LAND SUITABILITY EVALUATION FOR OKRA (Abelmoschus Esculentus L.) IN NAGARI NANGGALO, KOTO XI TARUSAN DISTRICT, PESISIR SELATAN REGENCY, INDONESIA USING GIS-AHP TECHNIQUE

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ABSTRACT

Land suitability analysis is a beneficial activity in land resource planning and management. This study aimed to evaluate land suitability for okra cultivation in Nagari Nanggalo, Koto XI Tarusan District, Pesisir Selatan Regency, Indonesia, by integrating the Analytical Hierarchy Process (AHP) method with Geographic Information Systems (GIS). Topographic factors, climate, and soil characteristics were considered in this suitability assessment. Based on the research, it was concluded that in the land evaluation for okra cultivation, soil factors played the most significant role, with a weight of 53.9% according to the AHP analysis, followed by climate factors at 29.7% and topographic factors at 16.4%. The land suitability analysis results indicated that 87.05% (321 ha) of the area was highly suitable (S1), and 12.95% (47.80 ha) of the area was moderately suitable (S2) for okra cultivation. This research demonstrated that the area had the potential for okra production. However, it should be noted that proper soil management, as well as soil and water conservation measures, should be considered to enhance the current land suitability and improve crop yield. The soil map for land suitability designed in this study is useful for management decision-making.

Keywords: land evaluation; GIS; AHP; okra cultivation

1. Introduction

The Pesisir Selatan Regency of West Sumatra (Sumbar) Indonesia, possesses a significant amount of suboptimal land. Suboptimal land refers to areas that have physical, chemical, and biological constraints, making them unsuitable for cultivating horticultural crops. These constraints include high land slopes, low soil fertility and high soil salinity.

In Pesisir Selatan, suboptimal land is commonly found in hilly and coastal areas. These lands are generally planted with perennial crops such as coconut, rubber, and coffee. However, the production of these crops is relatively low due to the limiting factors. According to data from the Central Statistics Agency (BPS) of West Sumatra in 2022, the area of suboptimal land in Pesisir Selatan reached 124,000 hectares (BPS, 2022). Of this amount, only about 40,000 hectares are utilized for agricultural activities.

Nagari Nanggalo is one of the villages located in Koto XI Tarusan District, Pesisir Selatan Regency. Nagari Nanggalo has a total area of 3.69 km² (0.76% of the total area of Koto XI Tarusan District). Nagari Nanggalo has a sufficient land area for agriculture. According to land use maps from the Geospatial Information Agency (BIG, 2023), of the total area of 369 ha, 146.92 ha are used as rice fields, 11.19 ha as dry fields, 163.71 ha as mixed gardens, 35.71 ha for settlements, and 11.61 ha as rivers. Nagari Nanggalo receives an average annual rainfall of 3,498 mm/year (Dinas PSA, 2023) and falls under a very wet climate classification (Type A) according to Schmidt and Ferguson (1951). This favorable environmental condition supports the cultivation of various crops, including okra, a versatile plant whose fresh leaves, pods, stems, and seeds can all be utilized.

Immature okra fruit is consumed as a vegetable, while okra seeds are a potential source of oil with varying concentrations. Based on research by Moosavia et al. (2018), if the oil content of the okra plant is 20%, it can produce up to 325 kg/ha of oil. Tests have shown that the most dominant fatty acids are linoleic acid (38-40%), palmitic acid (29-30%), and oleic acid (19-22%). Biodiesel derived from okra through transesterification using an ultrasonic system can meet ASTM D6751 standards with good results and a methyl ester content of over 96%, a viscosity of 2.3-2.4 kg.ms-1, and a flash point of 155-158 °C. Due to its high oil quality, okra holds promise as a new bioenergy source for biodiesel production in the future. However, the suitability of the land for okra cultivation in Koto XI Tarusan District, Pesisir Selatan Regency, especially in Nagari Nanggalo is not well known.

Okra production in Indonesia is currently low because the public is not yet widely aware of this plant and its benefits. In 2013, okra production was 1,317 tons, and in 2014 it increased slightly to 1,360 tons. In 2016, it was projected to reach 1,500 tons (Ichsan et al., 2018). In 2016, 500 tons of green okra fruit were exported to Japan. According to data from BPS (2024), okra production is currently only 1,624 tons. India is the largest producer of okra in the world, with an output of 5 million tons/year (Fatima et al., 2024). Okra development needs to emphasize high production (quantity) and quality according to market demands (Najafi et al., 2024).

The development of okra cultivation requires land evaluation, which is a crucial factor in determining the success of okra farming because it is closely related to land conditions, including nutrient availability, soil pH, soil texture, and resistance to diseases and other disturbances (Roy et al., 2022). Moreover, land suitability is also a key factor in determining the optimal type of crop to be grown in an area. Land suitability evaluation assists in determining the type of crop that best suits the existing land conditions. In this context, research on okra cultivation development is highly relevant and important for conducting land suitability evaluations (Baite et al., 2024). In the current digital era, Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) have become very useful tools for analyzing spatial data and decision-making (Tadesse &

Negese, 2020). The use of GIS and the AHP in this study will enable more efficient and accurate analysis in determining land suitability evaluation for okra cultivation in Nagari Nanggalo, Koto XI Tarusan District, Pesisir Selatan Regency.

GIS offers various opportunities to enhance the availability and accuracy of spatial data, more efficient data analysis, and improved data access (El Baroudy, 2016). However, GIS does not account for the interrelation of land evaluation criteria as all criteria have different levels of importance (Kazemi & Akinci, 2018). This issue cannot address the inconsistency problem when assessing and determining the relative importance levels of the criteria required for land suitability evaluation (Rad & Haghyghy, 2014). Therefore, land managers and land use planners are encouraged to use decision-making tools with multiple criteria combined with GIS to integrate and manage various heterogeneous factors (Torrieri & Batà, 2017). These techniques provide a well-structured and spatially explicit evaluation framework for sustainable land use management practices (Musakwa, 2018). Therefore, the AHP method is one of the commonly used multi-criteria decisionmaking techniques in GIS-based land suitability assessments because of its relevance in making decisions based on several factors ranked according to expert judgments (Oureshi et al., 2018). The Analytic Hierarchy Process (AHP) allows group decision evaluation (criteria) with a systematic approach and logic used to select the best alternative among the determined alternatives for a specific goal by considering various criteria (Saaty & Vargas, 2012).

This study aimed to evaluate land suitability for okra cultivation in Nagari Nanggalo, Koto XI Tarusan District, Pesisir Selatan Regency by using GIS and AHP methods as the main tools in analysis and decision-making. By combining GIS technology and the AHP model, it is expected that this study would provide more accurate and objective information regarding land suitability for okra cultivation in Nagari Nanggalo and identify the most suitable land for okra cultivation development.

2. Methods

2.1 Study area

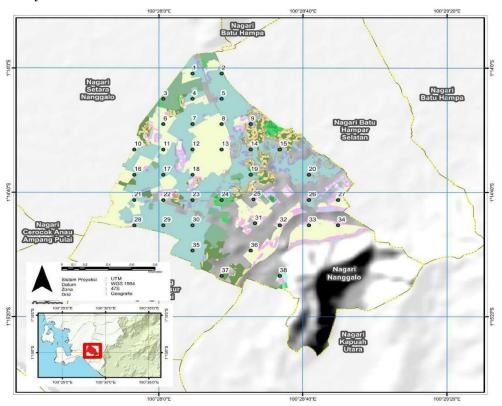


Figure 1 Location map of the study area

Nagari Nanggalo is located in Koto XI Tarusan subdistrict, Pesisir Selatan Regency (Figure 1), at coordinates $100^{\circ} 28' - 100^{\circ} 29'$ E and $1^{\circ} 13' - 1^{\circ} 15'$ S, covering an area of 369.15 hectares (0.76% of the subdistrict total area) and an elevation range of 0-170 meters above sea level (MASL) with 80% of the area at an elevation of 0-10 MASL. The region has an average annual rainfall of 3,498 mm and an average temperature of 29.1°C; therefore, the area belongs to the A-type climate category (very wet) according to Schmidt and Ferguson (1951), with no dry months throughout the year. Agricultural land in Nagari Nanggalo relies solely on rainfall, without any technical irrigation systems. The area contains two soil orders: 1) Inceptisols, with a great group of Dystrudepts covering 323.3 hectares (87.57%), and 2) Entisols, with a great group of Tropofluvents covering 46.45 hectares (12.5%). Soil samples were taken from the Dystrudepts great group, which is characterized by flat topography. Land use in Nagari Nanggalo includes forest (23.35%), rice fields (27.39%), community gardens (5.24%), shrubs (6.72%), fields (21.77%), settlements (12.39%), and rivers (3.15%). The region physiography consists of an alluvial plain, formed by sedimentation from the Batang Tarusan River and erosion from the surrounding hills, leading to deposits of clay and silt.

2.2 Soil sampling and analysis

Field data collection and soil sampling were carried out with attention to variations in land use. Samples were taken from four types of land use including paddy fields, dryland agriculture, mixed plantations, and shrubs. Soil profiles were opened to measure soil

depth conditions. Representative soil samples from a depth of 0 to 30 cm were collected to examine the soil's physical and chemical properties. At each sampling site, coordinates were recorded using a GPS (Global Positioning System) model Garmin Montana 750i Navigator. The soil sampling method used in this study was the Systematic Grid Sampling method (Wollenhaupt & Wolkowski, 1994; Watson et al., 2022), where coordinates were selected according to predetermined distances between points. This method is often used in spatial pattern studies as it facilitates the creation of map patterns derived from grids. Therefore, a distance of 250m x 250m was chosen between each sampling point. A total of 38 soil samples were collected for this study. The collected soil samples were air-dried, gently crushed with mortar and pestle, well-mixed, and passed through a 2-mm sieve. A 0.5-mm sieve was used to determine total nitrogen (N) and organic carbon (OM). The processed soil samples were then analyzed at the Chemistry and Fertility Laboratory of Andalas University, Padang, following standard analysis procedures (Table 1).

Table 1 Standard laboratory methods for soil sample analysis

Parameters	Applied standards for measurement
pH H ₂ O (1:5)	Electrometry (BPT, 2023)
Electrical Conductivity, EC (dS/m)	Electrometry (BPT, 2023)
Organic Carbon, OM (%)	Walkley dan Black (BPT, 2023)
Total Nitrogen, TN (%)	Kjeldahl (BPT, 2023)
Available Phosphorous, Av.P (ppm)	Bray 1 (BPT, 2023)
Cation Exchange Capacity, CEC (cmol/kg)	Leaching NH ₄ OAc 1 M (BPT, 2023)
Base Saturation, BS (%)	AAS (BPT, 2023)

The overall criteria for okra production suitability were identified (Table 2) based on various literature sources (modified from Tripathi et al., 2011) with framework from Sys et al. (1993) in Rossister (1996) and available data. Rainfall and temperature data were obtained from the Water Resources Management Agency of West Sumatra Province (Dinas PSA, 2023). Additionally, a digital elevation model with a 30m spatial resolution was used to generate the slope map from ASTER GDEM, obtained from the Aster Global Digital Elevation Map (http://gdex.cr.usgs.gov/gdex/) using the Spatial Analyst Tool in ArcGIS software for suitability map preparation.

Table 2
Rating of land use requirements for okra production

Criteria factors		Factor	rating	
	S1 (100)	S2 (75)	S3 (50)	N (25)
Mean temperature (°C)	25-30	20-25, 30-33	12-20, 33-35	<12, >35
Annual rainfall (mm)	1200-5000	800-1200	300-800	<300, >5000
Altitude (msal)	1-400	400-800	800-1000	>1000
Slope (%)	0-15	15-25	25-45	>45
Soil depth (cm)	>50	25-50	10-25	<10
Soil reaction (pH)	5.5-7.0	5.0-5.5	4.5-5.0	<4.5, >7.0
EC (dS/m)	<4	4-5	5-6	>6
CEC (cmol/kg)	>16	5-16	<5	-
Base Saturation (%)	>35	20-35	< 20	-
Organic Carbon (%)	>2.0	0.8-2.0	< 0.8	-
Total N (%)	>0.51	0.21-0.51	< 0.2	-
Available P (ppm)	>15	6-15	<5	-

Source: Modified from Tripathi et al. (2011) with framework from Sys et al. (1993)

2.3 Criteria weight estimation

The classification of land suitability evaluation (LSE) was carried out using the Analytical Hierarchy Process (AHP) method (Figure 2). The selection of criteria and subcriteria was based on land characteristics guided by Sys (1993) in Rosister (1996), where the important factors in land suitability evaluation were topography, climate, and soil. The sub-criteria followed the land evaluation table (Table 2), which was modified from Tripathi et al. (2011). Modifications were made to adjust the sub-criteria to the study area. The AHP method was used to determine the influence of each research parameter as well as to assign weights to these parameters through a pairwise comparison matrix based on expert opinion (Saaty, 2008). The experts were selected from agricultural academics at Andalas University and Padang State University, local agricultural practitioners, and local government officials. A total of 10 experts were chosen. Among the pairwise matrices constructed, the one with the most consistent Consistency Ratio (CR) (CR <10%) was selected. This selection was carried out to ensure that the expert assessments were truly consistent and could accurately represent the actual conditions. The AHP calculations in this study were conducted using Super Decisions software version 3.2, an application for data analysis using the AHP method, ensuring that the consistency ratio calculation results are automatically generated by the application.

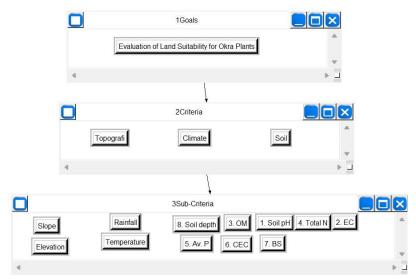


Figure 2 AHP model for LSE in Super Decisions

2.4 Method of analysis using GIS

After assigning weights to each parameter using the AHP, spatial interpolation using the Inverse Distance Weighted (IDW) method was performed with ArcGIS 10.4 software to generate raster layers for each criterion. The IDW method assumes that interpolated values will be more similar to sample data points that are closer rather than those that are farther away (Ozsahin & Ozdes, 2022). This method determines the value of an unknown point using a linear weighted combination of a set of sample points, making it suitable when combined with the AHP (Chu & Le, 2022). The values in the raster layers were then reclassified into common suitability classes (S1 for highly suitable, S2 for moderately suitable, S3 for marginally suitable, and N for not suitable). Finally, the weighted overlay method was used to generate the overall suitability raster layer (Everest & Gür, 2022). The reclassified raster layers were overlaid by multiplying the suitability value of each raster cell by the weight of the layer and summing the values to produce the overall suitability map. (Equation 1)

$$S = \sum_{i=0}^{n} (WiXi) \tag{1}$$

Where, S is the suitability, Wi is the weight of factor i, and Xi is the criterion score of factor i.

3. Results and discussion

3.1 Analytical Hierarchy Process

The pairwise comparison matrix for land evaluation includes the following three criteria: topography, climate, and soil. The topography criterion has the following two subcriteria: slope and elevation. The climate criterion includes the following two sub-criteria: temperature and rainfall. The soil criterion comprises the following eight sub-criteria: pH, electrical conductivity (EC), organic carbon (OM), total nitrogen (TN), available phosphorus (Av.P), cation exchange capacity (CEC), base saturation (BS), and soil depth. The pairwise comparison matrices are presented in Tables 3-7.

Table 3 Pairwise comparison matrix for land evaluation (CR = 0.009)

Criteria	Topography	Climate	Soil	
Topography	1	1/2	1/3	
Climate		1	1/2	
Soil			1	

Tabel 4 Pairwise comparison matrix for topography factor (CR = 0.00)

Sub-criteria	Slope	Elevation
Slope	1	1/4
Elevation		1

Table 5 Pairwise comparison matrix for climate factor (CR = 0.00)

Sub-criteria	Rainfall	Temperature
Rainfall	1	2
Temperature		1

Table 6 Pairwise comparison matrix for soil factor (CR = 0.091)

Sub-criteria	pН	EC	OM	TN	Av. P	CEC	BS	Soil depth
pН	1	2	2	2	3	3	2	3
EC		1	1/3	1/5	1/3	1/4	1/2	4
OM			1	2	2	5	3	4
TN				1	1	1	2	4
Av. P					1	1	1	4
CEC						1	2	4
BS							1	2
Soil depth								1

Table 7
Relative importance scores for land evaluation

Criteria	Sub-criteria	Global weight	Percentage
Topography (0.164)	Slope (0.200)	0.033	3.30%
	Elevation (0.800)	0.131	13.1%
Climate (0.297)	Rainfall (0.667)	0.198	19.8%
	Temperature (0.333)	0.099	9.90%
Soil (0.539)	pH (0.230)	0.124	12.4%
	EC (0.064)	0.035	3.50%
	OM (0.219)	0.118	11.8%
	TN (0.138)	0.074	7.40%
	Av. P (0.110)	0.059	5.90%
	CEC (0.119)	0.064	6.40%
	BS (0.082)	0.044	4.40%
	Soil depth (0.038)	0.020	2.00%
	Total	1	100

Table 7 shows that the soil factor played the most significant role, accounting for 53.9%, followed by the climate factor at 29.7%, and the topography factor at 16.4%. This indicated that the soil factor had the most substantial influence in land evaluation for okra cultivation. This was because plant growth was greatly affected by soil fertility, where fertile soil provided the necessary nutrients to support plant growth.

3.2 Topography suitability

The most important elements in topography are slope and elevation. Topographic analysis is essential for land management and assessing the potential for erosion hazards. The varying topographic conditions in an area influence the temperature conditions and the intensity of sunlight received by a plant.

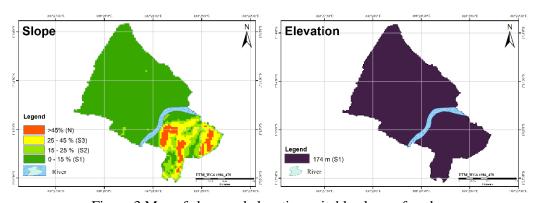


Figure 3 Map of slope and elevation suitable classes for okra

Based on Figure 3, the slope suitability results indicated that the suitable area (S1) covered 289.81 ha (78.51%), while the moderately suitable area (S2) covered 32.11 ha (8.70%). The marginally suitable area (S3) covered 30.34 ha (8.22%), and the unsuitable area (N) covered 16.87 ha (4.57%). Thus, 62.96% of the study area was categorized as marginally suitable and unsuitable for okra cultivation. Yasin & Yulnafatmawita (2018) stated that there were significant differences in the physicochemical properties of soils

across different slope positions, with soil properties at the lower slope being the best compared to those at the upper and middle slopes. This indicated that slope played an important role in land suitability evaluation, as the slope position determined the level of erosion and leaching of nutrients from the upper slopes to the lower areas. The slope classification was determined from the Digital Elevation Model (DEM) for the suitability classes in the study area (Otieno et al. 2023). Based on Figure 3, the elevation showed that all areas were highly suitable for okra cultivation. Elevation influenced plants due to differences in air temperature, humidity, and light intensity at different planting locations. Mewengkang et al. (2022) support that each elevation is dominated by different tree species. Their study shows a general pattern influenced by elevation on plants.

3.3 Climate suitability

Climate influences the growth and development of plants. Each plant species can thrive under specific climatic conditions; for example, coconut trees grow well in tropical climate regions but cannot thrive in tundra regions due to the differences in temperature, rainfall, and humidity between tropical and tundra climates.

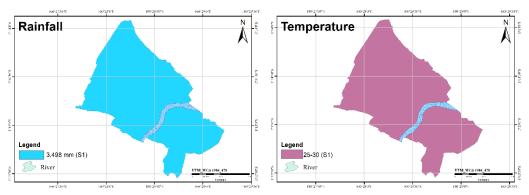


Figure 4 Map of rainfall and temperature suitability classes for okra

The study area is characterized by an equatorial rainfall pattern, where the region has a bimodal monthly rainfall distribution with two peaks of maximum rainy seasons and almost year-round fits the criteria for the rainy season. The equatorial pattern is characterized by a bimodal rainfall type (two rainfall peaks) that usually occurs around March and October or during the equinoxes. The mean annual rainfall is 3,498 mm, and the mean annual temperature is 29°C. The results indicated that the average annual rainfall and average temperature falls into the highly suitable category (S1), for okra cultivation in the study area (Figure 4).

3.4 Soil suitability

Soil is the primary medium and the growing environment for plants. The most important soil characteristics in land suitability evaluation include soil reaction (pH), organic carbon (OM), total nitrogen (TN), available phosphorus (Av.P), cation exchange capacity (CEC), base saturation (BS), electrical conductivity (EC), and soil depth. The statistics and results of the analysis of soil characteristics at 38 sample points in Nagari Nanggalo are shown in Tables 8 and 9.

Table 8 Statistical analysis of laboratory data

Statistic	Mean	Std dev	Median	Min	Max
pН	4.56	0.317	4.51	4.16	5.66
EC (dS/m)	0.24	0.016	0.23	0.22	0.29
OM (%)	1.45	0.503	1.45	0.70	2.44
TN (%)	0.30	0.094	0.30	0.11	0.53
Av. P (ppm)	5.15	1.307	5.14	2.52	9.50
CEC (cmol/kg)	10.88	3.913	10.67	4.15	20.87
BS (%)	17.10	6.441	15.05	8.31	32.12

Table 9
Results of laboratory analysis of soil chemical characteristics at 38 sample points (SP)

SP	pН	EC (dS/m)	OM (%)	TN (%)	P (ppm)	CEC (cmol/kg)	BS (%)
1	4.16	0.22	2.22	0.11	5.70	5.44	32.12
2	4.45	0.23	2.16	0.31	4.42	6.10	27.56
3	4.38	0.23	2.10	0.17	5.54	12.12	13.69
4	4.60	0.24	2.44	0.19	5.80	10.43	17.39
5	4.26	0.22	1.65	0.48	5.89	9.06	17.68
6	4.81	0.25	2.11	0.46	5.96	13.54	14.10
7	4.18	0.22	1.22	0.24	4.74	7.75	21.22
8	4.47	0.23	1.65	0.40	4.49	11.72	12.46
9	4.22	0.22	1.07	0.37	3.34	8.52	20.32
10	4.57	0.24	1.34	0.18	5.12	12.76	11.90
11	4.46	0.23	1.05	0.26	4.40	6.69	22.74
12	4.73	0.25	1.10	0.29	5.16	8.64	18.95
13	4.51	0.23	0.90	0.29	5.40	10.94	12.35
14	4.22	0.22	1.56	0.34	4.39	7.27	22.81
15	4.43	0.23	0.89	0.34	5.07	8.99	16.46
16	4.28	0.22	1.76	0.26	3.47	10.29	14.15
17	4.58	0.24	1.26	0.21	3.11	11.51	12.81
18	4.41	0.23	1.55	0.21	4.43	10.52	14.74
19	4.41	0.23	0.81	0.44	4.99	11.70	14.45
20	4.23	0.22	1.71	0.24	4.12	9.67	23.52
21	4.52	0.23	2.29	0.33	4.59	20.87	9.03
22	4.50	0.23	1.03	0.29	4.26	15.58	8.95
23	4.56	0.24	2.13	0.30	5.57	15.43	12.34
24	4.34	0.22	1.45	0.13	5.40	13.93	10.61

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SP	pН	EC (dS/m)	OM (%)	TN (%)	P (ppm)	CEC (cmol/kg)	BS (%)
25	4.73	0.25	0.94	0.31	5.45	14.29	9.72
26	4.58	0.24	0.80	0.30	5.81	15.05	9.67
27	4.70	0.24	0.73	0.31	5.42	11.13	13.62
28	4.37	0.23	1.38	0.35	5.95	11.37	13.14
29	4.35	0.23	1.68	0.34	2.52	10.82	15.37
30	4.66	0.24	1.44	0.24	4.75	20.66	8.31
31	5.02	0.26	1.46	0.24	7.36	12.66	11.73
32	4.74	0.25	1.13	0.24	5.63	7.76	20.73
33	4.56	0.24	0.91	0.27	4.66	4.15	31.77
34	5.05	0.26	0.98	0.32	5.60	4.74	28.97
35	4.36	0.23	1.45	0.39	3.37	8.24	20.15
36	4.72	0.24	0.70	0.37	6.25	6.38	25.29
37	5.42	0.28	2.31	0.43	8.04	17.09	23.46
38	5.66	0.29	1.82	0.53	9.50	9.54	15.35

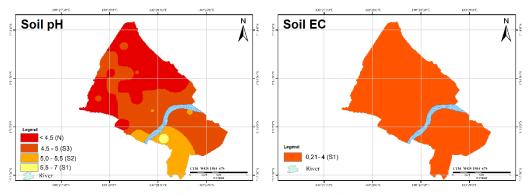


Figure 5 Map of soil pH and soil EC suitability classes for okra

Soil pH is a crucial criterion in land suitability classification as it influences many chemical properties of the soil. Soil pH provides information about the solubility and availability of nutrients for plants, thus determining the soil's suitability for specific crops (Brady & Weil, 2004). The soil pH measured from water extracts ranged from 4.16 to 5.66, indicating that the soil in the study area was very acidic to slightly acidic. As shown in Figure 5, the soil pH analysis indicated that 0.75% (2.77 ha) of the area was highly suitable (S1), 12.88% (47.55 ha) was moderately suitable (S2), 47.15% (174.05 ha) was marginally suitable (S3), and 39.22% (144.78 ha) was not suitable (N) for okra cultivation. Electrical conductivity (EC) reflected the salt content dissolved in the soil. The analysis results presented in Figure 5 showed that the area was highly suitable (S1) for okra cultivation.

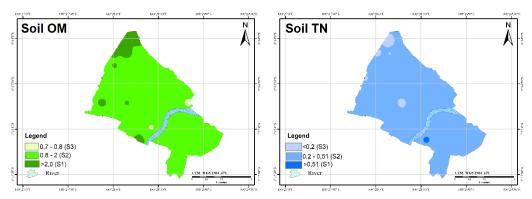


Figure 6 Map of OM and TN suitability classes for okra

The analysis of organic carbon (OM) content ranged from 0.70% (very low) to 2.44% (medium). The spatial distribution shown in Figure 6 indicated that 6.47% (23.88 ha) of the area was highly suitable (S1), 92.92% (343.01 ha) was moderately suitable (S2), and 0.61% (2.25 ha) was marginally suitable (S3). Soil organic matter is an important parameter that functions as a soil conditioner, maintaining soil structure stability, improving water retention, and forming aggregates to enhance erosion resistance (Yulnafatmawita et al., 2013). Nitrogen (N) is a major element in protein formation for plant growth, alongside sulfur (Sefano et al., 2023). The total nitrogen (TN) analysis ranged from 0.11% (low) to 0.53% (high). The spatial distribution shown in Figure 6 indicates that 0.33% (1.21 ha) of the area was highly suitable (S1), 97.22% (358.88 ha) was moderately suitable (S2), and 2.45% (9.04 ha) was marginally suitable (S3). The low total nitrogen content in the study area was attributed to low organic matter content (Sefano et al., 2023), limited application of nitrogen-rich organic materials, and mineralization of existing organic matter due to soil cultivation. In the study area, crop residues were often burned directly, leading to nitrogen loss from organic matter through combustion.

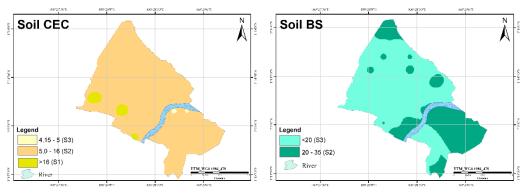


Figure 7 Map of CEC and BS suitability classes for okra

Cation exchange capacity (CEC) is an important indicator used to assess soil fertility (Sefano & Gusmini, 2024). Soils with low CEC typically have low organic matter content, and crop cultivation requires more fertilizer inputs, making them prone to leaching in high rainfall areas. Such soils usually have lower yield potential compared to soils with higher CEC under the same management conditions (Tadesse & Nagese, 2020). The CEC values in the study area ranged from 4.15 cmol/kg (very low) to 20.87

cmol/kg (medium). The spatial distribution shown in Figure 7 indicates that 2.67% (9.85 ha) of the area was highly suitable (S1), 97.03% (358.15 ha) was moderately suitable (S2), and 0.3% (1.10 ha) was marginally suitable (S3). Base saturation (BS) represents the amount of exchangeable base cations (Ca, Mg, K, Na) compared to CEC (Brady & Weil, 2004). The base saturation ranged from 8.31% (very low) to 32.12% (low). The low base saturation was consistent with the low pH values (Figure 5) because at low pH the presence of base cations was very low, and the soil was dominated by acidic cations (Al, Fe, and H). Figure 7 indicates that 32.68% (120.64 ha) of the area was moderately suitable (S2), while 67.32% (137.76 ha) was marginally suitable (S3) for okra cultivation.

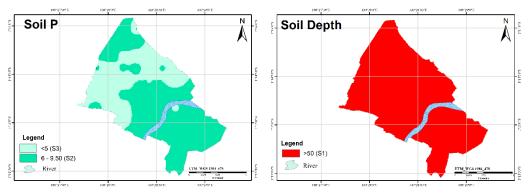


Figure 8 Map of available-P and soil depth suitability classes for okra

Phosphorus is a major macronutrient for plant growth and production (Brady & Weil, 2004). The available phosphorus (Av.P) analysis ranged from 2.52 ppm (very low) to 9.50 ppm (medium). The spatial distribution shown in Figure 8 indicates that 63.93% (235.99 ha) of the area was moderately suitable (S2) and 36.07% (133.16 ha) was categorized as marginally suitable (S3). Phosphorus in the soil often underwent fixation by Al and Fe (low pH), reducing its availability for plant growth. Soil depth was another important factor in the suitability analysis for okra cultivation. The results presented in Figure 8 indicates that 100% of the area was highly suitable (S1). This was because the study area had an alluvial physiography that periodically received clay and silt from flooding of the Batang Tarusan river and erosion of surrounding hills.

3.5 Overall suitability

Land suitability is influenced by land characteristics, which include physical environmental conditions such as climate, topography, and soil as the primary medium that can affect the quality of plant growth and development (Ritung et al., 2007). Land characteristics are crucial in evaluation, particularly in analyzing potential issues that may arise from the interaction between each environmental characteristic.

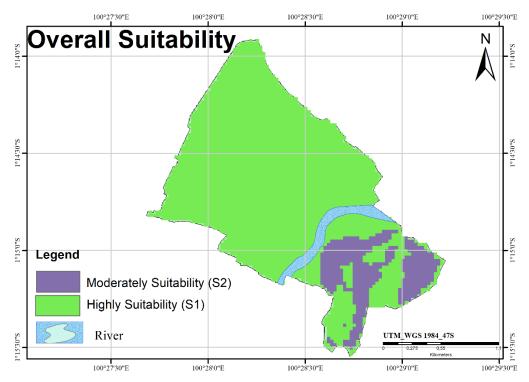


Figure 9 Overall suitability class-map for okra

The weighted overlay results shown in Figure 9 indicate that 87.05% (321 ha) of the area is highly suitable (S1), possessing all the qualities required for okra cultivation. Only 12.95% (47.80 ha) of the area falls under the moderately suitable (S2) category for okra cultivation. The S2 areas have constraints, primarily related to slope gradients (20% to over 45%). The residents of the area also use the land as secondary forest. The soil factor maps reveal that most of the soil in this region is low in organic matter content, has low pH, and contains low natural nutrient levels in the parent material from which the soil was formed. This situation has worsened as current land management practices continue without improvement. Therefore, increasing sustainable agricultural production will require integrated efforts from land-use planners, agricultural extension officers, researchers, and rural communities. This can be enhanced by implementing environmentally friendly and sustainable farming techniques such as soil and water conservation measures, integrated soil fertility management, and agronomic practices. Suitability class for okra in the study area shown in Table 9.

Table 9 Suitability class for okra in the study area

Criteria/factor	Level of suitability	Area (ha)	Percentage (%)
Slope (%)	Highly suitable (S1)	289.81	78.51
	Moderately suitable (S2)	32.11	8.70
	Marginally suitable (S3)	30.35	8.22
	Unsuitable (N)	16.87	4.57
	total	369.15	100.00
Elevation (msal)	Highly suitable (S1)	369.15	100.00
Rainfall (mm/y)	Highly suitable (S1)	369.15	100.00
Temperature (°C)	Highly suitable (S1)	369.15	100.00
pН	Highly suitable (S1)	2.77	0.75
	Moderately suitable (S2)	47.55	12.88
	Marginally suitable (S3)	174.05	47.15
	Unsuitable (N)	144.78	39.22
	total	369.15	100.00
EC (dS/m)	Highly suitable (S1)	369.15	100.00
OM (%)	Highly suitable (S1)	23.88	6.47
	Moderately suitable (S2)	343.01	92.92
	Marginally suitable (S3)	2.25	0.61
	total	369.15	100
TN (%)	Highly suitable (S1)	1.21	0.33
	Moderately suitable (S2)	358.88	97.22
	Marginally suitable (S3)	9.04	2.45
	total	369.15	100.00
Av. P (ppm)	Moderately suitable (S2)	235.99	63.93
	Marginally suitable (S3)	133.16	36.07
	total	369.15	100.00
CEC (cmol/kg)	Highly suitable (S1)	9.85	2.67
	Moderately suitable (S2)	358.15	97.03
	Marginally suitable (S3)	1.10	0.30
	total	369.15	100.00
BS (%)	Moderately suitable (S2)	120.64	32.68
	Marginally suitable (S3)	137.76	67.32
	total	369.15	100.00
Soil depth (cm)	Highly suitable (S1)	369.15	100.00

4. Conclusion and recommendations

Based on this research, it was concluded that in the land evaluation for okra cultivation, soil factors played the most significant role, with a weight of 53.9% according to the AHP analysis, followed by climate factors at 29.7% and topographic factors at 16.4%. According to the land suitability map, 87.05% (321 ha) of the area was highly suitable (S1), and 12.95% (47.80 ha) of the area was moderately suitable (S2) for okra cultivation. The limiting factors included low soil fertility, particularly low pH and organic matter content. In addition to fertility, slope was also a limiting factor in the moderately suitable (S2) area. To address the fertility constraints, soil amendments such as the addition of agricultural lime and organic fertilizers could be applied to improve soil fertility.

Data Availability Statement: The data from this study are available upon request; please contact the corresponding author for replicability and transparency reasons.

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