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Assessment of Land Suitability in Highly Area of Ende, East Nusa Tenggara, Indonesia, as a Basic Strategy for Growing Coffee (*Coffea arabica*)

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ABSTRAK/ABSTRACT

Penilaian kesesuaian lahan di Wilayah Ende, Nusa Tenggara Timur, Indonesia, sebagai strategi dasar menanam kopi (*Coffea arabica*)

Kecamatan Ende, Nusa Tenggara Timur, memiliki beragam topografi dengan ketinggian 0-1.100 m dpl yang berpotensi untuk budidaya kopi Arabika. Namun, sejauh ini belum ada ketersediaan informasi mengenai kesesuaian lahan untuk komoditas tersebut. Penelitian bertujuan untuk mengevaluasi kesesuaian lahan aktual untuk kopi Arabika berdasarkan karakteristik tanah dan lingkungan. Metode penelitian adalah deskriptif eksploratif melalui pendekatan survei lapangan yang didukung dengan analisis laboratorium. Penentuan Satuan Peta Tanah (SPT) dilakukan dengan metode *purposive sampling* melalui pengeboran di 31 titik, kemudian diklasifikasikan berdasarkan jenis tanah untuk memperoleh lima pedon yang mewakili SPT di Kecamatan Ende. Pengambilan sampel tanah dilakukan pada setiap lapisan pada setiap pedon. Analisis data menggunakan uji ANOVA dan korelasi Pearson untuk menemukan faktor penentu yang memengaruhi kelas kesesuaian lahan untuk kopi Arabika. Hasil evaluasi menunjukkan bahwa kesesuaian lahan aktual untuk kopi Arabika termasuk dalam kelas kesesuaian marginal (S3) dan tidak sesuai (N), dengan faktor pembatas suhu rata-rata, ketinggian, lamanya periode kering, drainase, kejenuhan basa, P tersedia, kemiringan lereng dan bahaya erosi. Hasil uji ANOVA menunjukkan bahwa ketinggian tempat secara signifikan memengaruhi kelas kesesuaian lahan, dengan kelas kesesuaian lahan terbaik pada ketinggian 800-1.100 m dpl. Berdasarkan korelasi antara kelas kesesuaian lahan dengan parameter karakteristik lahan, diperoleh bahwa faktor penentu kelas kesesuaian lahan adalah suhu rata-rata, kelembapan, drainase, tekstur, material kasar, total N, K tersedia, bahaya erosi, batuan permukaan, dan singkapan batuan. Upaya perbaikan lahan yang direkomendasikan untuk meningkatkan kelas kesesuaian lahan adalah pembuatan sistem irigasi, penyediaan tanaman peneduh, pemupukan N (urea) dan K (KCl), dan pembuatan terasering.

Keywords:
Actual land suitability, Coffee cultivation, Land improvement recommendation, Land suitability class, Soil characteristics

Ende Sub-District, East Nusa Tenggara, has various topographies with an altitude of 0-1,100 m asl that can potentially grow Arabica coffee. Still, there is no information available regarding the suitability of the land. This study aims to evaluate the actual land suitability of Arabica coffee based on soil and environmental characteristics. The research method is descriptive explorative through a field survey approach supported by laboratory analysis.

Determination of Soil Map Unit (SMU) was carried out using a purposive sampling method through boring at 31 points, then classified based on soil type to obtain five pedons that represent SMU in Ende Sub-District. Soil sampling was carried out on each layer of each pedon. Data analysis used ANOVA and Pearson correlation tests to determine the determining factors that influence the land suitability class of Arabica coffee. The evaluation results showed that the actual land suitability for Arabica coffee was marginally suitable (S3) and unsuitable (N) classes, with limiting factors, i.e. average temperature, altitude, length of dry period, drainage, base saturation, available P, slope, and erosion hazard. The results of the ANOVA test showed that altitude significantly affected the land suitability class for Arabica coffee, with the best land suitability class at an altitude of 800-1,100 m asl. Based on the correlation between land suitability class and land characteristic parameters, the determining factors for land suitability class include average temperature, humidity, drainage, texture, coarse material, total N, available K, erosion hazard, surface rocks, and rock outcrops. Land improvement recommendations are based on making an irrigation system, providing shade plants, N fertilization (urea fertilizer), K fertilization (KCl fertilizer), and terracing.

INTRODUCTION

Coffee is one of the strategic export commodities that plays an essential role in the national economy and the development of the plantation industry in Indonesia. Indonesia is one of the world's largest coffee-producing and exporting countries (Hall *et al.*, 2022). Coffee is a key commodity in Indonesia's plantation sub-sector, with strong demand both in domestic and international markets (Sihombing *et al.*, 2021). In 2022, Indonesian coffee exports increased by 12.99% compared to the previous year, with a total volume reaching 437.56 thousand tons (BPS-Statistics of Indonesia, 2023). Indonesian Arabica coffee has a distinctive taste, so it is in great demand, and export demand is relatively high (Najwa *et al.*, 2024). Indonesia's geographical advantages in the tropical zone and its many mountainous areas make this region very suitable for coffee cultivation (Purwadi, 2021).

However, coffee production in Indonesia still faces various challenges. This problem is related to the fact that a comprehensive land suitability study in Ende has not been conducted in terms of soil characteristics and climate conditions. This condition impacts low efficiency and productivity in developing coffee commodities at the national level. Coffee land productivity in Indonesia is still relatively low, and there is limited land suitable for cultivation, even though it has a large area. Meanwhile, Vietnam can maximize its land potential through technology, resulting in much higher coffee productivity. This is due to appropriate land management and cultivation techniques. Therefore, proper land management efforts are needed to increase the productivity of coffee cultivation in Indonesia (Suryana *et al.*, 2024).

One of the areas with potential for coffee development is the Ende Sub-District, Ende Regency, East Nusa Tenggara Province. This area has fertile hilly and valley topography and environmental conditions that support the growth of coffee plants (Mari, 2022). Coffee production in Ende Regency in 2022-2024 increased, consecutively recorded at 3,440.23 tons, 3,470.00 tons, and 3,484.00 tons (BPS-Statistics of Ende Regency, 2025). The Ende Sub-District has great potential for developing coffee cultivation. Still, until now, no information is available regarding the analysis of land suitability for Arabica coffee plants (*Coffea arabica*) in the area.

Land suitability information is important considering that each land has various characteristics that determine the level of suitability for certain commodities (Ratih, 2024; Budiman *et al.*, 2024). Land suitability studies are needed to optimize land use, increase productivity, and support sustainable agricultural management. Therefore, this study evaluated land suitability for Arabica coffee cultivation in Ende Sub-District as a basis for optimal planning and developing coffee commodities (Raeni *et al.*, 2023). This study aimed to identify the suitability of Arabica land, to determine the determining factors, and to provide recommendations for appropriate land management. Research on land suitability for Arabica coffee plants

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in Eastern Indonesia can encourage the development of remote areas by identifying suitable land to become new centers for Arabica coffee production.

MATERIALS AND METHODS

Research Area Description

The research was conducted in Ende Sub-District, Ende Regency, East Nusa Tenggara (Fig. 1). The geographical location of Ende Sub-District is at 8°39'5.60" LS — 8°48'43" LS and 121°32'15.50" BT — 121°42'8.20" BT. Based on data from the BPS-Statistics of Ende Regency (2024), Ende Sub-District is located in the northern part of the capital of Ende Regency with an area of 170.98 km^2. Ende Sub-District has diverse geographical conditions with topography consisting of coastal areas, lowlands, and hills. This area generally ranges from 0-1,100 m asl, with the dominant areas are at an altitude of 229 to 500 m asl. The diverse topography gives an area a variety of soil types with different characteristics. Ende Sub-District has a relatively dry tropical climate, with moderate rainfall intensity. Climate conditions affect the local community's lifestyle, especially in the agricultural and plantation sectors, which depend on rainfall. Based on the Ende Regency Regional Regulation Number 1 of 2023 concerning the Ende Regency Spatial Plan for 2023-2042, Ende Sub-District is a strategic development area for agricultural and plantation areas. One of the plantation commodities that can be developed as a superior commodity in the Ende Sub-District is coffee.

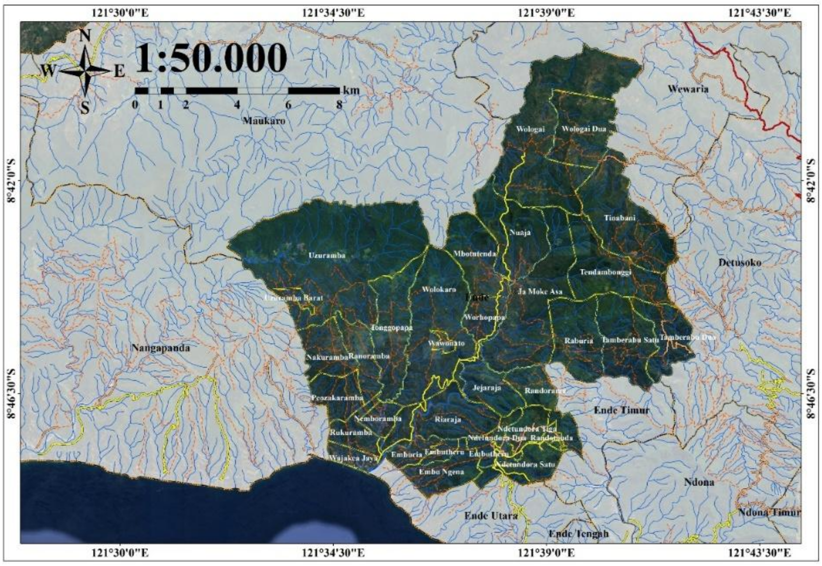

Figure 1. Administrative map of Ende Sub-District.

Research Design

This quantitative descriptive research used a field survey approach supported by laboratory analysis results. Research planning was carried out through literature studies and secondary data collection to compile a working map based on contours with 100-meter intervals. The determination of sampling points using the transect method cut the contour perpendicularly, and as many as 31 points can be seen in Fig. 2 to obtain a tentative Soil Map Unit (SMU) representing the Ende Sub-District contour. The field survey consisted of two stages, namely boring and pedon. Soil type was identified through rapid fingerprint analysis by collecting soil samples using an boring to a depth of 120 cm. Determination of pedons was carried out based on tentative SMU using a purposive sampling method that adjusted to field conditions. Soil sampling through pedons was carried out at each horizon for laboratory analysis.

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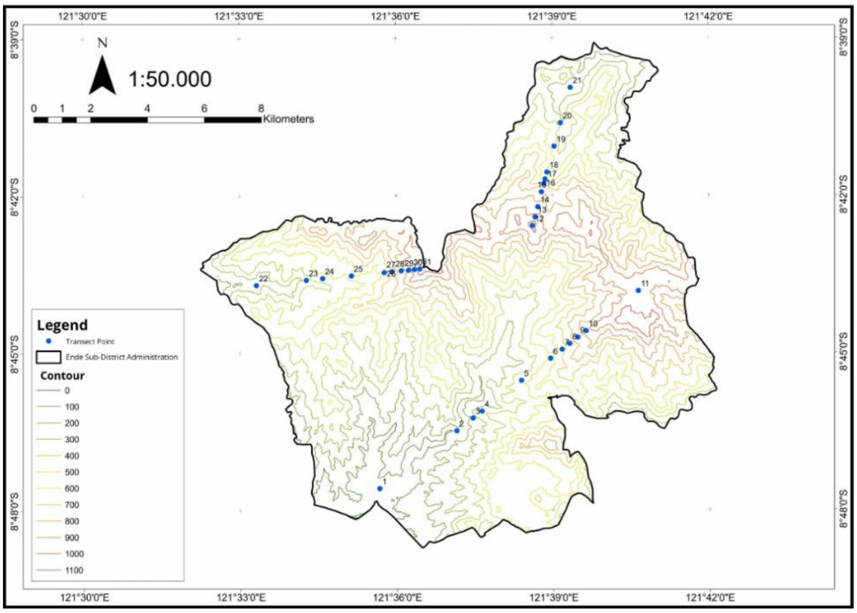

Figure 2. Work map (sampling point) of the Ende Sub-District.

Soil Analysis

Soil analysis in the laboratory, such as pH H_2O, pH NaF, CEC, base saturation, C-Organic, N-total, P-available, K-available, electrical conductivity, and soil texture using soil samples from each pedon layer. The indicators and methods used in laboratory analysis are based on Table 1.

Soil drainage analysis categorized soils into seven classes based on their hydraulic conductivity and water retention capacity. These range from excessively drained soils, which lose water too quickly for most crops, to very poorly drained soils, which remain saturated and can only support water-tolerant species. This classification is essential for evaluating land suitability and guiding agricultural use. Erosion hazard analysis was assessed by measuring the annual loss of topsoil, which was classified into five categories: very light (<0.15 cm/year), light (0.15–0.9 cm/year), moderate (0.9–1.8 cm/year), severe (1.8–4.8 cm/year), and very severe (>4.8 cm/year). The evaluation considered sheet, rill, and gully erosion, as well as the vulnerability of the A horizon, which is generally more susceptible due to its relatively high organic matter content. Greater soil loss indicates a higher erosion hazard, which can significantly reduce land quality and agricultural productivity.

The measurement of surface rock fragments and rock outcrops was conducted through visual field observation using sample plots, with results expressed as surface cover percentages. Surface rock fragments were estimated based on the proportion of soil area covered by loose rock fragments, while rock outcrops were determined from the proportion of land surface entirely exposed as solid bedrock without soil cover.

Table 1. Soil properties and methods

Soil properties	Parameters	Methods
Physics	Soil texture	Pipette
Chemistry	pH H_20	Electrometry
	pH NaF	Electrometry
	CEC (cation exchange capacity)	Ammonium acetate extraction
	Base saturation	Ammonium acetate extraction
	Organic-C	Walkley and Black
	Total-N	Kjeldahl
	P_2O_5	Olsen
	K_2O	Ammonium acetate extraction
	DHL (salinity)	Conductometer

*Sources: BPSI Soil and Fertilizer (2023).

Data Analysis

The analyzed data was used to determine the type of soil, the land suitability class, and its limiting factors using the matching and scoring methods based on land conditions and growing requirements for Arabica coffee plants. Determination of actual land suitability was carried out using matching and scoring method, which compared land qualities with crop's growth requirements (Marianto *et al.*, 2022). Land suitability criteria for Arabica coffee plants are presented in Table 2.

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Table 2. Land suitability criteria for Arabica coffee plants

Land use requirements/characteristics	Land suitability class			
	S1	S2	S3	N
Temperature (tc)				
Average temperature (°C)	16-20	15-16	14-15	< 14
		20-22	22-24	> 24
Altitude asl (m)	1,000-1,500	1,500-1,700	1,700-2,000	> 2,000
		700-1,000	500-700	< 500
Water availability (wa)				
Rainfall (mm)	1,200-1,800	1,000-1,200	2,000-3,000	> 2,000
		1,800-2,000	800-1,000	< 800
Length of dry period (months)	1-4	< 1	5-6	> 6
		4-5		
		30-40	20-30	< 20
Humidity (%)	40-70	70-80	80-90	> 90
Oxygen availability (oa)				
Drainage	Good	Moderate	Low hampered, Rather fast	Hampered, Very hampered, Fast
Root capacity (rc)				
Texture	Fine, Slightly fine, Moderate	Fine, Slightly fine, Moderate	Moderately coarse	Coarse, Very coarse
Coarse material (%)	< 15	15-35	35-60	> 60
Soil depth	> 100	75-100	50-75	< 50
Peat				
Thickness (cm)	< 100	100-200	200-300	> 300
Maturity	Saprik	Saprik, hemik	Hemik	Fibrik
Nutrient retention (nr)				
CEC (cmol)	> 16	5-16	< 5	
Base saturation (%)	> 50	35-50	< 35	
pH H_20	5.6-6.6	6.6-7.3	< 5.5 ; > 7.4	
Organic-C (%)	> 2.0	0.8-2.0	< 0.8	
Nutrient availability (na)				
Total-N (%)	Moderate	Low	Very low	-
P_2O_5 (mg/100g)	High	Moderate	Low-Very low	-
K_2O (mg/100g)	Moderate	Low	Very low	-
Toxicity (xc)				
Salinity (dS/m)	< 0,5	-	0,5-2	> 2
Sodicity (xn)				
Alkalinity/ESP (%)	-	-	-	-
Erosion hazard (eh)				
Slope (%)	< 8	8-15	15-30	> 30
Erosion hazard	Very low	Low-Moderate	High	Very high
Danger of flooding/puddles during planting (fh)				
High (cm)	-	-	-	25
Period (day)	-	-	-	< 7
Land preparation (lp)				
Surface rocks (%)	< 5	5-15	15-40	> 40
Rock outcrops (%)	< 5	5-15	15-25	> 25

Source: Ritung *et al.*, 2011.

ANOVA test with a 95% confidence level was conducted to determine the effect of altitude on land suitability classes for Arabica coffee plants, followed by Duncan's Multiple Range Test (DMRT) to determine if there was a significant difference. A correlation test was conducted to determine the relationship between land characteristic parameters and land suitability classes used as determining factors. The study results were a land suitability map with a scale of 1:50,000 created using ArcGIS software and land management recommendations based on determining factors in developing coffee cultivation in Ende Sub-District, Ende Regency, East Nusa Tenggara.

RESULTS AND DISCUSSION

Land Classification in the Ende Sub-District Research Area

The soil classification results in the Ende Sub-District showed three soil types: Inceptisols, Alfisols, and Andisols (Table 3). The three soil types are spread across four soil map units (SMU) with heights ranging from 0 to 1,100 meters above sea level (masl). Differences in altitude can cause differences in climate conditions, especially temperature and humidity. Fitriyani *et al.* (2023) stated that differences in climate are one of the main factors influencing the soil formation process.

Table 3. Results of soil type classification in Ende Sub-District

Pedon	Soil map units	Soil type	Altitude (m asl)	Total area (ha)	Area proportion
Pedon 1 and 5	SMU 1	Inceptisols	0-900	11,012.21	66%
Pedon 2	SMU 2	Alfisols	800-1,100	1,572.03	10%
Pedon 3	SMU 3	Andisols	800-1,100	1,294.01	8%
Pedon 4	SMU 4	Inceptisols	100-900	2,616.89	16%

Source: Field analysis results in Ende Sub-District.

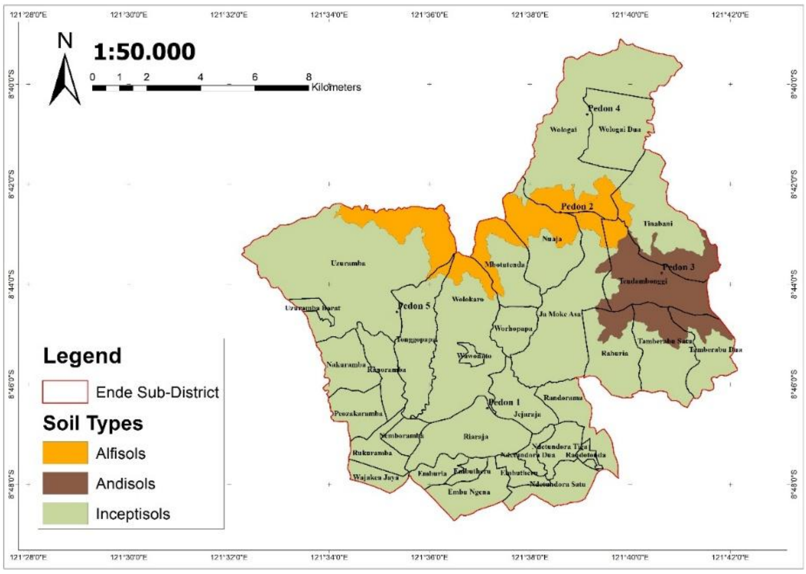
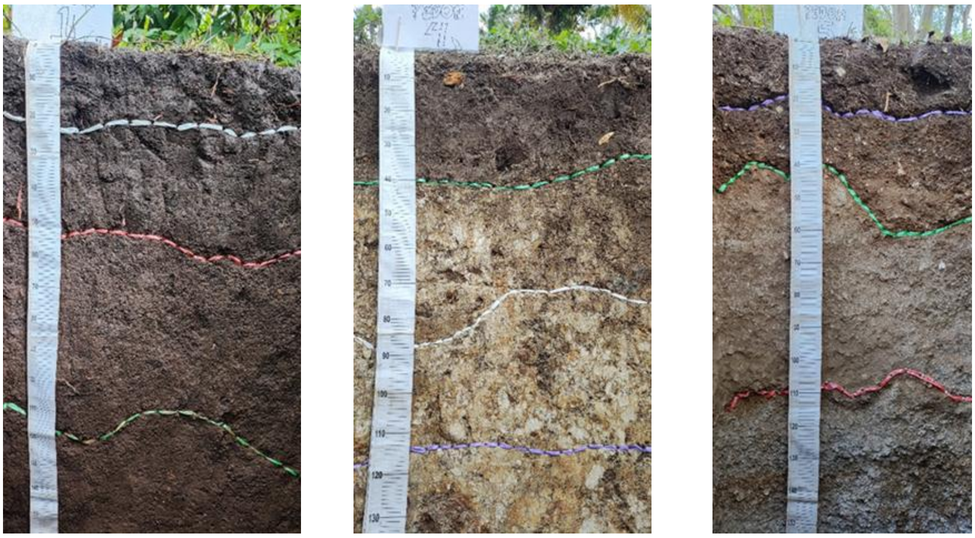


Figure 3. Ende Sub-District land map unit.

The field survey results through five pedon analyses showed that the research location has three types of soil in four soil map units (SMU) with different location heights (Fig. 3)—description of the three soil orders Inceptisols, Alfisols, and Andisols in Ende Sub-District as explained.

1. Inceptisols

   Inceptisols were found in SMU 1 (pedons 1 and 5) and SMU 4 (pedon 4), characterized by the development of young soil horizons, dominant sandy loam texture, and moderate coarse material content (35–60%) (Fig. 4). Inceptisols are young and newly developed soils, usually having a texture ranging from coarse to fine, depending on the level of weathering of the parent material. This soil type dominated the Ende Sub-District with an area of 13,629.1 ha. Inceptisols have a soil pH that tends to be acidic to neutral and low nutrient content (Widijanto *et al.*, 2023), making it less than optimal for Arabica coffee without land improvement.



(a) (b) (c)

Figure 4. Inceptisols (a = pedon 1; b = pedon 4; c = pedon 5).

2. Alfisols

Alfisols were found in SMU 2 (pedon 2) at around 800–1,100 m asl altitude (Figure 5). The presence of a Bt horizon characterizes Alfisols due to clay accumulation, base saturation >35%, and a pretty good fertility level. Alfisols are soils with the main characteristic of experiencing a lot of clay accumulation, causing the density of this soil to be high (Sulistiawati *et al.*, 2023).

Figure 5. Alfisols (pedon 2).

3. Andisols

Andisols were found in SMU 3 (pedon 3) with an area of 1,294.01 ha. Andisols, widely distributed throughout Indonesia, exhibit remarkable fertility characteristics that make them promising soils for cultivating arabika coffee (Karimah *et al.*, 2024). This soil comes from volcanic ash weathering and has a pH of NaF> 9.4, indicating the dominance of amorphous minerals such as allophane and imogolite. The soil texture is clay loam, has a crumb structure, and has a high organic matter content (> 2%). Andisols have a dark black color with a crumb structure, loose consistency, high organic matter content, and have smeary properties (Fig. 6).

Figure 6. Andisols (pedon 3).

Arabica Coffee Land Suitability Class

Land suitability evaluation was carried out using the matching and scoring method between actual soil characteristics and Arabica coffee growing requirements based on the criteria of Ritung *et al.* (2011). Arabica coffee plants have specific growing requirements, especially regarding altitude, humidity, and temperature factors. Arabica coffee plants can grow well in highlands with a tropical climate (Susilo & Wicaksono, 2023). The results of the land suitability evaluation for Arabica coffee plants in each pedon in Ende Sub-District can be seen in Table 4-8.

Table 4. Evaluation of land suitability for Arabica coffee plants on pedon 1

Land use requirements/characteristics	Analysis results	Actual land suitability class		Improvement efforts	Potential land suitability class
Temperature (tc)			N	-	N
Average temperature (°C)	20.90-26.30	N			
Altitude asl (m)	0-900	N			
Water availability (wa)			S3		S3
Rainfall (mm)	1,102	S2			
Length of dry period (month)	5,60	S3			
Humidity (%)	65,80	S1			
Oxygen availability (oa)			S3		S3
Drainage	rather fast	S3			
Root capacity (rc)			S3		S3
Texture	moderately coarse	S3			
Coarse material (%)	35-60	S3			
Soil depth	155	S1			
Peat:			-		-
Thickness (cm)	-	-			
Maturity	-	-			
Nutrient retention (nr)			S2		S2
CEC (cmol)	18.71	S1			
Base saturation (%)	38.33	S2			
pH H_20	7.28	S2			
Organic-C (%)	2.26	S1			
Nutrient availability (na)			S3		S3
Total-N (%)	0.24	S1			
P_2O_5 (mg/100g)	3.70	S3			
K_2O (mg/100g)	0.34	S2			
Toxicity (xc)			S1		S1
Salinity (dS/m)	0.13	S1			
Sodicity (xn)			-		-
Alkalinity/ESP (%)	-	-			
Erosion hazard (eh)			S2		S2
Slope (%)	8-15	S2			
Erosion hazard	moderate	S2			
Danger of flooding/puddles during planting (fh)			S1		S1
High (cm)	-	S1			
Period (day)	-	S1			
Land preparation (lp)			S2		S2
Surface rocks (%)	5-15	S2			
Rock outcrops (%)	< 5	S1			
Assessment Results		N (tc)			N (tc)

Information:

- \- No improvement can be made
- \+ Improvements can be made and will result in a promotion to one level higher (S3 to S2)
- ++ Promotion to two levels higher (S3 to S1)
- +++ Promotion to a third grade higher (N to S1)

Table 5. Evaluation of land suitability for Arabica coffee plants on pedon 2

Land use requirements/characteristics	Analysis results	Actual land suitability class		Improvement efforts	Potential land suitability class
Temperature (tc)					
Average temperature (°C)	19.70-21.50	S2	S2		S2
Altitude asl (m)	800-1100	S2			
Water availability (wa)					
Rainfall (mm)	1,102	S2	S3	+	S2
Length of dry period (month)	5.60	S3			
Humidity (%)	71.90	S2			
Oxygen availability (oa)			S3	+	S2
Drainage	low hampered	S3			
Root capacity (rc)					
Texture	fine	S1	S2		S2
Coarse material (%)	< 15	S1			
Soil depth	82	S2			
Peat:					
Thickness (cm)	-	-	-		-
Maturity	-	-			
Nutrient retention (nr)					
CEC (cmol)	28.81	S1			
Base saturation (%)	35.90	S2	S2		S2
pH $H_2 0$	5.73	S1			
Organic-C (%)	4.84	S1			
Nutrient availability (na)					
Total-N (%)	0.28	S1	S3	++	S1
P_2O_5 (mg/100g)	0.62	S3			
K_2O (mg/100g)	0.81	S1			
Toxicity (xc)			S1		S1
Salinity (dS/m)	0.09	S1			
Sodicity (xn)			-		-
Alkalinity/ESP (%)	-	-			
Erosion hazard (eh)					
Slope (%)	15-30	S3	S3	+	S2
Erosion hazard	high	S3			
Danger of flooding/puddles during planting (fh)			S1		S1
High (cm)	-	S1			
Period (day)	-	S1			
Land preparation (lp)					
Surface rocks (%)	< 5	S1	S1		S1
Rock outcrops (%)	-	-			
Assessment Results		S3 (wa, oa, na, eh)			S2 (tc, wa, oa, rc, nr, eh)

Information:

- \- No improvement can be made
- \+ Improvements can be made and will result in a promotion to one level higher (S3 to S2)
- ++ Promotion to two levels higher (S3 to S1)
- +++ Promotion to a third grade higher (N to S1)

Table 6. Evaluation of land suitability for Arabica coffee plants on pedon 3

Land use requirements/characteristics	Analysis results	Actual land suitability class		Improvement efforts	Potential land suitability class
Temperature (tc)					
Average temperature (°C)	19.70-21.50	S2	S2		S2
Altitude asl (m)	800-1100	S2			
Water availability (wa)					
Rainfall (mm)	1,102	S2	S3	+	S2
Length of dry period (month)	5.60	S3			
Humidity (%)	72.20	S2			
Oxygen availability (oa)			S1		S1
Drainage	good	S1			
Root capacity (rc)					
Texture	slightly	S2	S2		S2
Coarse material (%)	fine 15-35	S2			
Soil depth	160	S1			
Peat:					
Thickness (cm)	-	-	-		-
Maturity	-	-			
Nutrient retention (nr)					
CEC (cmol)	24.92	S1			
Base saturation (%)	21.23	S3	S3	++	S1
pH H20	6.15	S1			
Organic-C (%)	3.29	S1			
Nutrient availability (na)					
Total-N (%)	0.35	S1			
P_2O_5 (mg/100g)	0.19	S3	S3	++	S1
K_2O (mg/100g)	0.38	S1			
Toxicity (xc)			S1		S1
Salinity (dS/m)	0.08	S1			
Sodicity (xn)			-		-
Alkalinity/ESP (%)	-	-			
Erosion hazard (eh)					
Slope (%)	15-30	S3	S3	+	S2
Erosion hazard	high	S3			
Danger of flooding/puddles during planting (fh)			S1		S1
High (cm)	-	S1			
Period (day)	-	S1			
Land preparation (lp)					
Surface rocks (%)	< 5	S1	S1		S1
Rock outcrops (%)	-	-			
Assessment Results		S3 (wa, nr, na, eh)			S2 (tc, wa, rc, eh)

Information:

- \- No improvement can be made
- \+ Improvements can be made and will result in a promotion to one level higher (S3 to S2)
- ++ Promotion to two levels higher (S3 to S1)
- +++ Promotion to a third grade higher (N to S1)

Table 7. Evaluation of land suitability for Arabica coffee plants on pedon 4

Land use requirements/characteristics	Analysis results	Actual land suitability class		Improvement efforts	Potential land suitability class
Temperature (tc)					
Average temperature (°C)	20.90-25.70	N	N	-	N
Altitude asl (m)	100-900	N			
Water availability (wa)					
Rainfall (mm)	1,102	S2	S3		S3
Length of dry period (month)	5.60	S3			
Humidity (%)	67.60	S1			
Oxygen availability (oa)			S3		S3
Drainage	rather fast	S3			
Root capacity (rc)					
Texture	moderately coarse	S3	S3		S3
Coarse material (%)	35-60	S3			
Soil depth	62	S3			
Peat:					
Thickness (cm)	-	-	-		-
Maturity	-	-			
Nutrient retention (nr)					
CEC (cmol)	23.03	S1			
Base saturation (%)	24.68	S3	S3		S3
pH H_20	6.31	S1			
Organic-C (%)	2.51	S1			
Nutrient availability (na)					
Total-N (%)	0.18	S2	S3		S3
P_2O_5 (mg/100g)	0.42	S3			
K_2O (mg/100g)	0.23	S2			
Toxicity (xc)			S1		S1
Salinity (dS/m)	0.06	S1			
Sodicity (xn)			-		-
Alkalinity/ESP (%)	-	-			
Erosion hazard (eh)					
Slope (%)	8-15	S2	S2		S2
Erosion hazard	moderate	S2			
Danger of flooding/puddles during planting (fh)			S1		S1
High (cm)	-	S1			
Period (day)	-	S1			
Land preparation (lp)					
Surface rocks (%)	5-15	S2	S2		S2
Rock outcrops (%)	5-15	S2			
Assessment Results		N (tc)			N (tc)

Information:
- \- No improvement can be made
- \+ Improvements can be made and will result in a promotion to one level higher (S3 to S2)
- ++ Promotion to two levels higher (S3 to S1)
- +++ Promotion to a third grade higher (N to S1)

Table 8. Evaluation of land suitability for Arabica coffee plants on pedon 5

Land use requirements/characteristics	Analysis results	Actual land suitability class		Improvement efforts	Potential land suitability class
Temperature (tc)					
Average temperature (°C)	20.90-25.10	N	N	-	N
Altitude asl (m)	200-900	N			
Water availability (wa)					
Rainfall (mm)	1,102	S2	S3		S3
Length of dry period (month)	5.60	S3			
Humidity (%)	68.80	S1			
Oxygen availability (oa)			S3		S3
Drainage	rather fast	S3			
Root capacity (rc)					
Texture	moderately coarse	S3	S3		S3
Coarse material (%)	35-60	S3			
Soil depth	66	S3			
Peat:					
Thickness (cm)	-	-	-		-
Maturity	-	-			
Nutrient retention (nr)					
CEC (cmol)	20.21	S1			
Base saturation (%)	37.80	S2	S2		S2
pH H2O	6.70	S2			
Organic-C (%)	5.70	S1			
Nutrient availability (na)					
Total-N (%)	0.28	S1	S3		S3
P_2O_5 (mg/100g)	4.60	S3			
K_2O (mg/100g)	0.32	S2			
Toxicity (xc)			S1		S1
Salinity (dS/m)	0.23	S1			
Sodicity (xn)			-		-
Alkalinity/ESP (%)	-	-			
Erosion hazard (eh)					
Slope (%)	15-30	S3	S3		S3
Erosion hazard	high	S3			
Danger of flooding/puddles during planting (fh)			S1		S1
High (cm)	-	S1			
Period (day)	-	S1			
Land preparation (lp)					
Surface rocks (%)	5-15	S2	S2		S2
Rock outcrops (%)	5-15	S2			
Assessment Results		N (tc)			N (tc)

Information:
- \- No improvement can be made
- \+ Improvements can be made and will result in a promotion to one level higher (S3 to S2)
- ++ Promotion to two levels higher (S3 to S1)
- +++ Promotion to a third grade higher (N to S1)

Land suitability evaluation serves as a fundamental basis for land use planning and informed decision-making processes (Rendana *et al.*, 2022). Based on the land suitability assessment results, the land suitability criteria for Arabica coffee plants in Ende Sub-District are included in class S3 (marginally suitable) and N (not suitable). The limiting factors of each pedon as a whole include temperature (tc), water availability (wa), oxygen availability (oa), nutrient retention (nr), nutrient availability (na), and erosion hazard (eh). The results of the land suitability assessment are presented in the form of a land suitability class map for Arabica coffee as shown in Fig. 7.

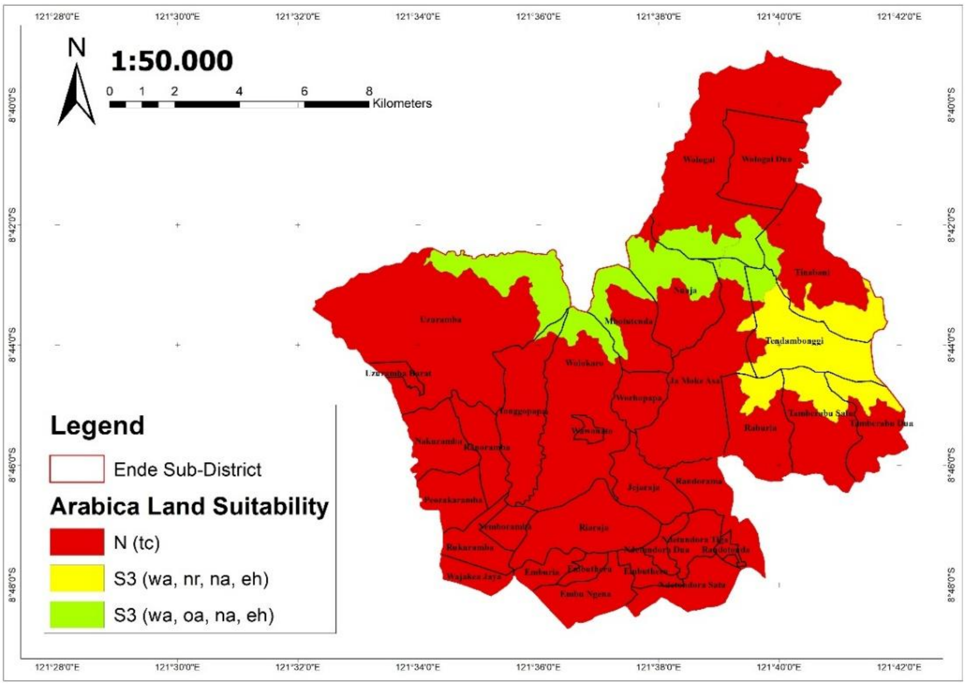


Figure 7. Actual land suitability map for Arabica coffee in Ende Sub-District

Distribution of Arabica Coffee Land Suitability at Various Altitudes

Altitude is included in the environmental morphology that plays an essential role in supporting the growth and productivity of Arabica coffee cultivation. An One-way ANOVA test was conducted to determine the effect of various altitudes on the land suitability class for Arabica coffee plants (Nirwanto *et al.*, 2024). The results of the ANOVA test showed a significant effect, so further testing was needed using the DMRT test (Wilujeng *et al.*, 2021). The results of the ANOVA and DMRT test of altitude on Arabica coffee land suitability classes are shown in Tables 9 and 10.

Table 9. Results of the ANOVA test of altitude on Arabica coffee suitability class

ANOVA[a]					
	Sum of squares	df	Mean square	F	Sig.
Regression	2063.600	3	11,012.21	46.326	0.000[b]
Residual	163.333	11	1,572.03		
Total	2226.933	14			

Information: a = Dependent variable: Arabica Coffee Suitability Class. b = Factor: Altitude.

Table 10. DMRT further test results for Arabica coffee land suitability classes at various altitudes

Altitude asl (m)	Land suitability class
0-900	Pedon 1 (b) (N; tc)
100-900	Pedon 4 (c) (N; tc)
200-900	Pedon 5 (b) (N; tc)
800-1100	Pedon 2 (a) (S3; wa, oa, na, eh)
800-1100	Pedon 3 (a) (S3; wa, nr, na, eh)

Information: Numbers followed by different letters indicate significant differences in the DMRT test with an α level of 0.05. Source: Analysis results, 2025.

The results of the DMRT further test indicate significant differences in various altitudes towards the Arabica land suitability class. This difference shows that higher altitudes have a significant effect on increasing the Arabica land suitability class. Altitudes between 800-1,100 meters above sea level show the same letter notation for the Arabica coffee land suitability class, including category S3 with limiting factors in the form of water availability, drainage, nutrient retention, nutrients, and erosion hazards. Arabica coffee plants can grow and develop well at altitudes around 1,000-1,500 m asl (S1) (Ritung *et al.*, 2011). Conversely, at lower altitudes between 0-900 m asl, the land suitability class for

Arabica coffee plants is included in category N. At these altitudes, different letter notations are shown due to the location of the pedon (SMU 1 for pedons 1 and 5) and (SMU 4 for pedon 4), so they have different soil and microclimate factor limitations. The optimal height for Arabica coffee plants ranges from 1,000 to 1,700 m asl. The plants are susceptible to leaf rust disease if they are less than 1,000 meters above sea level (Fiqhry *et al.*, 2024).

Determining Factors of Arabica Coffee Land Suitability Class

The results of the correlation analysis (Table 11) show that several land characteristic indicators are determining factors for the Arabica land suitability class, including average temperature, humidity, drainage, texture, coarse material, total N, Available K, erosion hazard, surface rocks, and rock outcrops. These land characteristic indicators show a significant relationship to the Arabica coffee land suitability class, both positive and negative.

Table 11. Results of correlation analysis of land characteristic indicators with Arabica coffee land suitability class (N= 30)

Indicator	Correlation Coefficient (r)
Average temperature	-0.73**
Humidity	0.77**
Drainage	-0.90**
Texture	-0.63*
Coarse Material	-0.78**
Total-N	0.61*
K_2O	0.85**
Erosion Hazard	-0.77**
Surface Rocks	-0.84**
Rock Outcrops	-0.56*

Information: N = Total sample; * significant correlation at 0.05 level; ** very significant correlation at 0.01 level.

The average temperature shows a negative correlation (r = -0.73**) with the land suitability class, which means that an increase in temperature can reduce the land suitability class for Arabica coffee plants. Efandri and Vauzia (2025) stated that the decrease in average temperature also increases with increasing altitude, but the air humidity is getting higher. Humidity shows a positive correlation (r = 0.77**), meaning that increasing humidity in an area can increase the land suitability class for Arabica coffee. Arabica coffee plants cannot grow optimally in areas with high temperatures and low humidity. Air temperature and humidity are influenced by altitude, the higher a place is, the lower the air temperature will be and the air humidity can increase (Adimas *et al.*, 2023).

The results of the correlation analysis of drainage with the land suitability class of Arabica coffee showed a negative correlation coefficient (r = -0.90**), which means that poor drainage conditions (e.g. too slow or flooded) will reduce land suitability. Arabica coffee plants require conditions with adequate oxygen availability, so a good drainage system is needed (Dahlia *et al.*, 2021). Texture has a negative correlation coefficient value (r = -0.63*), meaning that non-ideal soil texture (e.g., too coarse or very fine) indicates a low land suitability class. Topographic characteristics, including altitude, significantly affect the distribution of soil texture (Setiawan & Arifin, 2023). Altitude affects the distribution of soil texture through erosion, deposition, and translocation, soil type also affects differences in soil texture.

Coarse material has a negative correlation coefficient (r = -0.78**), indicating that the higher the coarse material content, the lower the suitability class of Arabica coffee land. Inceptisol soil types mostly dominate the area in the Ende Sub-District. Inceptisols are dominated by minerals with coarse fractions (Nainggolan, 2024), such as manganese, which is often found in the form of manganese oxide, which can be contained in coarse particles (rocks and gravel) (Ruqqqayya, 2024). A high percentage of coarse material can reduce the soil's ability to store water and nutrients, thus impacting the suitability of Arabica coffee land. The nutrients determining factors in the suitability class of Arabica coffee land are total-N and available K. The results of the correlation analysis showed a positive correlation coefficient for total N (r = 0.61*) and available K (r = 0.85**), which means that the higher the total-N and available K content in the soil, the higher the land suitability class for Arabica coffee plants. Maulana *et al.* (2024) stated that at higher altitudes, the accumulation of organic matter in the soil increases, which can be associated with various environmental factors. The quality of other nutrients such as organic matter, influences total-N and available K levels. The levels of N and K in the soil result from the decomposition of organic matter (Febriantika *et al.*, 2022).

Erosion hazard, surface rocks, and rock outcrops are indicators of land characteristics included in the interrelated topographic factors and affect the suitability class of Arabica coffee land. Erosion hazard is negatively correlated (r = -0.77**) to the Arabica coffee land suitability level, indicating that the steeper the slope, the greater the risk of erosion hazard, and indicating a low land suitability class for Arabica coffee plants. Altitude and slope gradient play a role in controlling the surface flow rate and erosion (Krisnawati *et al.*, 2022). Many surface rocks can occur due to intense erosion processes on steep slopes. Surface rocks and rock outcrops have negative correlation coefficient values (r = -0.84**) and (r = -0.56*). Saputra *et al.* (2022) stated that steep slopes have the potential for erosion that carries small rocks, such as gravel to lower places. Hilly topography is mainly found with rock outcrops (Reza *et al.*, 2024). Both indicators show that a high percentage of surface rocks and rock outcrops can reduce the land suitability class for Arabica coffee plants.

Land Management Recommendations for Arabica Coffee Development in Ende Sub-District

Actual land suitability improvement efforts can improve land characteristics in the most ideal conditions, so that there are only fixed limiting factors that are difficult to improve. Apart from the limiting factors that affect the land suitability class for Arabica coffee plants, there are also determining factors for the Arabica land suitability class. Land management that can be done to improve the determining factors for slope gradient and erosion hazard is terracing. Findayani *et al.* (2024) revealed that terracing changes slopes into terraces that reduce the speed of surface water flow, so that water will be retained and absorbed into the soil. Land management can be used to increase the percentage of air humidity by providing shade plants. Eliyin *et al.* (2024) explained that shade plants protect coffee plants from excessive exposure to sunlight and help maintain humidity and reduce the risk of erosion. Providing shade plants also controls weed growth and prevents coffee plants from wind shocks. Shade trees commonly used in coffee plantations include lamtoro, avocado, and sengon.

Efforts made to improve the determining factors of drainage are the creation of irrigation systems, including at the medium level of land management. The creation of irrigation systems improves land quality by providing sufficient water availability for plants (Mangkunegara & Firdamayanti, 2021). Irrigation systems can provide sufficient water availability for Arabica coffee plants. Available nutrient indicators, especially total N and available K, determine the suitability class of Arabica coffee land. Land management efforts to improve land suitability classes are carried out by fertilizing N and K at a high level of land management. Proper fertilization is needed to improve the harvest quality and achieve high coffee production efficiency. Low N elements in the soil can be enhanced by administering urea fertilizer, while soil lacking K elements can be given KCl (potassium chloride) fertilizer (Lesmana, 2022).

CONCLUSION

This study showed that altitude affects the land suitability class for Arabica coffee plants. Assessment of land suitability for Arabica coffee (*Coffea arabica*) cultivation in the hilly areas of Ende Sub-District shows that this area has three dominant soil types, namely Inceptisols, Alfisols, and Andisols, with various altitudes between 0 and 1,100 masl. The climate of this area is classified as dry with an average rainfall of 1,102 mm/year, a dry period of 5.60 months, an average temperature ranging from 19.7 °C to 26.3 °C, and relative humidity between 65.80% and 72.20%. The actual land suitability for Arabica coffee is classified S3 (marginally suitable) 2,866.04 ha and N (not suitable) 13,629.1 ha, which are influenced by several limiting factors such as average temperature and altitude (tc), duration of dry season (wa), drainage (oa), base saturation (nr), availability of phosphorus (na), and slope and level of erosion hazard (eh). The main determinants of land suitability class include average temperature, humidity, drainage, soil texture, coarse material content, total nitrogen content, potassium availability, erosion hazard, surface rocks, and rock outcrops. To improve the land suitability class of Arabica coffee, it is recommended to implement improvement strategies such as building irrigation systems, using shade plants, applying nitrogen (urea) and potassium (KCl) fertilizers, and implementing soil conservation techniques such as terracing.

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