing grazing reserves – Temperature

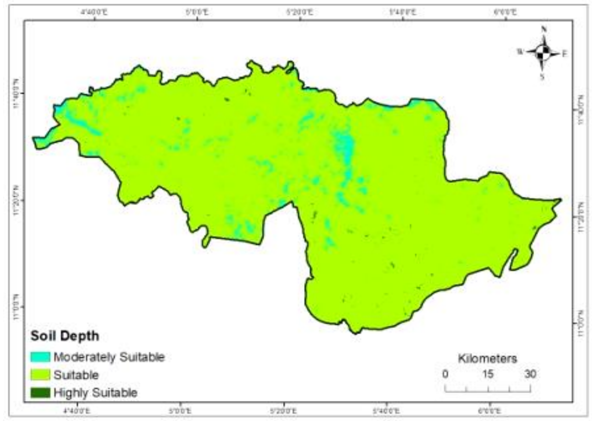

Fig. 4f: Suitability analysis of criteria for establishing grazing reserves – Soil depth

From **Table 4f** and **Fig. 4f** soil depth suitability for grazing is analyzed. It shows that most land in Zuru Emirate is suitable with 95.10% having a soil depth between 100 cm and 150 cm. 4.57% falls under the moderately suitable category with a soil depth less than 100 cm. The highly suitable category with a depth greater than 150 cm only constitutes 0.33% of the total area. This information can help policymakers and land managers make informed decisions about grazing reserves. Rajakaruna and Boyd (2008) asserts that soil depth is a key factor in determining plant variety, as shallow soil provides less water and nutrients, while deeper soil generally supports more plants.

Table 4f: Suitability analysis of criteria for establishing grazing reserves
f: Soil depth

Criterion (f)	Category (cm)	Rank	%	Level of Suitability
Soil Depth	<100	5	4.57	Moderately Suitable
	100-150	7	95.10	Suitable
	>150	9	0.33	Highly Suitable
	Total		100	

In **Table 4g** and **Fig. 4g**, soil organic carbon distribution is analyzed for its suitability for establishing grazing reserve. The highly suitable category covers 25.99% of the total area, with soil organic carbon levels exceeding 2%. The suitable category covers 65.35%, covering 5779.19 sq.km. The moderately suitable category covers 8.20%, covering 725.04 sq.km. The least suitable category covers 0.46%, covering 40.82 sq.km. Areas with soil organic carbon levels below 0.8% are less suitable for siting grazing reserves.

Table 4g: Suitability analysis of criteria for establishing grazing reserves
f: Soil organic carbon

Criterion (g)	Category	Rank	%	Level of Suitability
Soil Organic Carbon	>2	9	25.99	Highly Suitable
	1.2-2	7	65.35	Suitable
	0.8-1.2	5	8.20	Moderately Suitable
	<0.8	3	0.46	Less Suitable
	Total		100	

The largest classification, suitable, covers 65.35% of the total area. Murphy (2015) suggests that soil organic matter can affect soil properties, with higher organic carbon concentrations indicating better suitability for grazing reserves.

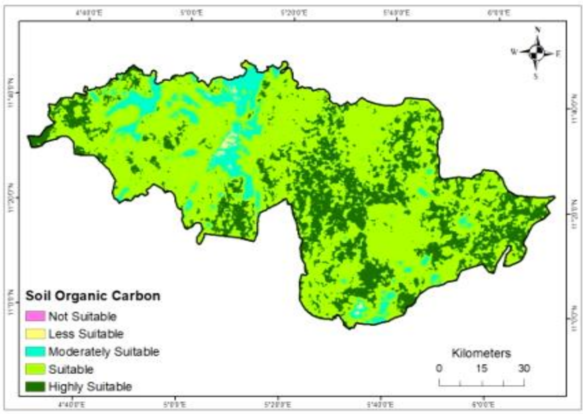

Fig. 4g: Suitability analysis of criteria for establishing grazing reserves – Soil organic carbon

From **Table 4h** and **Fig. 4h**. The study presents a suitability analysis of soil reaction (pH) for siting grazing reserves, emphasizing its importance in determining nutrient availability and vegetation health. It reveals that grazing reserves are most suitable in areas with a pH range of 6.5-7, covering 0.41% of the analyzed region. Areas with a pH range of 6-6.5, covering 84.79% are moderately suitable, while a pH range of 5.5-6, covering 14.79%, are suitable.

Majority of the area falls within the suitable category, with the largest being the pH range of 6-6.5. Soil acidity can lead to toxicity, reduced yields, and plant growth issues particularly impacting potential grazing yield, with the most severe toxicity being caused by induced soil aluminium mobility (Lopes *et al.*, 2021).

Table 4h: Suitability analysis of criteria for establishing grazing reserves
h: Soil pH

Criterion (h)	Category	Rank	%	Level of Suitability
	6.5-7	9	0.41	Highly Suitable
Soil pH	6-6.5	7	84.79	Suitable
	5.5-6	5	14.79	Moderately Suitable
	Total		100	

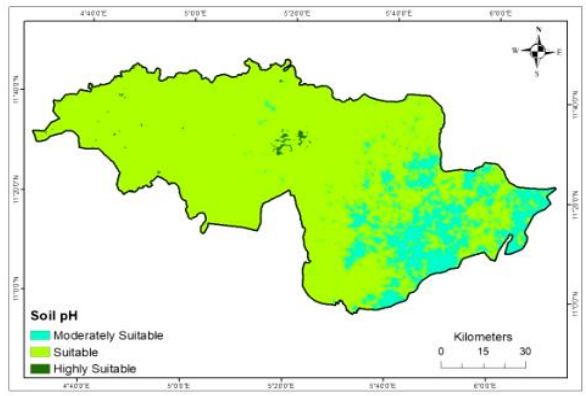

Fig. 4h: Suitability analysis of criteria for establishing grazing reserves – Soil pH

The study evaluated distance from road for grazing reserve siting. From **Table 4i** and **Fig. 4i**, the study reveals that areas less than 250m or more than 10,000m from roads are not suitable for grazing reserve siting. It shows those areas between 250m and 1000m (573.72 sq.km) highly suitable; 1000m to 2000m (1842.63 sq.km) suitable; 2000m to 5000m (2912.52 sq.km) moderately suitable, and 5000m to 10000m (2444.76 sq.km) less suitable. The study suggests that areas near the road network are more suitable for grazing reserve siting due to the need to transport animals and their products to other locations (Samuel *et al.*, 2020).

Table 4i: Suitability analysis of criteria for establishing grazing reserves
h: Distance from road

Criterion (i)	Category (m)	Rank	%	Level of Suitability
Distance from Road	<250, >10000	1	12.09	Not Suitable
	250-1000	9	6.49	Highly Suitable
	1000-2000	7	20.84	Suitable
	2000-5000	5	32.94	Moderately Suitable
	5000-10000	3	27.65	Less Suitable
	Total		100	

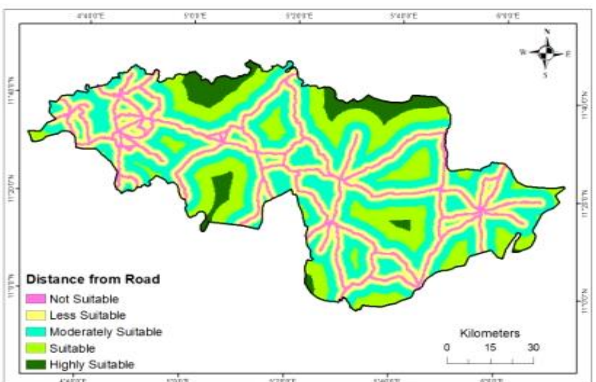

Fig. 4i: Suitability analysis of criteria for establishing grazing reserves – Distance from road

Table 4j and **Fig. 4j**, illustrates suitability map of distances from river. The study ranked five suitable grazing reserve locations based on river distances. It reveals that areas within 0-500 meters and 500-1000 meters from rivers are highly suitable, and over 5000 meters away are considered unsuitable for grazing reserves. Proximity to a water source is crucial for grazing reserve siting, as all animals require drinking water.

Table 4j: Suitability analysis of criteria for establishing grazing reserves
j: Distance from river

Criterion (j)	Category (m)	Rank	%	Level of Suitability
Distance from River	0-500	9	3.16	Highly Suitable
	500-1000	7	3.15	Suitable
	1000-3000	5	9.50	Moderately Suitable
	3000-5000	3	12.24	Less Suitable
	>5000	1	71.95	Not Suitable
	Total		100	

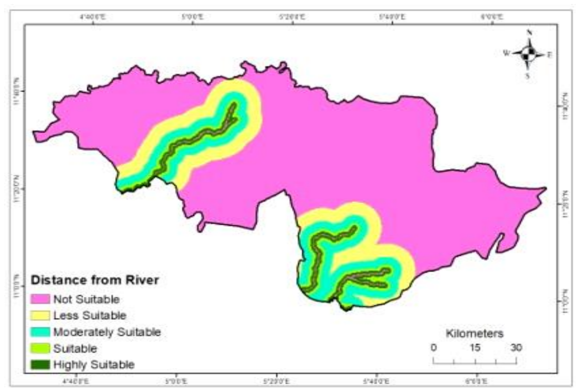

Fig. 4j: Suitability analysis of criteria for establishing grazing reserves – Distance from river

Table 4k and **Fig. 4k** presents suitability analysis of distance from settlement for siting grazing reserves. The analysis categorized distance ranges, provides rankings, area coverage, and suitability levels for each category, aiding in understanding suitability based on settlement distance. The study indicates that areas over 10,000m from settlements are ideal for grazing reserves, accounting for 16.46% of the total area. Grazing reserves between 5000m and 10,000m are also suitable, accounting for 42.47%. Moderately suitable areas are between 3000m and 5000m, covering 22.59%. Less suitable areas are between 1000m and 3000m, covering 16.00%. The smallest expanse is 2.48% of the total area. It is recommended to establish grazing reserves in close proximity to herder settlements and areas dominated by cattle keepers, who require grazing areas the most (Houessou *et al.*, 2020).

Table 4k: Suitability analysis of criteria for establishing grazing reserves
k: Distance from settlement

Criterion (k)	Category (m)	Rank	%	Level of Suitability
Distance from Settlement	>10000	9	16.46	Highly Suitable
	5000-10000	7	42.47	Suitable
	3000-5000	5	22.59	Moderately Suitable
	1000-3000	3	16.00	Less Suitable
	<1000	1	2.48	Not Suitable
	Total		100	

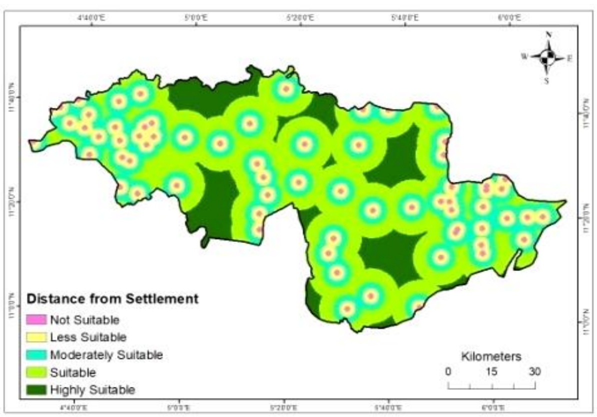

Fig. 4k: Suitability analysis of criteria for establishing grazing reserves – Distance from settlement

3.3 Normalized AHP pair-wise comparison matrix

Table 5 presents a normalized pairwise comparison matrix of the AHP used to evaluate various criteria for establishing grazing reserves in Zuru Emirate.

Table 5 shows a strong preference for each criterion in establishing grazing reserves, with a level of consistency of 0.04, below 0.1 (10%), indicating satisfactory results. Land use and land cover are the most weighted criteria, with a weight of 0.22, indicating highest importance in the evaluation process. Other factors like slope, road distance, soil pH, rainfall, temperature, elevation, soil depth, and soil organic carbon have lower weights, indicating lesser significance compared to higher weighted criteria.

3.4 Land suitability map for grazing reserves in Zuru Emirate

A suitability map of Zuru Emirate was created considering all criteria, revealing four levels of suitability: less suitable, moderately suitable, suitable, and highly suitable areas, as shown in **Table 6** and **Fig. 5**.

The less suitable land area, 81.76 sq.km, makes up 0.92% of the total land area suitable for grazing reserve. The secan be found in Wasagu, Jakasa, Yanlugga and Sabon Gari. This is consistent with the report of Aina (2022), which used GIS, AHP, and weighted overlay analysis to produce a suitability map for juniper and chanterelle planting which shows 11% and 8% less suitable. The moderately suitable category covers 7262.77 sq.km, accounting for 82.13% of the total area, mainly in Gunabi, Dankawo, Noma, Kawo and

Table 5: Normalized AHP pair-wise comparison matrix

	DW	SL	DR	LC	pH	RF	DS	TP	EL	SD	SOC	Weight
DW	0.13	0.14	0.29	0.08	0.15	0.14	0.10	0.15	0.13	0.23	0.18	0.16
SL	0.06	0.06	0.04	0.06	0.09	0.06	0.03	0.06	0.09	0.06	0.06	0.06
DR	0.03	0.10	0.07	0.13	0.13	0.10	0.02	0.16	0.17	0.12	0.09	0.10
LC	0.40	0.24	0.13	0.24	0.26	0.22	0.13	0.19	0.22	0.23	0.18	0.22
pH	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.09	0.09	0.06	0.02	0.04
RF	0.08	0.08	0.06	0.09	0.09	0.08	0.17	0.06	0.07	0.07	0.11	0.09
DS	0.12	0.18	0.29	0.16	0.11	0.16	0.09	0.10	0.10	0.05	0.05	0.13
TP	0.06	0.06	0.03	0.08	0.03	0.08	0.05	0.06	0.04	0.08	0.06	0.06
EL	0.04	0.03	0.02	0.04	0.02	0.05	0.04	0.06	0.04	0.06	0.09	0.04
SD	0.02	0.04	0.02	0.04	0.03	0.05	0.15	0.03	0.03	0.04	0.12	0.05
OC	0.02	0.03	0.02	0.04	0.06	0.02	0.20	0.03	0.01	0.01	0.03	0.04
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Distance to water: DW; Slope: SL; Distance from Road: DR; Land use Land Cover: LC; Rainfall: RF; Soil Reaction: pH; Distance from Settlement: DS; Temperature: TP; Elevation: EL; Soil Depth: SD; Soil Organic carbon: SOC

Dankadai settlements, indicating a significant portion of the region is suitable for cultivation.

Table 6: Land Suitability for grazing reserves in Zuru Emirate

Level of Suitability	Area (Sq. Km)	Percentage (%)
Less Suitable	81.76	0.92
Moderately Suitable	7262.77	82.13
Suitable	1457.67	16.48
Highly Suitable	40.84	0.46
Total	8843.04	100.00

This result is in line with the report of Akomolafe (2015). A study conducted in Kaduna and Niger State found that 62% of the study area was moderately suitable for siting grazing reserve, contradicting Emenike *et al.*, (2016) findings. A study in Irepodun, Osun state, identified 15% of the area as moderately suitable for livestock grazing, while the suitable category covers 16.48% of the total area, covering 1457.67 sq.km indicating the need for further research and mapping.

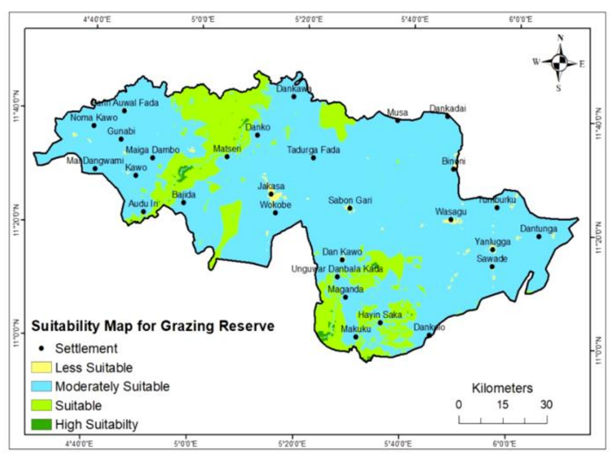

Fig. 5: Land suitability for grazing reserves in Zuru Emirate

The Emirate's suitable grazing areas are found in Matseri, Hayin Saka, and Unguwar Danbala, indicating limited land area suitable for sitting such reserves, in line with the findings of Ujoh *et al.*, (2019). A multicriteria evaluation was used to map rice cultivation areas in Benue, Nigeria, revealing that 10.2% of the area was suitable, with the smallest highly suitable area at 40.84sq.km, indicating a limited proportion of land suitable for grazing reserve establishment. The study found that areas near Maiga Dambo, Bajida, Danko, and Makuku are highly suitable, aligning with the findings of Ostovari *et al*. (2019) who used AHP to determine land suitability for rapeseed farming discovered that only 0.81% of the study area was highly suitable for rapeseed farming. A land suitability map is crucial for establishing grazing reserves in Zuru Emirate, which will aid authorities, land managers, and stakeholders in identifying suitable areas, ensuring efficient resource allocation, and promoting sustainable land utilization.

3.5 Validation of land suitability map for siting grazing reserves in Zuru Emirate

The study used the Normalized Difference Variation Index NDVI method to validate the suitability map, using the zonal statistics tool in ArcGIS 10.8 to calculate the mean value of each land suitability class, as shown in **Table 7**.

Table 7 shows that highly suitable classes have the highest mean NDVI value of 0.5057, indicating dense and healthy vegetation cover. The suitable category has a mean NDVI value of 0.5055, suggesting good vegetation cover for grazing activities. The moderately suitable class has a mean NDVI value of 0.4978, suggesting slightly better vegetation cover. The less suitable category has a mean NDVI value of 0.4114, indicating low vegetation density. These results confirm the accuracy of the land suitability map, as the highly suitable class has the highest mean NDVI value of 0.5057, while the low suitable class has the lowest. NDVI is a widely used index in remote sensing and vegetation studies.

Table 7: Mean NDVI value of each land suitability class

Level of Suitability	Mean
Less Suitable	0.4114
Moderately Suitable	0.4978
Suitable	0.5055
highly Suitable	0.5057

4. Conclusion

The study in Zuru Emirate, Kebbi State, used geospatial techniques and MCDA tools to evaluate land suitability for siting grazing reserves. The study reveals that a majority of the area is suitable for grazing reserves, with land use being the most influential factor. The study also found that 0.92% of the area is less suitable, with 83.13% being moderately suitable and 16.48% being suitable. The highly suitable category had the highest mean NDVI value of 0.5057.

The findings can help assess land use patterns and decision-making criteria for grazing reserve development, addressing issues between farmers and pastoralists. Grazing reserves development can also improve the socio-economic well-being of rural farmers.

Furthermore, this study has focused on Zuru Emirate only. The study did not go outside the context of establishing grazing reserves. However, the analyses used for the study were within the acceptable results as compared to related studies.

5. Conflict of Interest

There is no conflict of interest among the authors.

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