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Editorial Team of Sains Tanah <jurnal@mail.uns.ac.id> 12 November 2021 pukul 02.58
Kepada: Nurdin Nurdin Kyai Baderan <nurdin@ung.ac.id>

Dear Nurdin Nurdin Kyai Baderan:

Thank you for submitting the manuscript, "A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY" to SAINS TANAH - Journal of Soil Science and Agroclimatology. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

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Thank you for considering the STJSSA journal as a venue for your work.

Best regards.

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Title and Abstract

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Bio Statement —

Title and Abstract

Title Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

Abstract Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to became very suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II or the land that had a little limiting factor turned out to be more dominant with the recommendation of adding P and organic fertilizer.

Indexing

Keywords Land, suitability, coffee, liberica, endemic, Plateau, Pinogu

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Supporting Agencies

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COVER PAGE

I. Manuscript Title

A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

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VIII. The main findings and why they are important and useful.

1. Land suitability class for liberica coffee in Pinogu Plateau is the result of research that was first produced in this region and in the province of Gorontalo, both with the limiting factor method and the parametric method. Thus, the results are very important in planning and sustainable land use for liberica coffee as well as for land management in this region given its position as the upstream of the Bone watershed.

2. It turns out that the land suitability class using the parametric method is more sensitive and approaches the profitability conditions of Liberica coffee which are more real in the field, so that it has an impact on land management inputs that are less than the limiting factor method. Consequently, by using the land suitability class as a result of the parametric method, Liberica coffee farmers will get the efficiency of their plantation business.
3. The use of the coffee profitability estimating equation is proven to be able to produce profitability values that are close to the existing conditions of profitability for liberica coffee, so that the limitations of profitability data on land units can be overcome.

IX. Why the readers of the journal would be interested in the work.

1. Liberica coffee is a refreshing commodity that is strategic and closely related to the daily life of coffee lovers, so its availability is needed both nationally and globally. Thus, efforts to develop coffee by intensification and extensification on existing and potential land in a sustainable manner will always be carried out.
2. Readers will obtain information on the potential of land resources through land suitability for liberica coffee, so that the information will become a reference for the parties to increase the production and profitability of liberica coffee in a sustainable manner.
3. Readers will get a choice of adequate information about the results of the land suitability assessment for liberica coffee using the limiting factor method and the parametric method, so that later decision making will be wiser and wiser, especially with regard to Pinogu Plateau's position as the headwaters of the Bone watershed.

X. Suggested Reviewers : *(at least 2 reviewers)*

No	Name	Affiliation	Review Interests	E-mail address And Phone contact number (if any)	ORCID ID/ Scopus ID/ Linkedin ID/ Google Scholar Profile Address
1	Soemarno	Brawijaya University	Soil Science, land use planning	smno@ub.ac.id; 082143001150	SINTA ID: 5993552
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A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these profitability is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. The input for land management with the parametric method was P fertilization only compared to the limiting factor method that more input of land managements.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee is still a strategic commodity for Indonesia because it can contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or increased by 2.62% from the previous year with a value of 809,158,900 US$ (BPS, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Ditjendbun, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu plateau. This district has long been known as a coffee producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. Pinogu coffee has a distinctive taste, including: a more fragrant aroma, tastes like jackfruit with a moderate acidity level, so it is not too bitter and is safe in the stomach (Liputan6.com, 2017). The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (Coffea Liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species only exists and grows in an area (KBBI, 2021) in this case in Pinogu District only for Gorontalo Province. Liberika coffee has the advantage of good taste (Gusfarina, 2014), relatively low caffeine content (1.1-1.3%), so it is safe for consumers who are sensitive to caffeine (Puslitkoka, 2014). This condition makes pinogu coffee an icon and superior commodity of Bone Bolango Regency (Zainuddin, 2020).

Efforts to maintain the sustainability of liberika coffee products have so far encountered several obstacles, one of which is the low profitability of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its profitability is still low at only 0.75 tons ha^{-1} $year^{-1}$. In fact, the profitability of liberica coffee can reach 1.69 – 1.98 tons ha^{-1} (Balittri, 2015). The report of BPS Kabupaten Bone Bolango (2021) shows that Pinogu District has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 32.43 tons. Such conditions will affect the availability of coffee raw materials to meet market demand later. The low profitability of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land. Land potential is generally determined based on the characteristics and quality of the land inherent in the land (Nurdin, 2021).

Until now, there is no available information about the potential of land for the development of Liberika Coffee in the Pinogu Plateau area, except for the potential of land for Robusta coffee because it is more developed as a research report by Taslim (2018); Indrianti (2020) and Humola et al., (2021). Even though this liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 2014; Balittri, 2015). Ignorance of coffee planters regarding land potential will greatly affect the profitability of the land in supporting the growth and production of liberica coffee itself. Diversity of land characteristics and quality will be responded differently by each plant because each land-based commodity requires certain requirements to be able to grow and produce optimally (Rayes, 2007; Ritung et al., 2011).

Sustainable land management requires land evaluation methods that contain plant growth requirements for optimal production (Suryani, 2012) through land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment for Liberika Coffee. However, often the results of land suitability assessments do not match the facts of actual production achievements in the field (Nurdin, 2021). Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the interaction between all variables (Baja, 2012). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that interactions between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm (BPP Pinogu District, 2021), so based on the agro-climatic zone (Oldeman and Darmiyati, 1977), the research area is included in the agro-climatic zone. C1 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while the monthly wind speed is between 2 knots to 2.60 knots (BMKG Moutong, 2021). The research area is the upstream of the Bone watershed which flows to Tomini Bay.

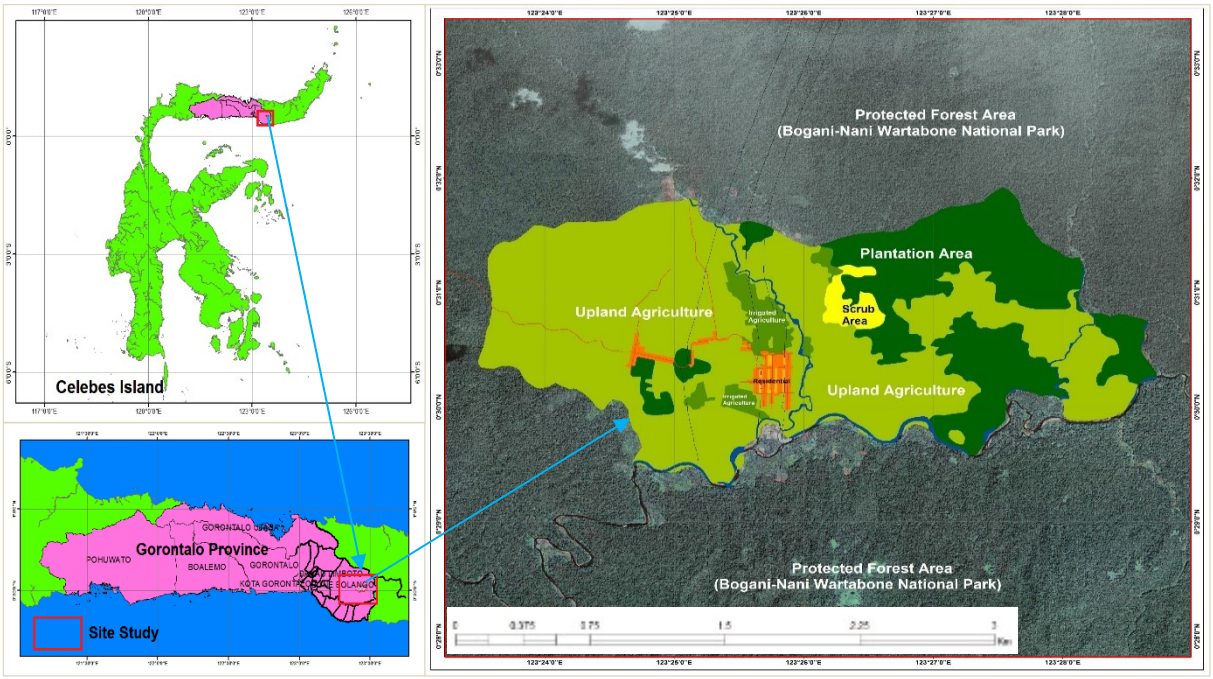

Figure 1. Research Location Map

Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in dbf or xls format.

Land Suitability Assesment

The deskwork in the suitability assessment is carried out based on the parameters of the selected land characteristics which are the same between the limiting factor method and the parametric method. Assessment of land suitability classes using the limiting factor method follows the land evaluation framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units. Furthermore, the data on land characteristics and quality were compared with the selected Liberika Coffee land suitability criteria (Table 1) according to the Ditjendbun (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability class is obtained.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land characteristics	Land suitability class			
	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes-sl (%)	0 – 8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 – 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

Remark: (Ditjendbun, 2014), modifed.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the profitability of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely: Y = -2.672+0.026X (elevation), Y = 17,190-0.090X (slope), Y = 3.055+0.005X (soil pH), Y = 4.050-0.019X (C-organic), Y = -28.796+0.621X (P availability), Y = 32.450-0.109X (CEC), and Y = 0.457-0.002X (base saturation). In this case, Y = estimated production (tonnes/ha), X = soil and land properties parameters, CEC = cation exchange capacity, and KB = base saturation. The assumption of optimal profitability of liberica coffee used is 0.75 tons ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated profitability of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At - Ft)^2}{n}}$$

where: RMSE = root mean square error, At = actual profitability (ton ha^{-1}), Ft = estimated profitability (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}}$$

where: LI = land index; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the profitability of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

RESULTS

Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau (Table 2, Figure 2). It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. While the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau include: nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were corrected with the addition of organic matter, while

the limiting factor for available nutrients in the form of low P availability was corrected with the addition of P fertilizer. The most dominant potential land suitability class was very suitable (S1) covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Luas (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

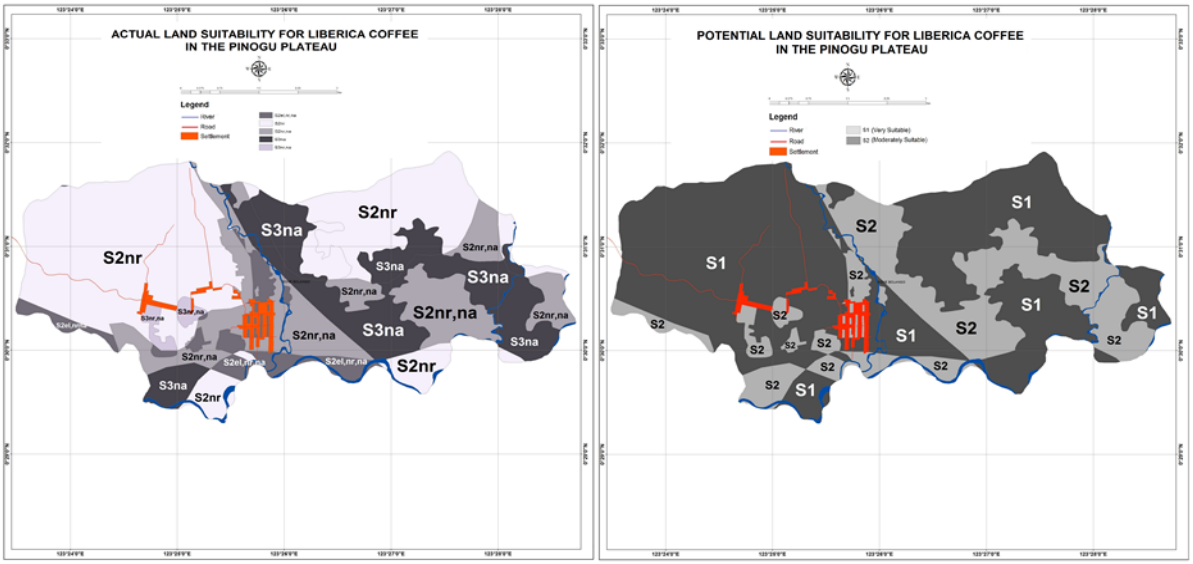

Figure 2. Actual and Potential of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Based on Parametric Method

The results of the profitability analysis (productivity) of liberica coffee based on each land characteristic showed that the highest profitability was obtained on the slope characteristics which averaged 1.69 tons ha^{-1}, while the lowest profitability was obtained on the available P characteristics which only ranged from 0.16 – 0.24 ton ha^{-1} with an average of 0.20 ton ha^{-1} (Table 4). The remaining land characteristics has an average profitability 0.30. The results of the RMSE analysis on the alleged profitability of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The profitability of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of profitability for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71.

Table 4. Estimated Value of Liberica Coffee Provitability in Pinogu Plateau

Characteristic /*Provitability*	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (ton ha^{-1})	*0.49*	*0.53*	*0.55*	*0.52*	*0.54*	*0.53*	*0.49*	*0.48*	*0.61*	*0.51*	*0.60*	*0.53*	*0.54*
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (ton ha^{-1})	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.65*	*1.69*	*1.65*	*1.69*
pH	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00
Y (ton ha^{-1})	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (ton ha^{-1})	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (ton ha^{-1})	*0.30*	*0.30*	*0.29*	*0.30*	*0.30*	*0.29*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (ton ha^{-1})	*0.39*	*0.39*	*0.40*	*0.41*	*0.40*	*0.40*	*0.38*	*0.38*	*0.38*	*0.37*	*0.39*	*0.38*	*0.41*
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (ton ha^{-1})	*0.20*	*0.19*	*0.23*	*0.21*	*0.18*	*0.17*	*0.20*	*0.16*	*0.19*	*0.23*	*0.18*	*0.19*	*0.24*
$\bar{Y}$ (ton ha^{-1})	*0.60*	*0.60*	*0.61*	*0.60*	*0.60*	*0.60*	*0.60*	*0.59*	*0.61*	*0.60*	*0.61*	*0.59*	*0.61*
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the value of the land index, the land suitability class for liberica coffee was more dominant S2 with covering an area of 2,489.37 ha or 88.77% (Table 5). Meanwhile, the S1 class was 202.07 ha or 7.21% and the S3 class was 112.84 ha or 4.02% only without not suitable class (N).

Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Profitability /LC Value	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (ton ha^{-1})	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-Sl. (ton ha^{-1})	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (ton ha^{-1})	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (ton ha^{-1})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (ton ha^{-1})	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52

Y-BS (ton ha^{-1})	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (ton ha^{-1})	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

Remark: LMU = land mapping unit, Y = profitability, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and Their Impact on Land Management

Based on the results of the land suitability assessment using the limiting factor method and the parametric method, there were similarities in land suitability class (S2 = S2) covering an area of 621.91 ha or 22.18% at LMU 1, 7 and LMU 10 with (Table 6, Figure 3). While the difference in results between the two methods follows a pattern: S1 ≠ S2 covering 1,867.46 ha or 66.59% at LMU 2, 4, 5, 6, 9, 11, and LMU 12, S2 ≠ S1 pattern covering an area of 202.07 ha or 7.21% at LMU 3 and LMU 13, while the S1 ≠ S3 pattern was only 112.84 ha or 4.02% at LMU 8.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Area	
	Limiting Factor Method	Parametric Method	ha	%
1, 7, 10	S2	S2	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	1,867.46	66.59
3, 13	S2	S1	202.07	7.21
8	S1	S3	112.84	4.02
	Area (ha)		2,804.28	100.00

Remark: LMU = land mapping unit.

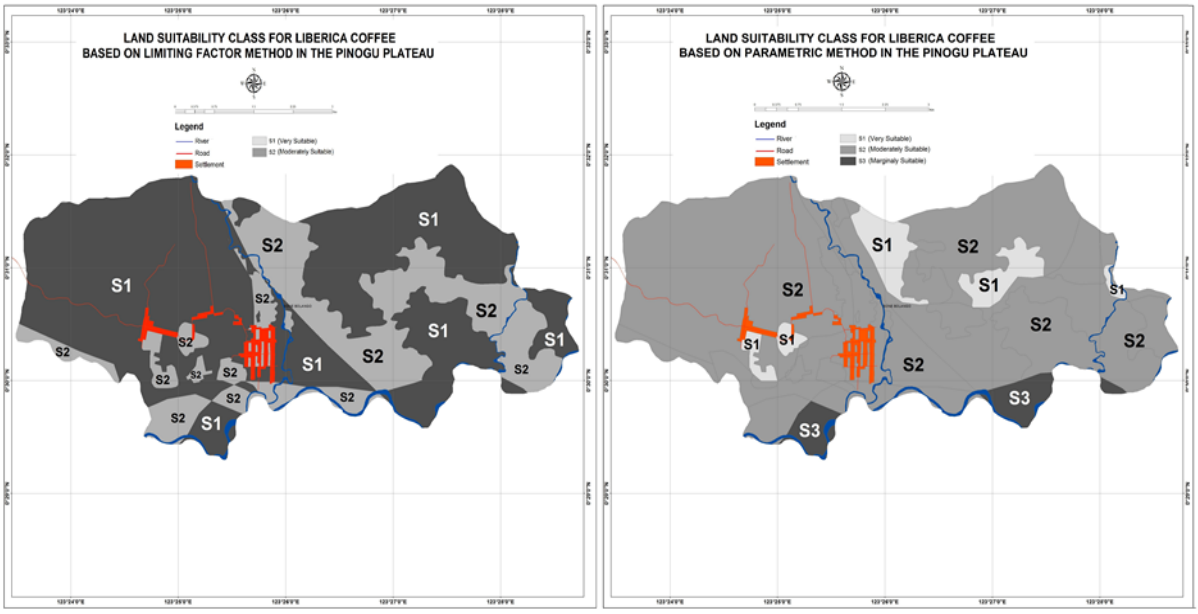

Figure 3. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

DISCUSSION

The level of land suitability for a particular use, both in actual and after repair or potential conditions, was known as land suitability (Ritung et al., 2011), where the results become the basis for developing a land use on a large scales (Hardjowigeno & Widiatmaka, 2007). In land suitability assessment for liberica coffee using the limiting factor method on the actual land suitability class, it turned out that the S2 class was more dominant with the limiting factors of elevation, nutrient retention (C-organic, base saturation and soil pH) and available nutrients (availability of P). All of these limiting factors can be improved, except for the elevation limiting factor which according to Hardjowigeno & Widiatmaka (2007) cannot be improved. The ideal elevation for Liberica coffee is between 300 – 500 m above sea level (Ditjendbun, 2014). Land suitability class S3 has limiting factors for nutrient retention (C-organic) and available nutrients (availability of P). The limiting factors for nutrient retention (C-organic, base saturation and soil pH) can be improved by adding organic matter (Suheri et al., 2018) because it can increase soil pH and C-organic (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015). While the availability of nutrients (available P) can be improved by applying fertilizers (Suheri et al., 2018), especially P fertilizers. According to Singh et al., (2003) and Mahapatra et al., (2019), land management can be done by adding organic matter and fertilization according to the recommended dose of fertilizer. Land management factors play a very important role in maintaining soil organic matter content (Dariah et al., 2005). Meanwhile, according to (Suheri et al., 2018), fertilization is intended to add nutrients to the soil for plants.

The improvement of the actual suitability class was able to increase the liberica coffee class in Pinogu Plateau to a potential land suitability whose assessment results were dominant in the S1 class compared to S2, without the S3 class and the N class with the class S1 > S2 pattern, so that the area and distribution of these classes also increased. This is in line with the statement (Refitri et al., 2016) that land that has a suitability class of S3 has the opportunity to be improved through various land improvement efforts, so that it becomes class S2 to class S1. However, the land suitability class assessment using the limiting factor method has not at all linked the class acquisition to the profitability of liberica coffee itself, so that there is often a contrast between the land suitability class and its real profitability. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked again in the field.

In principle, the parametric method in evaluating land suitability is to assign values to different limiting levels of land properties, on a normal scale given a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). In land suitability assessment for liberica coffee in Pinogu Plateau with parametric method dominated by S2 class followed by S1 class and S3 class without class N with class pattern S2 > S1 > S3. It seems that the land index obtained by the parametric method is closer to the real conditions in the field, where the average production of liberica coffee in the Pinogu Plateau ranges from 0.51 to 0.61 tons ha^{-1}, while the profitability of Pinogu coffee currently reaches 0.75. ton ha-1 (Martono, 2018). This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020), so that the minimum rating in this case the low availability of P nutrients causes the low land suitability class. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Low nutrient availability can be corrected by applying fertilizers (Suheri et al., 2018), especially P.

The difference in land suitability class between the two methods has an impact on land management for liberica coffee in Pinogu Plateau. In the limiting factor method, differences in land suitability classes were caused by prominent limiting factors (Table 3) including: elevation, nutrient retention (pH, organic C, base saturation), and nutrient availability (available P). This condition resulted in more land management inputs needed, including the addition of organic matter and P fertilization. Meanwhile, the difference in land suitability classes in the parametric method was caused by the interaction of all soil and land properties parameters with the profitability of liberica coffee in Pinogu Plateau (Table 5), although the levels of The available P yields the lowest profitability and the slope with the highest profitability. Thus, the low availability of P nutrients can be corrected by only P fertilization, resulting in fewer inputs for land management.

This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that differences in land suitability assessment results are not caused by differences in land characteristics. but because of the final value produced by both methods. In addition, the use of land characteristics is also based on the availability of mathematical equations to estimate the profitability of liberica coffee because only LMU 3, 9, 10 and LMU 13 have liberica coffee plants and have produced 0.75 tons ha^{-1} (Martono, 2018). Meanwhile, other LMUs do not have liberica coffee plants, so the profitability must be estimated.

Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. This refers to the land suitability criteria for liberica coffee (Ditjendbun, 2014), where the characteristics of land that have not been used in this study are: annual rainfall, dry month length, effective depth, texture, rock on the surface, inundation, drainage class, nitrogen (N), salinity and aluminum saturation (Al). However, the results of this study have shown that the use of the parametric method is more sensitive to the increase or decrease in the profitability of liberica coffee and better describes the real conditions in the field. Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee is higher, is in contrast to the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Pinogu Plateau is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, liberica coffee is also found in the Modayag District, East Bolaang Mongondow Regency, North Sulawesi Province, which is still an island of Sulawesi and was endemic in the province, so that future research is interesting and can be focused on comparing land suitability classes for liberica coffee in the two regions and their agronomic performance and profitability.

CONCLUSION

The actual of land suitability class for liberica coffee using the limiting factor method consists of moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and nutrient availability constraints. Efforts to improve the class by adding organic matter and fertilization, so the potential class were very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 class. The input for land management using the parametric method was P fertilization only.

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STATEMENT OF COMPETING INTEREST

The authors state that no competing financial or personal interests might arise and affect the work reported in this paper.

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[STJSSA] Editor Decision (RESUBMIT FOR REVIEW)

1 pesan

Editorial Team of Sains Tanah <jurnal@mail.uns.ac.id> 24 November 2021 pukul 16.14
Balas Ke: STJSSA Editorial Team <sainstanah@mail.uns.ac.id>
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Dear Nurdin:

We have reached a decision regarding your submission to SAINS TANAH - Journal of Soil Science and Agroclimatology, "A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY".

Our decision is: Resubmit for Review (due date is: 2021-12-08)

Please revise your article according to the comments. We believe you can revise it quickly before the due date.

We kindly ask you to resubmit the corrected article under the same identification number. To do so, login into the system, click on this article and fill in the "Upload Author Version" input field.

The revised version must include highlighted changes and modifications recommended in the first revision to ensure that all reviewer(s)' comments were considered.

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Best regards.

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COVER PAGE

I. Manuscript Title

A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

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VIII. The main findings and why they are important and useful.

1. Land suitability class for liberica coffee in Pinogu Plateau is the result of research that was first produced in this region and in the province of Gorontalo, both with the limiting factor method and the parametric method. Thus, the results are very important in planning and sustainable land use for liberica coffee as well as for land management in this region given its position as the upstream of the Bone watershed.

2. It turns out that the land suitability class using the parametric method is more sensitive and approaches the profitability conditions of Liberica coffee which are more real in the field, so that it has an impact on land management inputs that are less than the limiting factor method. Consequently, by using the land suitability class as a result of the parametric method, Liberica coffee farmers will get the efficiency of their plantation business.
3. The use of the coffee profitability estimating equation is proven to be able to produce profitability values that are close to the existing conditions of profitability for liberica coffee, so that the limitations of profitability data on land units can be overcome.

IX. Why the readers of the journal would be interested in the work.

1. Liberica coffee is a refreshing commodity that is strategic and closely related to the daily life of coffee lovers, so its availability is needed both nationally and globally. Thus, efforts to develop coffee by intensification and extensification on existing and potential land in a sustainable manner will always be carried out.
2. Readers will obtain information on the potential of land resources through land suitability for liberica coffee, so that the information will become a reference for the parties to increase the production and profitability of liberica coffee in a sustainable manner.
3. Readers will get a choice of adequate information about the results of the land suitability assessment for liberica coffee using the limiting factor method and the parametric method, so that later decision making will be wiser and wiser, especially with regard to Pinogu Plateau's position as the headwaters of the Bone watershed.

X. Suggested Reviewers : *(at least 2 reviewers)*

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2	Yiyi Suleman	BPTP Jawa Barat	Soil mapping and land evaluation	yiyisulaeman@pertanian.go.id; 081386452039	Scopus ID: 49862318400
3	Mujiyo	Universitas Sebelas Maret	Pedology and Soil Survey	mujiyo@staff.uns.ac.id	Scopus ID: 57192577929

A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these profitability is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. The input for land management with the parametric method was P fertilization only compared to the limiting factor method that more input of land managements.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee is still a strategic commodity for Indonesia because it can contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or increased by 2.62% from the previous year with a value of 809,158,900 US$ (BPS, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Ditjendbun, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu plateau. This district has long been known as a coffee producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. Pinogu coffee has a distinctive taste, including: a more fragrant aroma, tastes like jackfruit with a moderate acidity level, so it is not too bitter and is safe in the stomach (Liputan6.com, 2017). The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

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All tables and Figures should be replaced after the texts.

Commented [B33]: What is the scientific name for this variety?

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-The land suitability of liberica coffee worldwide
- The commodities which are suitable (according to land suitability analysis method) in the study site and surroundings

Liberica coffee (Coffea Liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species only exists and grows in an area (KBBI, 2021) in this case in Pinogu District only for Gorontalo Province. Liberika coffee has the advantage of good taste (Gusfarina, 2014), relatively low caffeine content (1.1-1.3%), so it is safe for consumers who are sensitive to caffeine (Puslitkoka, 2014). This condition makes pinogu coffee an icon and superior commodity of Bone Bolango Regency (Zainuddin, 2020).

Efforts to maintain the sustainability of liberika coffee products have so far encountered several obstacles, one of which is the low profitability of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its profitability is still low at only 0.75 tons ha^{-1} $year^{-1}$. In fact, the profitability of liberica coffee can reach 1.69 – 1.98 tons ha^{-1} (Balittri, 2015). The report of BPS Kabupaten Bone Bolango (2021) shows that Pinogu District has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 32.43 tons. Such conditions will affect the availability of coffee raw materials to meet market demand later. The low profitability of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land. Land potential is generally determined based on the characteristics and quality of the land inherent in the land (Nurdin, 2021).

Until now, there is no available information about the potential of land for the development of Liberika Coffee in the Pinogu Plateau area, except for the potential of land for Robusta coffee because it is more developed as a research report by Taslim (2018); Indrianti (2020) and Humola et al., (2021). Even though this liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 2014; Balittri, 2015). Ignorance of coffee planters regarding land potential will greatly affect the profitability of the land in supporting the growth and production of liberica coffee itself. Diversity of land characteristics and quality will be responded differently by each plant because each land-based commodity requires certain requirements to be able to grow and produce optimally (Rayes, 2007; Ritung et al., 2011).

Sustainable land management requires land evaluation methods that contain plant growth requirements for optimal production (Suryani, 2012) through land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment for Liberika Coffee. However, often the results of land suitability assessments do not match the facts of actual production achievements in the field (Nurdin, 2021). Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the interaction between all variables (Baja, 2012). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that interactions between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm (BPP Pinogu District, 2021), so based on the agro-climatic zone (Oldeman and Darmiyati, 1977), the research area is included in the agro-climatic zone. C1 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while the monthly wind speed is between 2 knots to 2.60 knots (BMKG Moutong, 2021). The research area is the upstream of the Bone watershed which flows to Tomini Bay.

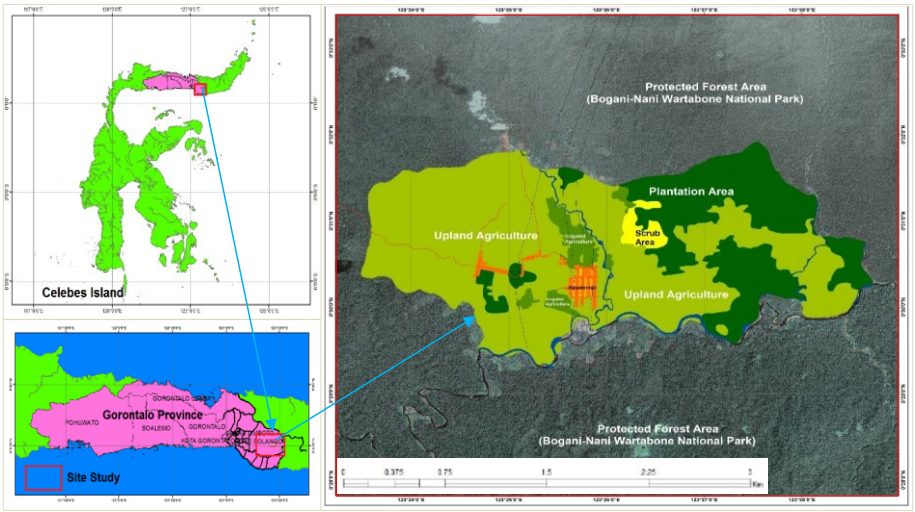

Figure 1. Research Location Map

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Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105^oC, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in dbf or xls format.

Land Suitability Assesment

The deskwork in the suitability assessment is carried out based on the parameters of the selected land characteristics which are the same between the limiting factor method and the parametric method. Assessment of land suitability classes using the limiting factor method follows the land evaluation framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units. Furthermore, the data on land characteristics and quality were compared with the selected Liberika Coffee land suitability criteria (Table 1) according to the Ditjendbun (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability class is obtained.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land characteristics	Land suitability class			
	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes-sl (%)	0 – 8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 – 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

Remark: (Ditjendbun, 2014), modifed.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the profitability of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely: Y = -2.672+0.026X (elevation), Y = 17,190-0.090X (slope), Y = 3.055+0.005X (soil pH), Y = 4.050-0.019X (C-organic), Y = -28.796+0.621X (P availability), Y = 32.450-0.109X (CEC), and Y = 0.457-0.002X (base saturation). In this case, Y = estimated production (tonnes/ha), X = soil and land properties parameters, CEC = cation exchange capacity, and KB = base saturation. The assumption of optimal profitability of liberica coffee used is 0.75 tons ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated profitability of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At - Ft)^2}{n}}$$

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Example:
Y=ax+b ..... (1)

where: RMSE = root mean square error, At = actual profitability (ton ha^{-1}), Ft = estimated profitability (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir. 1986). namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x\ \ldots x\ \frac{N}{100}}$$

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where: LI = land index; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the profitability of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

RESULTS

Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau (Table 2, Figure 2). It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the maTable 3rginally suitable class (S3) which was only 654.64 ha or only 23.34%. While the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau include: nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

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LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were corrected with the addition of organic matter, while

the limiting factor for available nutrients in the form of low P availability was corrected with the addition of P fertilizer. The most dominant potential land suitability class was very suitable (S1) covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Luas (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

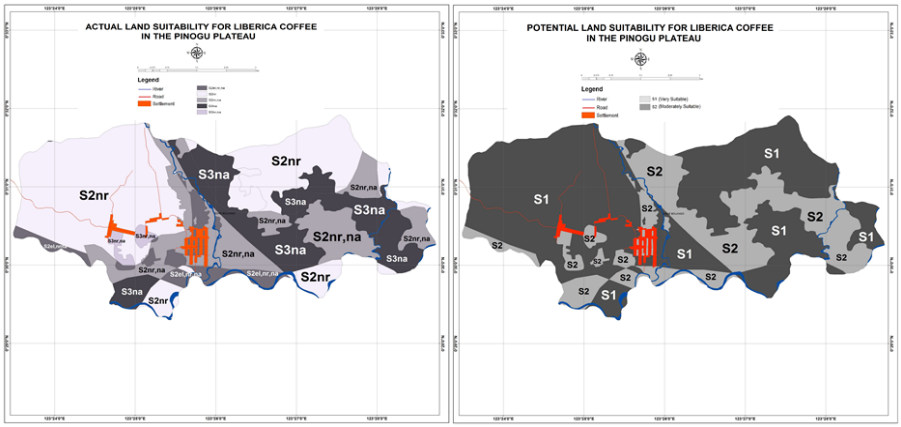

Figure 2. Actual and Potential of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Based on Parametric Method

The results of the profitability analysis (productivity) of liberica coffee based on each land characteristic showed that the highest profitability was obtained on the slope characteristics which averaged 1.69 tons ha^{-1}, while the lowest profitability was obtained on the available P characteristics which only ranged from 0.16 – 0.24 ton ha^{-1} with an average of 0.20 ton ha^{-1} (Table 4). The remaining land characteristics has an average profitability 0.30. The results of the RMSE analysis on the alleged profitability of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The profitability of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

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It seems that the relative land characteristic index values follow the pattern of profitability for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71.

Table 4. Estimated Value of Liberica Coffee Provitability in Pinogu Plateau

Characteristic /*Provitability*	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (ton ha^{-1})	*0.49*	*0.53*	*0.55*	*0.52*	*0.54*	*0.53*	*0.49*	*0.48*	*0.61*	*0.51*	*0.60*	*0.53*	*0.54*
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (ton ha^{-1})	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.65*	*1.69*	*1.65*	*1.69*
pH	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00
Y (ton ha^{-1})	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (ton ha^{-1})	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (ton ha^{-1})	*0.30*	*0.30*	*0.29*	*0.30*	*0.30*	*0.29*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (ton ha^{-1})	*0.39*	*0.39*	*0.40*	*0.41*	*0.40*	*0.40*	*0.38*	*0.38*	*0.38*	*0.37*	*0.39*	*0.38*	*0.41*
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (ton ha^{-1})	*0.20*	*0.19*	*0.23*	*0.21*	*0.18*	*0.17*	*0.20*	*0.16*	*0.19*	*0.23*	*0.18*	*0.19*	*0.24*
$\bar{Y}$ (ton ha^{-1})	*0.60*	*0.60*	*0.61*	*0.60*	*0.60*	*0.60*	*0.60*	*0.59*	*0.61*	*0.60*	*0.61*	*0.59*	*0.61*
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the value of the land index, the land suitability class for liberica coffee was more dominant S2 with covering an area of 2,489.37 ha or 88.77% (Table 5). Meanwhile, the S1 class was 202.07 ha or 7.21% and the S3 class was 112.84 ha or 4.02% only without not suitable class (N).

Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Profitability /LC Value	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (ton ha^{-1})	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-Sl. (ton ha^{-1})	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (ton ha^{-1})	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (ton ha^{-1})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (ton ha^{-1})	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52

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Y-BS (ton ha^{-1})	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (ton ha^{-1})	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

Remark: LMU = land mapping unit, Y = profitability, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and Their Impact on Land Management

Based on the results of the land suitability assessment using the limiting factor method and the parametric method, there were similarities in land suitability class (S2 = S2) covering an area of 621.91 ha or 22.18% at LMU 1, 7 and LMU 10 with (Table 6, Figure 3). While the difference in results between the two methods follows a pattern: S1 ≠ S2 covering 1,867.46 ha or 66.59% at LMU 2, 4, 5, 6, 9, 11, and LMU 12, S2 ≠ S1 pattern covering an area of 202.07 ha or 7.21% at LMU 3 and LMU 13, while the S1 ≠ S3 pattern was only 112.84 ha or 4.02% at LMU 8.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Area	
	Limiting Factor Method	Parametric Method	ha	%
1, 7, 10	S2	S2	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	1,867.46	66.59
3, 13	S2	S1	202.07	7.21
8	S1	S3	112.84	4.02
	Area (ha)		2,804.28	100.00

Remark: LMU = land mapping unit.

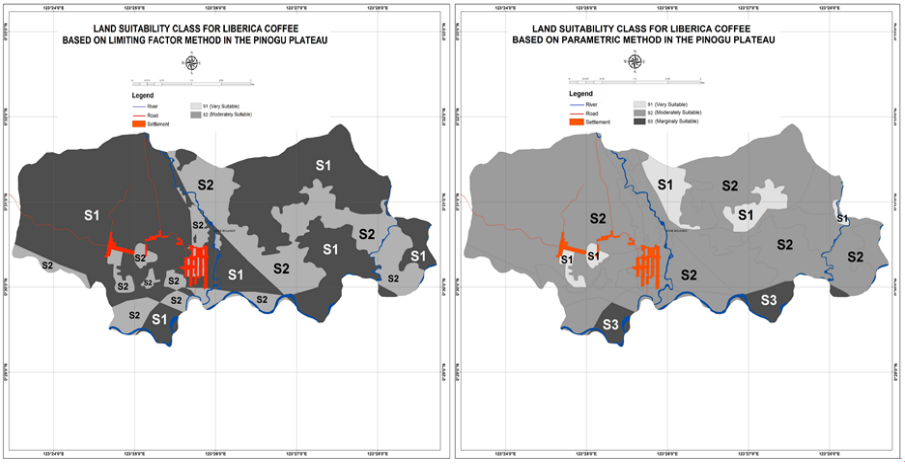

Figure 3. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

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DISCUSSION

The level of land suitability for a particular use, both in actual and after repair or potential conditions, was known as land suitability (Ritung et al., 2011), where the results become the basis for developing a land use on a large scales (Hardjowigeno & Widiatmaka, 2007). In land suitability assessment for liberica coffee using the limiting factor method on the actual land suitability class, it turned out that the S2 class was more dominant with the limiting factors of elevation, nutrient retention (C-organic, base saturation and soil pH) and available nutrients (availability of P). All of these limiting factors can be improved, except for the elevation limiting factor which according to Hardjowigeno & Widiatmaka (2007) cannot be improved. The ideal elevation for Liberica coffee is between 300 – 500 m above sea level (Ditjendbun, 2014). Land suitability class S3 has limiting factors for nutrient retention (C-organic) and available nutrients (availability of P). The limiting factors for nutrient retention (C-organic, base saturation and soil pH) can be improved by adding organic matter (Suheri et al., 2018) because it can increase soil pH and C-organic (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015). While the availability of nutrients (available P) can be improved by applying fertilizers (Suheri et al., 2018), especially P fertilizers. According to Singh et al., (2003) and Mahapatra et al., (2019), land management can be done by adding organic matter and fertilization according to the recommended dose of fertilizer. Land management factors play a very important role in maintaining soil organic matter content (Dariah et al., 2005). Meanwhile, according to (Suheri et al., 2018), fertilization is intended to add nutrients to the soil for plants.

The improvement of the actual suitability class was able to increase the liberica coffee class in Pinogu Plateau to a potential land suitability whose assessment results were dominant in the S1 class compared to S2, without the S3 class and the N class with the class S1 > S2 pattern, so that the area and distribution of these classes also increased. This is in line with the statement (Refitri et al., 2016) that land that has a suitability class of S3 has the opportunity to be improved through various land improvement efforts, so that it becomes class S2 to class S1. However, the land suitability class assessment using the limiting factor method has not at all linked the class acquisition to the profitability of liberica coffee itself, so that there is often a contrast between the land suitability class and its real profitability. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked again in the field.

In principle, the parametric method in evaluating land suitability is to assign values to different limiting levels of land properties, on a normal scale given a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). In land suitability assessment for liberica coffee in Pinogu Plateau with parametric method dominated by S2 class followed by S1 class and S3 class without class N with class pattern S2 > S1 > S3. It seems that the land index obtained by the parametric method is closer to the real conditions in the field, where the average production of liberica coffee in the Pinogu Plateau ranges from 0.51 to 0.61 tons ha^{-1}, while the profitability of Pinogu coffee currently reaches 0.75. ton ha-1 (Martono, 2018). This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020), so that the minimum rating in this case the low availability of P nutrients causes the low land suitability class. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Low nutrient availability can be corrected by applying fertilizers (Suheri et al., 2018), especially P.

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Discussion should be started with the answer to your objective, not citations.
Please use the citations only to support your findings.
Discuss your results COMPREHENSIVELY by comparing the general results between two methods.
DO NOT discuss your results per parameter again because it is clearly explained in "Results" section. Linkage the parameter each other as a comprehensive discussion.
What was lack in the first method, and can be identified in the second method?

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The difference in land suitability class between the two methods has an impact on land management for liberica coffee in Pinogu Plateau. In the limiting factor method, differences in land suitability classes were caused by prominent limiting factors (Table 3) including: elevation, nutrient retention (pH, organic C, base saturation), and nutrient availability (available P). This condition resulted in more land management inputs needed, including the addition of organic matter and P fertilization. Meanwhile, the difference in land suitability classes in the parametric method was caused by the interaction of all soil and land properties parameters with the profitability of liberica coffee in Pinogu Plateau (Table 5), although the levels of The available P yields the lowest profitability and the slope with the highest profitability. Thus, the low availability of P nutrients can be corrected by only P fertilization, resulting in fewer inputs for land management.

This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that differences in land suitability assessment results are not caused by differences in land characteristics. but because of the final value produced by both methods. In addition, the use of land characteristics is also based on the availability of mathematical equations to estimate the profitability of liberica coffee because only LMU 3, 9, 10 and LMU 13 have liberica coffee plants and have produced 0.75 tons ha^{-1} (Martono, 2018). Meanwhile, other LMUs do not have liberica coffee plants, so the profitability must be estimated.

Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. This refers to the land suitability criteria for liberica coffee (Ditjendbun, 2014), where the characteristics of land that have not been used in this study are: annual rainfall, dry month length, effective depth, texture, rock on the surface, inundation, drainage class, nitrogen (N), salinity and aluminum saturation (Al). However, the results of this study have shown that the use of the parametric method is more sensitive to the increase or decrease in the profitability of liberica coffee and better describes the real conditions in the field. Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee is higher, is in contrast to the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Pinogu Plateau is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, liberica coffee is also found in the Modayag District, East Bolaang Mongondow Regency, North Sulawesi Province, which is still an island of Sulawesi and was endemic in the province, so that future research is interesting and can be focused on comparing land suitability classes for liberica coffee in the two regions and their agronomic performance and profitability.

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CONCLUSION

The actual of land suitability class for liberica coffee using the limiting factor method consists of moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and nutrient availability constraints. Efforts to improve the class by adding organic matter and fertilization, so the potential class were very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 class. The input for land management using the parametric method was P fertilization only.

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STATEMENT OF COMPETING INTEREST

The authors state that no competing financial or personal interests might arise and affect the work reported in this paper.

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We have reached a decision regarding your submission to SAINS TANAH - Journal of Soil Science and Agroclimatology, "A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY".

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Title	Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia
Section	RESEARCH
Editor	Komariah Komariah

Peer Review

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THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these productivity is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land management recommendations for liberica coffee were priority I and II based on parametric methods.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica coffee in the world because of its limited area, so that publications are also relatively limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or an increase of 2.62% from the previous year with a value of 809,158,900 US$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km^2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee

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Land suitability evaluation, liberica coffea, Pinogu Plateu, Sulawesi

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producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha^{-1} $year^{-1}$. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 ton ha^{-1} (Indonesia Research Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 ton (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land.

Until now there is no available information about the potential of land for the development of Liberika Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica coffee itself, because differences in land potential will be responded by variously by plants according to growing conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different land evaluation methods have different data requirements and varying quality of estimates, but there is no fixed rule that defines when and what method to use when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and

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consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). The aAnnual rainfall is 2,541.90 mm andwith thean average monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research study area is included in the agro-climatic zone of C1 because the number of dry month (montly rainfall less than< 100 mm) is only 1 month and the number of wet month (monthly rainfall more than 200 mm) is 6 months is wet (>200 mm). The monthly air temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%, while the monthly wind speed is between 2 knots to 2.60 knots. The research study area is the upstream of the Bone watershed which flows to Tomini Bay.

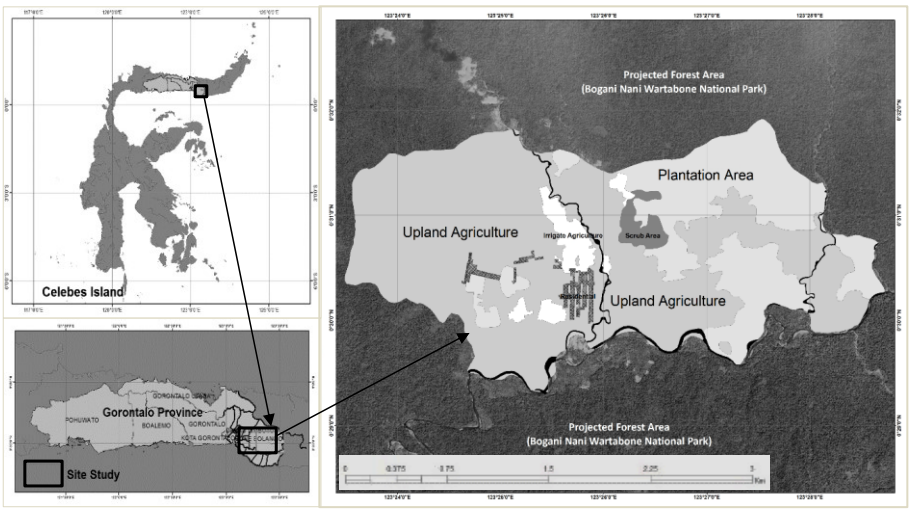

Figure 1. Research Location Map

Soil Survey and Land Observation

A set of soil survey tools, includeding: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber

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band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in spreasheet. ~~dbf or xls format.~~

Land Suitability Assesment

The ~~deskwork in the~~land suitability assessment is carried out based on the parameters of ~~the~~ selected land characteristics which are the same between the limiting factor method and the parametric method. The a~~A~~ssessment ~~t t~~ of land suitability classes used ~~using~~ the limiting factor method, follow~~in~~(g~~s~~ the land evaluation framework ~~according to~~ (FAO, ~~(~~ 1976). ~~from the order and class categories (suitable, not suitable) to units. Furthermore, the data on l~~Land characteristics and quality were compared with the selected ~~*Coffea liberica* HP.~~ land suitability criteria (Table 1) from~~according to~~ the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability class is obtained.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land characteristics	Land suitability class			
	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes-sl (%)	0 – 8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (cmol/kg)	>15	10 – 15	5 – 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

Source~~Remark:~~ ~~(~~Indonesian Directorate General of Plantations~~,~~ ~~(~~2014), *modifed*.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the productivity of coffee (Y) uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely:

Y = -2.672+0.026X (elevation) ..... (1)

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Y = 17,190-0.090X (slope) ..... (2)
Y = 3.055+0.005X (soil pH) ..... (3)
Y = 4.050-0.019X (C-organic) ..... (4)
Y = -28.796+0.621X (P availability) ..... (5)
Y = 32.450-0.109X (CEC) ..... (6)
Y = 0.457-0.002X (base saturation) ..... (7)

In this case, Y = estimated production (t ha^{-1}), X = soil and land properties parameters, and CEC = cation exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (t ha^{-1}), Ft = estimated productivity (t ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100} \; x \; \frac{B}{100} \; x \; \frac{C}{100} \; x \ldots x \; \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC_{min} = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC.

The determination of land suitability classification based on lan index (LI) is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

RESULTS

Land Suitability Class Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation	Slope	pH		C-Organic	CEC	BS	Ava-P	Actual LSC	Area	
	LSC	LSC	LC	LSC	LSC	LSC	LSC	LSC		ha	%

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	LC (m sl)		LC (%)				LC (%)		LC (cmol)		LC (%)		LC (ppm)				
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
									Area (ha)							2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were improved with the addition of organic matter, while the limiting factor for available nutrients of low P availability was improved with the addition of P fertilizer. As a result, the most dominant potential land suitability class was S1 covering ~~an area of~~ 1,980.30 ha or 70.62% of total area and the rest is~~ncluding~~ S2 ~~class~~ covering ~~an area of~~ 823.98 ha or 29.38% of total area~~only~~.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area ha	Area %
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
			Luas (Ha)		2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

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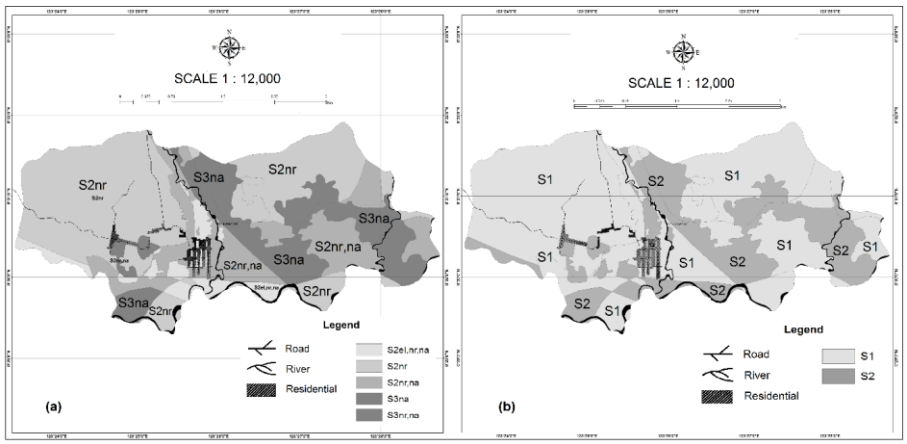

Figure 2. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability class Based on Parametric Method

The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which averaged 1.69 t ha^{-1}, while the lowest productivity was obtained on the available P characteristics which only ranged from 0.16 – 0.24 t ha^{-1} with an average of 0.20 t ha^{-1} (Table 4). The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of productivity for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which the averaged ~~a~~ value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39 ~~only~~. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71. So...what?

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic /*Productivity*	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha^{-1})	*0.49*	*0.53*	*0.55*	*0.52*	*0.54*	*0.53*	*0.49*	*0.48*	*0.61*	*0.51*	*0.60*	*0.53*	*0.54*
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha^{-1})	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.65*	*1.69*	*1.65*	*1.69*
pH	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

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Characteristic /Productivity	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha^{-1})	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha^{-1})	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha^{-1})	*0.30*	*0.30*	*0.29*	*0.30*	*0.30*	*0.29*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha^{-1})	*0.39*	*0.39*	*0.40*	*0.41*	*0.40*	*0.40*	*0.38*	*0.38*	*0.38*	*0.37*	*0.39*	*0.38*	*0.41*
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha^{-1})	*0.20*	*0.19*	*0.23*	*0.21*	*0.18*	*0.17*	*0.20*	*0.16*	*0.19*	*0.23*	*0.18*	*0.19*	*0.24*
Ȳ (t ha^{-1})	*0.60*	*0.60*	*0.61*	*0.60*	*0.60*	*0.60*	*0.60*	*0.59*	*0.61*	*0.60*	*0.61*	*0.59*	*0.61*
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% of… (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 4.02% only without not suitable class (N).

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Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

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Productivity /LC Value	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha^{-1})	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-Sl. (t ha^{-1})	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha^{-1})	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t ha^{-1})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha^{-1})	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha^{-1})	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t ha^{-1})	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

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Comparison of Land Suitability Classes and their Recommendations on Land Management

Based on the results of the land suitability assessment between the limiting factor and the parametric method were shown in Table 6 and Figure 3. The comparison between the two methods shows the similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10). But the most dominant class differences follow the pattern: S1 ≠ S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11, and LMU 12), followed by class pattern: S2 ≠ S1 of 7.21% (LMU 3, and LMU 13), while the lowest was

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the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was different from the land suitability class using the parametric method, where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Recomendation	Area	
	Limiting Factor Method	Parametric Method		ha	%
1, 7, 10	S2	S2	Priority I	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59
3, 13	S2	S1	Priority I	202.07	7.21
8	S1	S3	Priority III	112.84	4.02
Area (ha)				2,804.28	100.00

Remark: LMU = land mapping unit.

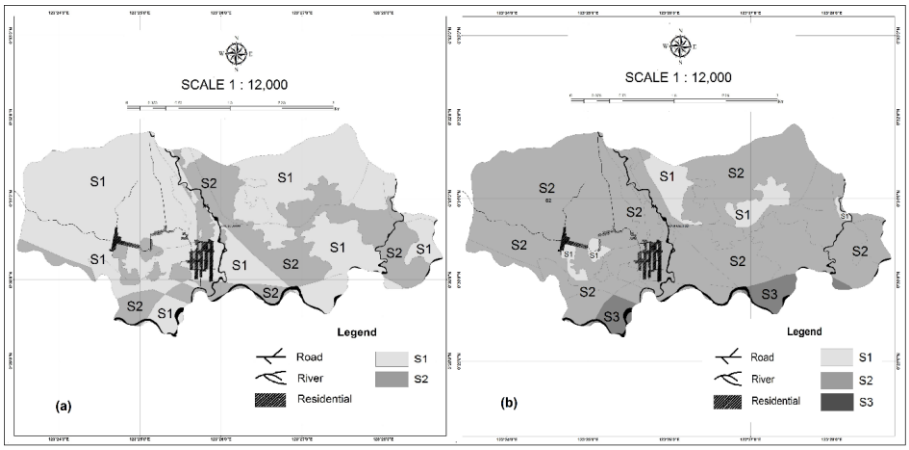

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

DISCUSSION

The suitability of land for liberica coffee with the limiting factor method and the parametric method turned out to be different, both in terms of class and area. This study shown that the land suitability class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the land suitability class using the parametric method was more dominant of moderately suitable. Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all

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with the productivity of liberica coffee. The limiting factor method has weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018). In contrast to the land suitability class with the parametric method, besides being based on the performance of land characteristics, it has also been directly related to the productivity of liberica coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), the precision and reliability of parametric methods more greater than other land evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map. This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index should be improved so that the plant grows optimally (Israminanti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be done by adding organic matter and fertilizing according to the recommended dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked again in the field. While the parameteric method in principle gives values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the parametric method is closer to the real conditions in the field, where the average liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there is a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes also increases quantitatively.

This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that the difference in the results of the land suitability assessment is not caused by differences in the characteristics of the land but because of the

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final value produced by the two methods. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor method makes it possible to determine the suitability class but without further specification (Abbasi et al., 2019). While in the parametric method, the use of land characteristics is based on the availability of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee plants, so their productivity must be estimated. In determining land suitability using the parametric method, the most limiting factor will have less effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. In fact, it can include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee is higher, often contrasts with the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of land suitability classes for liberica coffee in each of these areas along with their agronomic performance and productivity.

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CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

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THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these productivity is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land management recommendations for liberica coffee were priority I and II based on parametric methods.

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Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica coffee in the world because of its limited area, so that publications are also relatively limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 ts, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 ts or an increase of 2.62% from the previous year with a value of 809,158,900 US$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 ts or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and

mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha^{-1} $year^{-1}$. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 t ha^{-1} (Indonesia Research Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 t (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land.

Until now there is no available information about the potential of land for the development of Liberika Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica coffee itself, because differences in land potential will be responded by variously by plants according to growing conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different land evaluation methods have different data requirements and varying quality of estimates, but there is no fixed rule that defines when and what method to use when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized.

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- AbdelRahman, M.A.E., Natarajan, A. & Hegde R. 2016. Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India, Egypt. *J. Remote Sensing Space Sci.* (2016), http://dx.doi.org/10.1016/j.ejrs.2016.02.001
- A. Shalaby, M.A.E. AbdelRahman, A. A. Belal (2017). A GIS Based Model for Land Evaluation Mapping: A Case Study North Delta Egypt. Egypt. J. Soil Sci. Vol. 57 No. 3, pp.339 - 351 (2017).
- Mohamed A. E. AbdelRahman, Adel Shalaby, E. F. Essa (2018). Quantitative land evaluation based on fuzzy-multi-criteria spatial model for sustainable land-use planning. *Modeling Earth Systems and Environment*, 4(1), 1-13. (2018). https://doi.org/10.1007/s40808-018-0478-1
- Mohamed A.E.AbdelRahman, A.Shalaby, E.S.Mohamed (2018). Comparison of two soil quality indices using two methods based on geographic information system. Egypt. *J. Remote Sensing Space Sci.*, https://doi.org/10.1016/j.ejrs.2018.03.001
- Zakarya, Y.M.; Metwaly, M.M.; AbdelRahman, M.A.E.; Metwalli, M.R.; Koubouris, G. Optimized Land Use through Integrated Land Suitability and GIS Approach in West El-Minia Governorate, Upper Egypt. Sustainability 2021, 13, 12236. https://doi.org/10.3390/su132112236
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Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research area is included in the agro-climatic zone C1 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while the monthly wind speed is between 2 knots to 2.60 knots. The research area is the upstream of the Bone watershed which flows to Tomini Bay.

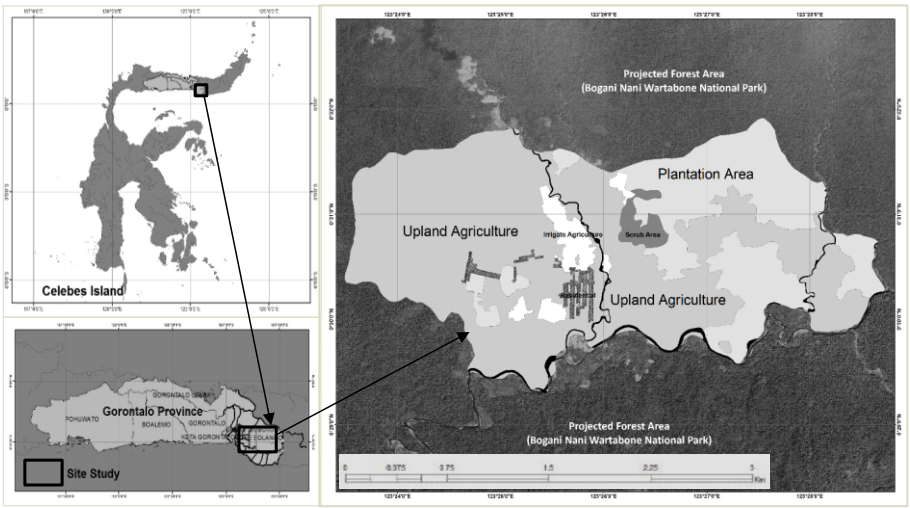

Figure 1. Research Location Map

Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps,

landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105^oC, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in dbf or xls format.

Land Suitability Assesment

The deskwork in the suitability assessment is carried out based on the parameters of the selected land characteristics which are the same between the limiting factor method and the parametric method. Assessment of land suitability classes using the limiting factor method follows the land evaluation framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units. Furthermore, the data on land characteristics and quality were compared with the selected *Coffea liberica* HP. land suitability criteria (Table 1) according to the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability class is obtained.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land characteristics	Land suitability class			
	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes-sl (%)	0 – 8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 – 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

Remark: (Indonesian Directorate General of Plantations, 2014), modifed.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the productivity of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely:

Y = -2.672+0.026X (elevation) ..... (1)

Y = 17,190-0.090X (slope) ..... (2)
Y = 3.055+0.005X (soil pH) ..... (3)
Y = 4.050-0.019X (C-organic) ..... (4)
Y = -28.796+0.621X (P availability) ..... (5)
Y = 32.450-0.109X (CEC) ..... (6)
Y = 0.457-0.002X (base saturation) ..... (7)

In this case, Y = estimated production (t ha^{-1}), X = soil and land properties parameters, and CEC = cation exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (t ha^{-1}), Ft = estimated productivity (t ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

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RESULTS

Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation	Slope	pH	C-Organic	CEC	BS	Ava-P	Actual	Area

	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	LSC	ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
								Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were improved with the addition of organic matter, while the limiting factor for available nutrients of low P availability was improved with the addition of P fertilizer. As a result, the most dominant potential land suitability class was S1 covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Luas (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

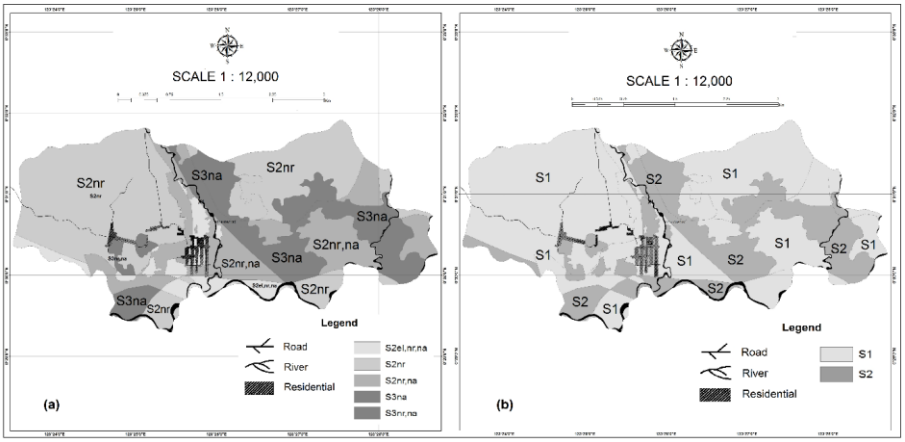

Figure 2. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Based on Parametric Method

The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which averaged 1.69 t ha^{-1}, while the lowest productivity was obtained on the available P characteristics which only ranged from 0.16 – 0.24 t ha^{-1} with an average of 0.20 t ha^{-1} (Table 4). The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of productivity for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic /*Productivity*	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha^{-1})	*0.49*	*0.53*	*0.55*	*0.52*	*0.54*	*0.53*	*0.49*	*0.48*	*0.61*	*0.51*	*0.60*	*0.53*	*0.54*
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha^{-1})	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.65*	*1.69*	*1.65*	*1.69*
pH	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

Characteristic /*Productivity*	LMU 1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha^{-1})	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha^{-1})	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha^{-1})	*0.30*	*0.30*	*0.29*	*0.30*	*0.30*	*0.29*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha^{-1})	*0.39*	*0.39*	*0.40*	*0.41*	*0.40*	*0.40*	*0.38*	*0.38*	*0.38*	*0.37*	*0.39*	*0.38*	*0.41*
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha^{-1})	*0.20*	*0.19*	*0.23*	*0.21*	*0.18*	*0.17*	*0.20*	*0.16*	*0.19*	*0.23*	*0.18*	*0.19*	*0.24*
Ȳ (t ha^{-1})	*0.60*	*0.60*	*0.61*	*0.60*	*0.60*	*0.60*	*0.60*	*0.59*	*0.61*	*0.60*	*0.61*	*0.59*	*0.61*
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 4.02% only without not suitable class (N).

Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity /LC Value	LMU 1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha^{-1})	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-Sl. (t ha^{-1})	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha^{-1})	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t ha^{-1})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha^{-1})	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha^{-1})	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t ha^{-1})	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Based on the results of the land suitability assessment between the limiting factor and the parametric method were shown in Table 6 and Figure 3. The comparison between the two methods shows the similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10). But the most dominant class differences follow the pattern: S1 ≠ S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11, and LMU 12), followed by class pattern: S2 ≠ S1 of 7.21% (LMU 3, and LMU 13), while

the lowest was the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was different from the land suitability class using the parametric method, where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Recomendation	Area	
	Limiting Factor Method	Parametric Method		ha	%
1, 7, 10	S2	S2	Priority I	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59
3, 13	S2	S1	Priority I	202.07	7.21
8	S1	S3	Priority III	112.84	4.02
Area (ha)				2,804.28	100.00

Remark: LMU = land mapping unit.

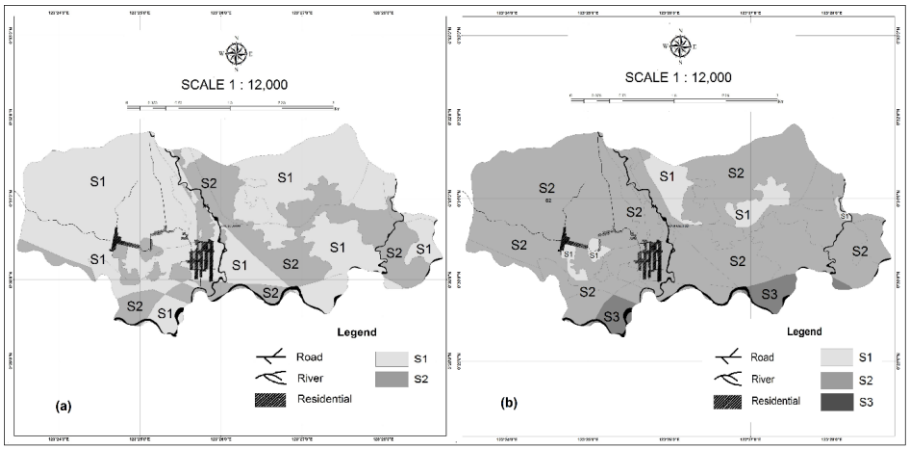

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

DISCUSSION

The suitability of land for liberica coffee with the limiting factor method and the parametric method turned out to be different, both in terms of class and area. This study shown that the land suitability class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the land suitability class using the parametric method was more dominant of moderately suitable. Although the land suitability class using this limiting factor method appears to be of a higher class

and wider distribution, it was only based on the characteristics of the land and has not been linked at all with the productivity of liberica coffee. The limiting factor method has weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018). In contrast to the land suitability class with the parametric method, besides being based on the performance of land characteristics, it has also been directly related to the productivity of liberica coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), the precision and reliability of parametric methods more greater than other land evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map. This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be done by adding organic matter and fertilizing according to the recommended dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked again in the field. While the parameteric method in principle gives values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the parametric method is closer to the real conditions in the field, where the average liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there is a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes also increases quantitatively.

This research uses both land suitability assessment methods to be the same and consistent in terms

of the type and number of land characteristics used, so that the difference in the results of the land suitability assessment is not caused by differences in the characteristics of the land but because of the final value produced by the two methods. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor method makes it possible to determine the suitability class but without further specification (Abbasi et al., 2019). While in the parametric method, the use of land characteristics is based on the availability of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee plants, so their productivity must be estimated. In determining land suitability using the parametric method, the most limiting factor will have less effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. In fact, it can include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee is higher, often contrasts with the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of land suitability classes for liberica coffee in each of these areas along with their agronomic performance and productivity.

CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

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Response to the Reviewer's comments

REVIEWER B

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REVIEWER D

Page number	Line number	Reviewer's Comment	Author's Revision

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THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these productivity is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land management recommendations for liberica coffee were priority I and II based on parametric methods.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica coffee in the world because of its limited area, so that publications are also relatively limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 ts, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 ts or an increase of 2.62% from the previous year with a value of 809,158,900 US$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 ts or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee

producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha^{-1} $year^{-1}$. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 t ha^{-1} (Indonesia Research Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 t (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land.

Until now there is no available information about the potential of land for the development of Liberika Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica coffee itself, because differences in land potential will be responded by variously by plants according to growing conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different land evaluation methods have different data requirements and varying quality of estimates, but there is no fixed rule that defines when and what method to use when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and

consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research area is included in the agro-climatic zone C1 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while the monthly wind speed is between 2 knots to 2.60 knots. The research area is the upstream of the Bone watershed which flows to Tomini Bay.

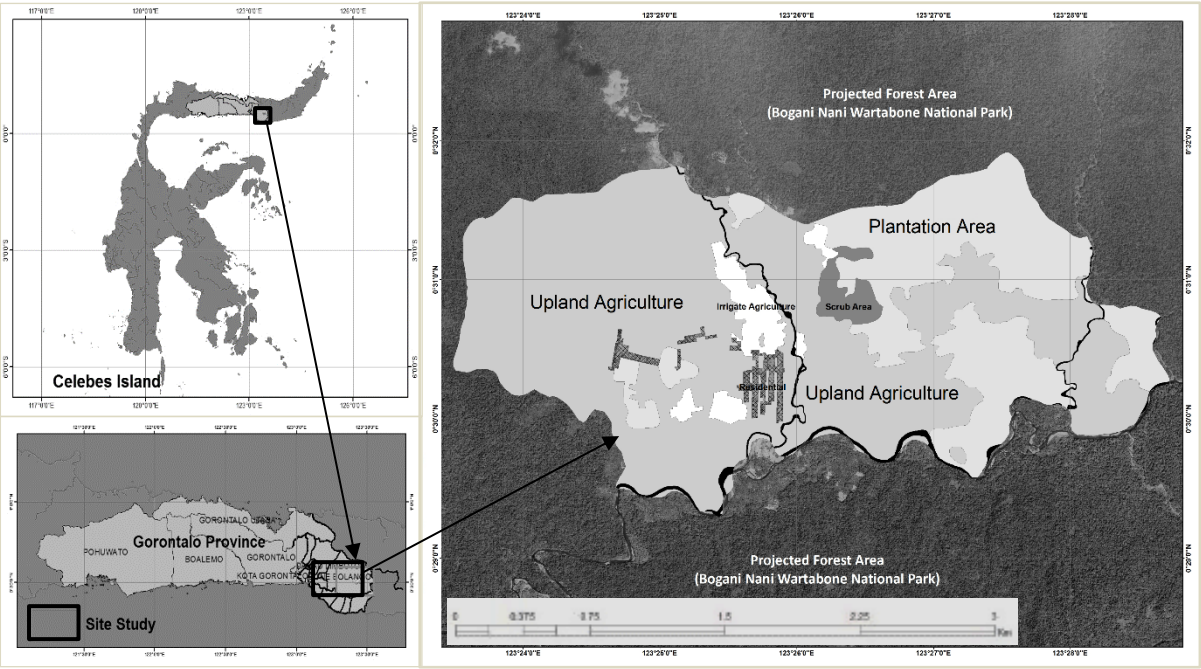

Figure 1. Research Location Map

Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory

analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105^oC, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in dbf or xls format.

Land Suitability Assesment

The deskwork in the suitability assessment is carried out based on the parameters of the selected land characteristics which are the same between the limiting factor method and the parametric method. Assessment of land suitability classes using the limiting factor method follows the land evaluation framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units. Furthermore, the data on land characteristics and quality were compared with the selected *Coffea liberica* HP. land suitability criteria (Table 1) according to the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability class is obtained.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land characteristics	Land suitability class			
	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes-sl (%)	0 – 8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 – 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

Remark: (Indonesian Directorate General of Plantations, 2014), modifed.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the productivity of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely:

Y = -2.672+0.026X (elevation) ..... (1)

Y = 17,190-0.090X (slope) ..... (2)

Y = 3.055+0.005X (soil pH) ..... (3)

Y = 4.050-0.019X (C-organic) ..... (4)

Y = -28.796+0.621X (P availability) ..... (5)

Y = 32.450-0.109X (CEC) ..... (6)

Y = 0.457-0.002X (base saturation) ..... (7)

In this case, Y = estimated production (t ha^{-1}), X = soil and land properties parameters, and CEC = cation exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (t ha^{-1}), Ft = estimated productivity (t ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

RESULTS

Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28

6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were improved with the addition of organic matter, while the limiting factor for available nutrients of low P availability was improved with the addition of P fertilizer. As a result, the most dominant potential land suitability class was S1 covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
Luas (Ha)					2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

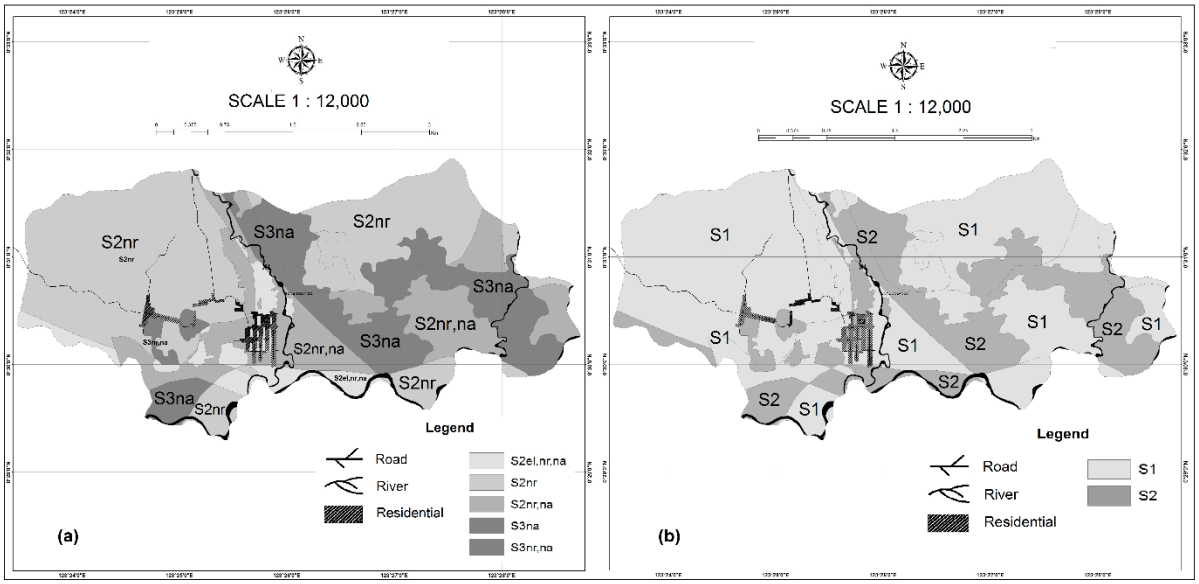

Figure 2. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Based on Parametric Method

The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which averaged 1.69 t ha^{-1}, while the lowest productivity was obtained on the available P characteristics which only ranged from 0.16 – 0.24 t ha^{-1} with an average of 0.20 t ha^{-1} (Table 4). The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of productivity for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic	LMU												
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha^{-1})	*0.49*	*0.53*	*0.55*	*0.52*	*0.54*	*0.53*	*0.49*	*0.48*	*0.61*	*0.51*	*0.60*	*0.53*	*0.54*
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha^{-1})	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.65*	*1.69*	*1.65*	*1.69*
pH	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

Characteristic /*Productivity*	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha^{-1})	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha^{-1})	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha^{-1})	*0.30*	*0.30*	*0.29*	*0.30*	*0.30*	*0.29*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha^{-1})	*0.39*	*0.39*	*0.40*	*0.41*	*0.40*	*0.40*	*0.38*	*0.38*	*0.38*	*0.37*	*0.39*	*0.38*	*0.41*
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha^{-1})	*0.20*	*0.19*	*0.23*	*0.21*	*0.18*	*0.17*	*0.20*	*0.16*	*0.19*	*0.23*	*0.18*	*0.19*	*0.24*
$\bar{Y}$ (t ha^{-1})	*0.60*	*0.60*	*0.61*	*0.60*	*0.60*	*0.60*	*0.60*	*0.59*	*0.61*	*0.60*	*0.61*	*0.59*	*0.61*
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 4.02% only without not suitable class (N).

Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity /LC Value	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha^{-1})	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-Sl. (t ha^{-1})	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha^{-1})	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t ha^{-1})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha^{-1})	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha^{-1})	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t ha^{-1})	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Based on the results of the land suitability assessment between the limiting factor and the parametric method were shown in Table 6 and Figure 3. The comparison between the two methods shows the similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10). But the most dominant class differences follow the pattern: S1 ≠ S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11, and LMU 12), followed by class pattern: S2 ≠ S1 of 7.21% (LMU 3, and LMU 13), while the lowest was

the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was different from the land suitability class using the parametric method, where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Recomendation	Area	
	Limiting Factor Method	Parametric Method		ha	%
1, 7, 10	S2	S2	Priority I	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59
3, 13	S2	S1	Priority I	202.07	7.21
8	S1	S3	Priority III	112.84	4.02
Area (ha)				2,804.28	100.00

Remark: LMU = land mapping unit.

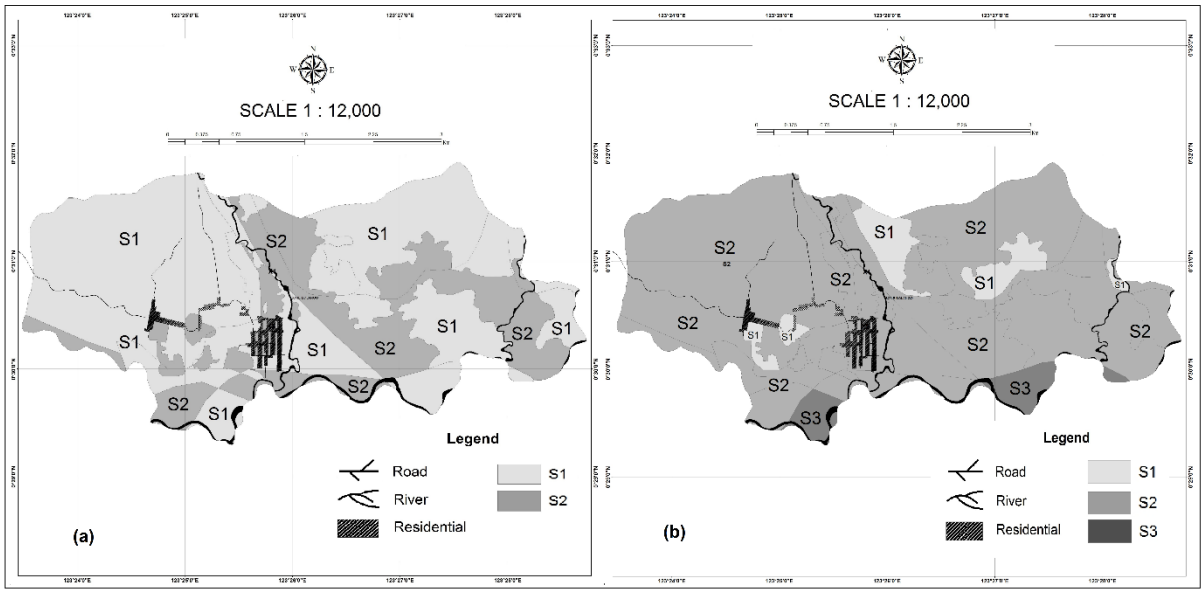

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

DISCUSSION

The suitability of land for liberica coffee with the limiting factor method and the parametric method turned out to be different, both in terms of class and area. This study shown that the land suitability class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the land suitability class using the parametric method was more dominant of moderately suitable. Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all

with the productivity of liberica coffee. The limiting factor method has weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018). In contrast to the land suitability class with the parametric method, besides being based on the performance of land characteristics, it has also been directly related to the productivity of liberica coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), the precision and reliability of parametric methods more greater than other land evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map. This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be done by adding organic matter and fertilizing according to the recommended dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked again in the field. While the parameteric method in principle gives values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the parametric method is closer to the real conditions in the field, where the average liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there is a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes also increases quantitatively.

This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that the difference in the results of the land suitability assessment is not caused by differences in the characteristics of the land but because of the

final value produced by the two methods. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor method makes it possible to determine the suitability class but without further specification (Abbasi et al., 2019). While in the parametric method, the use of land characteristics is based on the availability of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee plants, so their productivity must be estimated. In determining land suitability using the parametric method, the most limiting factor will have less effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. In fact, it can include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee is higher, often contrasts with the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of land suitability classes for liberica coffee in each of these areas along with their agronomic performance and productivity.

CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

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THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these productivity is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and their impact on land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land management recommendations for liberica coffee were priority I and II based on parametric methods.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica coffee in the world because of its limited area, so that publications are also relatively limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 ts, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 ts or an increase of 2.62% from the previous year with a value of 809,158,900 US$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 ts or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee

producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha^{-1} $year^{-1}$. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 t ha^{-1} (Indonesia Research Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 t (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land.

Until now there is no available information about the potential of land for the development of Liberika Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica coffee itself, because differences in land potential will be responded by variously by plants according to growing conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different land evaluation methods have different data requirements and varying quality of estimates, but there is no fixed rule that defines when and what method to use when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and

consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research area is included in the agro-climatic zone C1 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while the monthly wind speed is between 2 knots to 2.60 knots. The research area is the upstream of the Bone watershed which flows to Tomini Bay.

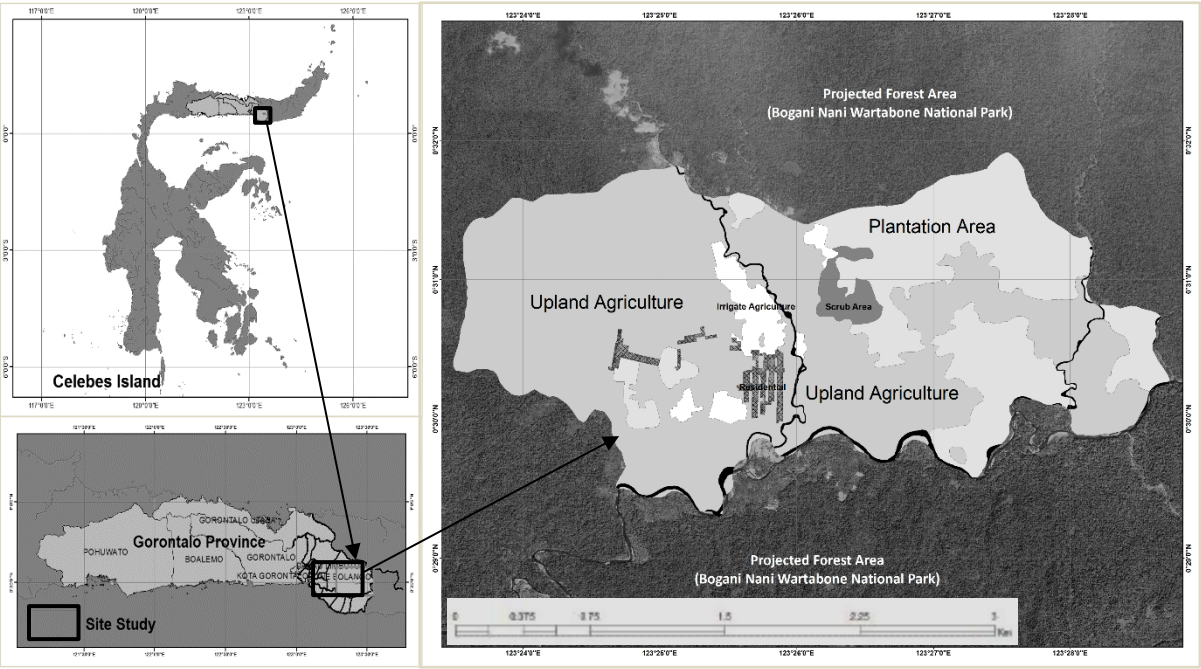

Figure 1. Research Location Map

Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory

analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105^oC, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in dbf or xls format.

Land Suitability Assesment

The deskwork in the suitability assessment is carried out based on the parameters of the selected land characteristics which are the same between the limiting factor method and the parametric method. Assessment of land suitability classes using the limiting factor method follows the land evaluation framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units. Furthermore, the data on land characteristics and quality were compared with the selected *Coffea liberica* HP. land suitability criteria (Table 1) according to the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability class is obtained.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land characteristics	Land suitability class			
	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes-sl (%)	0 – 8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 – 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

Remark: (Indonesian Directorate General of Plantations, 2014), modifed.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the productivity of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely:

Y = -2.672+0.026X (elevation) ..... (1)

Y = 17,190-0.090X (slope) ..... (2)

Y = 3.055+0.005X (soil pH) ..... (3)

Y = 4.050-0.019X (C-organic) ..... (4)

Y = -28.796+0.621X (P availability) ..... (5)

Y = 32.450-0.109X (CEC) ..... (6)

Y = 0.457-0.002X (base saturation) ..... (7)

In this case, Y = estimated production (t ha^{-1}), X = soil and land properties parameters, and CEC = cation exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (t ha^{-1}), Ft = estimated productivity (t ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

RESULTS

Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28

6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were improved with the addition of organic matter, while the limiting factor for available nutrients of low P availability was improved with the addition of P fertilizer. As a result, the most dominant potential land suitability class was S1 covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
Luas (Ha)					2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

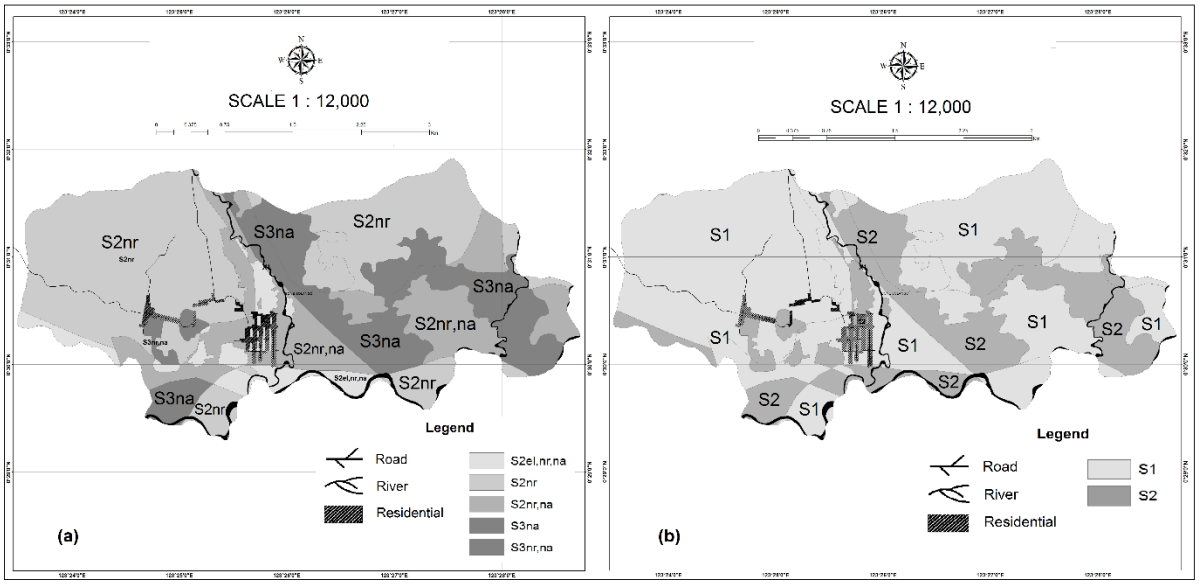

Figure 2. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Based on Parametric Method

The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which averaged 1.69 t ha^{-1}, while the lowest productivity was obtained on the available P characteristics which only ranged from 0.16 – 0.24 t ha^{-1} with an average of 0.20 t ha^{-1} (Table 4). The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of productivity for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic	LMU												
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha^{-1})	*0.49*	*0.53*	*0.55*	*0.52*	*0.54*	*0.53*	*0.49*	*0.48*	*0.61*	*0.51*	*0.60*	*0.53*	*0.54*
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha^{-1})	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.69*	*1.65*	*1.69*	*1.65*	*1.69*
pH	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

Characteristic /*Productivity*	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha^{-1})	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha^{-1})	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*	*0.40*
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha^{-1})	*0.30*	*0.30*	*0.29*	*0.30*	*0.30*	*0.29*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*	*0.30*	*0.29*
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha^{-1})	*0.39*	*0.39*	*0.40*	*0.41*	*0.40*	*0.40*	*0.38*	*0.38*	*0.38*	*0.37*	*0.39*	*0.38*	*0.41*
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha^{-1})	*0.20*	*0.19*	*0.23*	*0.21*	*0.18*	*0.17*	*0.20*	*0.16*	*0.19*	*0.23*	*0.18*	*0.19*	*0.24*
$\bar{Y}$ (t ha^{-1})	*0.60*	*0.60*	*0.61*	*0.60*	*0.60*	*0.60*	*0.60*	*0.59*	*0.61*	*0.60*	*0.61*	*0.59*	*0.61*
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 4.02% only without not suitable class (N).

Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity /LC Value	LMU												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha^{-1})	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-Sl. (t ha^{-1})	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha^{-1})	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t ha^{-1})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha^{-1})	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha^{-1})	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t ha^{-1})	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Based on the results of the land suitability assessment between the limiting factor and the parametric method were shown in Table 6 and Figure 3. The comparison between the two methods shows the similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10). But the most dominant class differences follow the pattern: S1 ≠ S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11, and LMU 12), followed by class pattern: S2 ≠ S1 of 7.21% (LMU 3, and LMU 13), while the lowest was

the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was different from the land suitability class using the parametric method, where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Recomendation	Area	
	Limiting Factor Method	Parametric Method		ha	%
1, 7, 10	S2	S2	Priority I	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59
3, 13	S2	S1	Priority I	202.07	7.21
8	S1	S3	Priority III	112.84	4.02
Area (ha)				2,804.28	100.00

Remark: LMU = land mapping unit.

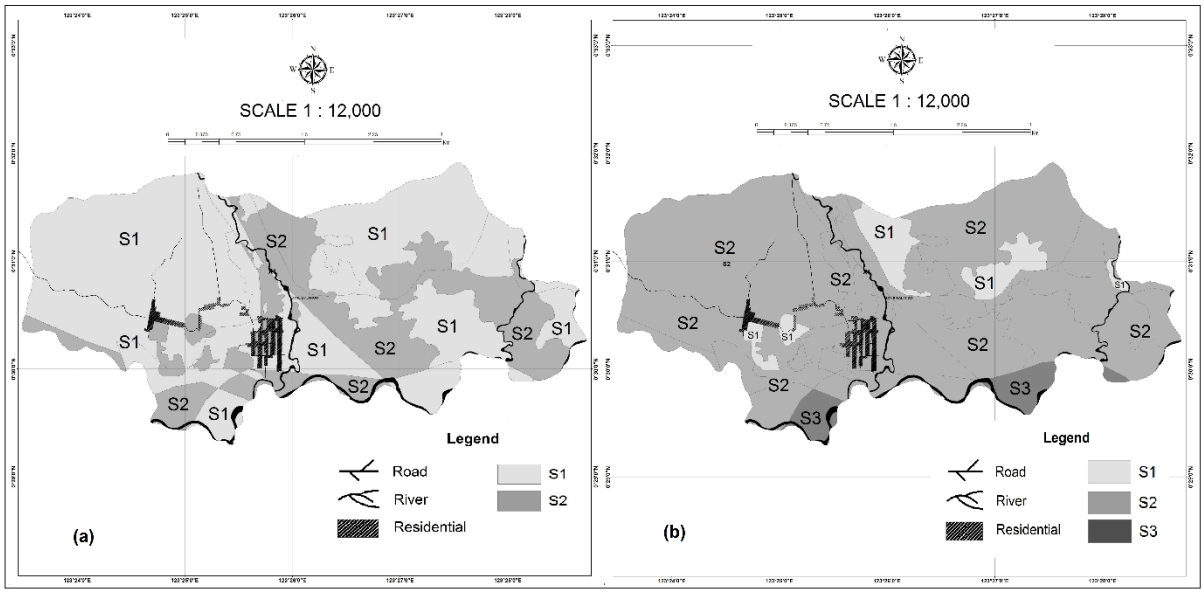

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

DISCUSSION

The suitability of land for liberica coffee with the limiting factor method and the parametric method turned out to be different, both in terms of class and area. This study shown that the land suitability class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the land suitability class using the parametric method was more dominant of moderately suitable. Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all

with the productivity of liberica coffee. The limiting factor method has weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018). In contrast to the land suitability class with the parametric method, besides being based on the performance of land characteristics, it has also been directly related to the productivity of liberica coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), the precision and reliability of parametric methods more greater than other land evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map. This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be done by adding organic matter and fertilizing according to the recommended dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked again in the field. While the parameteric method in principle gives values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the parametric method is closer to the real conditions in the field, where the average liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there is a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes also increases quantitatively.

This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that the difference in the results of the land suitability assessment is not caused by differences in the characteristics of the land but because of the

final value produced by the two methods. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor method makes it possible to determine the suitability class but without further specification (Abbasi et al., 2019). While in the parametric method, the use of land characteristics is based on the availability of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee plants, so their productivity must be estimated. In determining land suitability using the parametric method, the most limiting factor will have less effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. In fact, it can include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee is higher, often contrasts with the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of land suitability classes for liberica coffee in each of these areas along with their agronomic performance and productivity.

CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

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PLEASE REVISE IN THIS FILE!

Response to the Reviewer's comments

REVIEWER B

Page number	Line number	Reviewer's Comment	Author's Revision
1	9, 10, 11	Tidak sesuai antara tujuan di abstrak dan di naskah/pendahuluan. Mana yang benar?	Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau.
1	11	Iya kah? Tidak ada survey dijelaskan di metode	already explained in the method
1	12	? dudung	Comparison of different land suitability classes (LSC) was implemented using the limiting factor and the parametric methods. Meanwhile, the land management were referred to recommendation I or equal to very suitable (S1), II or equal to moderately suitable (S2), III or equal to marginaly suitable (S3) and recommendation IV or equal to not suitable (N).
1	13-19	Abtstrak tidak mengulang kesimpulan	The results showed that the actual LSC for liberica coffee using the limiting factor method were consisted of S2 and S3 classes. After improvement of LSC, the potentialof LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method consisted of S1, S2 and S3 classes. The land for liberica coffee with the limiting factor method consist of recommendation I and II, while the parametric method consist of recommendation I, II and III. The results revealed that the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.
1	21	Ikuti standard untuk keywords Land suitability evaluation, liberica coffea, Pinogu Plateu, Sulawesi Keyword adalah kata untuk pencarian di perpustakaan atau web yang mencerminkan isi tulisan	Land suitability evaluation, liberica coffea, Pinogu Plateau, Sulawesi
1	40	Kecamatan=district	District
1	41	km2)	km^2
2	9	Juga dijumpai di Jambi, Riau, Bengkulu. Cek lagi	become an endemic plant because this species only exists and grows in Pinogu District for the northern part of Sulawesi.
2	21, 22	Cek penulisan. Liberika vs Liberica. Lihat baris 8.	Liberica coffee

2	25	? jangan dikode, tp deskripsi; agak sesuai	Moderately suitable
3	4	Rekomendasai belum banyak dibahas di naskah hanya prioritas saja. Apa maksud rekomendasai di sini?	already repaired
3	9	North	North
3	36	?	Soil belt
3	36	?	Was removed
3	37	?	permanent spidol
3	38	maps 1 : 12,000 scale land unit	already repaired
3	38	rubber band	fastening rubber
4	10	using	were determined
4	16	Agar kalimat diperbaiki, maknanya tidak jelas	The land suitability assessment was carried out based on the parameters of selected land characteristics which were the same between the limiting factor method and the parametric method
4	23, 24	Ini diperbaiki kalimatnya	Furthermore, the limiting factor of the actual land suitability class was carried out improvement efforts, in order to obtain a potential land suitability class.
4	26	Ini dijelaskan di catatan di bawah tabel. Artinya apa?	already repaired
4	28, 29, 30	Diperbaiki kailimatnya. Buat kalimat sederhana saja	already repaired
5	20-25	Diperbaiki kalimatnya, tidak begitu mudah difahami	The determination of land suitability class based on land index (LI) was calculated from all LC values that affect of the liberica coffee productivity. The LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and N class (not suitable) with value 0 – 25. The formulation recommendations of land management for liberica coffee was determined based on the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the land with land suitability of S2 class and recommendation III was the land with land suitability of S3 class. Meanwhile, not recommended was the land with land suitability of N class. All data and information obtained were described and presented in tabular form, while their spatial distribution was presented in map form.
6	3	Ini harus dibahas di metode. Buat sub bab LMU	LMU sub-chapter has been made

6	12	Ini diuraikan di metode sebagai data input. Jelaskan juka data karakteristik lahan di metode	already discussed in the method
7	2	Dicek lagi petanya, kecil peluang batas peta berupa garis lurus seperti yang bagian tengah	The change in the shape of the map is thought to be due to a different Microsoft Office application, so it changes
7	5 – 8	Kalimat ini kepanjangan dsn sulit difahami. Buat yang kalimat sederehana dan efisien. Table 4 show that…	Table 4 show that the highest productivity of liberica coffee was obtained on the slope characteristics with an average of 1.69 ton ha^{-1}, while the lowest was on the P availability with an average of 0.20 ton ha^{-1}.
7	24	Dibuat kagi format tabel yang mudah difahami oleh pembaca..	the table has been rearranged
8	4-5	Persentase dari mana? 4.02% of total area?	Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% of total area (Table 5). Meanwhile, the S1 class was 7.21% of total area and the S3 class was 4.02% of total area without not suitable class (N).
8	8	Susun tabel ini lebih sederhana, boleh juga dibuat beberapa tabel. Membingungkan bagi pembaca.	the table has been rearranged
8	14-15	Hindari pengulangan, ini sudah di metode. Dalam bahasa inggris, buat kalimat sederhana, singkat, langsung ke point, selalu hemat kata (jangan wordy) Table 6 show…	Table 6 show that the comparison between the two methods shows the similarity of the land suitability class (S2 : S2) of 22.18% of total area (LMU 1, 7 and LMU 10). But the most dominant class differences (S1 : S2) of 66.59% of total area (LMU 2, 4, 5, 6, 9, 11, and LMU 12), class S2 : S1 of 7.21% of total area (LMU 3, and LMU 13), while the lowest was the class (S1 : S3) of 4.02% of total area (LMU 8).
9	1-6	Kalimat ini sulit difahami oleh pembaca. Kata only dalam bahasa inggris hanya untuk mata uang	Based on land suitability class of the limiting factor method, the land that was included in recommendation I (S1) was 70.62% of the total area, while recommendation II (S2) was 29.38% of the total area, without land recommendation III (S3) and recommendation IV (N). In contrast to the parametric method, where land that was included in recommendation I (S1) was 7.21% of the total area, recommendation II (S2) was 88.77% of the total area, while land with recomendation III (S3) was 4.20% of the total area without land recommendation IV (N).

9	18-19	This study shown that, by limiting factor method, the dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class is moderately suitable (S2).	This study shown that, by limiting factor method, the dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class is moderately suitable (S2).
10	15	Cari yg satu kata	Evidently
10	26	Paragraph terlalu panjang. Bisa dibagi 2. Semakin panjang paragraf semakin sulit dimengerti.. Semakin panjang kalimat semakin sulit difahami	Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use were irrigated rice fields and swamps that often inundated was classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were without further specifications (Abbasi et al., 2019). Meanwhile, with the parametric method, LMU 4 and LMU 6 are included in the quite appropriate class (S2) which is more realistic with the conditions of land use. The parameteric method in principle assigns values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). On the parametric method, the most limiting factor will reduce its effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).
11	41-43	Ini mau menulis apa? Apa yang ingin disampaikan. Sebelum menulis, selalu tulis pikiran utamanya	already repaired

Remarks: in the revised copy, it must include highlighted changes and modifications recommended in the revision to ensure that all editor/reviewer(s)' comments were considered.

REVIEWER D

Page number	Line number	Reviewer's Comment	Author's Revision
1	12-13	A complete sentence with the practical meaning but missing the linguistic meaning	Comparison of different land suitability classes (LSC) was implemented using the limiting factor and the parametric methods.
1	16-17	A complete sentence with the practical meaning but missing the linguistic meaning	After improvement of LSC, the potentialof LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method consisted of S1, S2 and S3 classes.
3	33-42	I recommend to read the following article to be added in this portion:	already cited in the manuscript
5	25	I think a small comparison between using the limiting factor method and the parametric method is needed here at the end of the methodology.	already repaired
11	31-36	Not enough, more detailed could be added.	The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low P nutrients. The land for liberica coffee with the limiting factor method consist of recommendation I and II. Meanwhile, the parametric method consist of recommendation I, II and III for liberica coffee. Land suitability assessment using the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.

Remarks: in the revised copy, it must include highlighted changes and modifications recommended in the revision to ensure that all editor/reviewer(s)' comments were considered.

THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these productivity is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability classes (LSC) was implemented using the limiting factor and the parametric methods. Meanwhile, the land management were referred to recommendation I or equal to very suitable (S1), II or equal to moderately suitable (S2), III or equal to marginaly suitable (S3) and recommendation IV or equal to not suitable (N). The results showed that the actual LSC for liberica coffee using the limiting factor method were consisted of S2 and S3 classes. After improvement of LSC, the potentialof LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method consisted of S1, S2 and S3 classes. The land for liberica coffee with the limiting factor method consist of recommendation I and II, while the parametric method consist of recommendation I, II and III. The results revealed that the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica coffee in the world because of its limited area, so that publications are also relatively limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or an increase of 2.62% from the previous year with a value of 809,158,900 US$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km^2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and become an endemic plant because this species only exists and grows in Pinogu District for the northern part of Celebes. Liberica coffee has the advantage of good taste (Gusfarina, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 ton ha^{-1} (Indonesian Industrial and Beverage Crops Research Institute, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 ton (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land.

Until now there is no available information about the potential of land for the development of Liberica Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable (S3) class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the moderately suitable class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica coffee itself, because differences in land potential will be responded by variously by plants according to growing conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is an important contribution in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (Abdelrahman et al., 2016) and efficient use in agriculture land (Zakarya et al., 2021). Information of the land use potential forms were presented on the output of the land evaluation, including of their consequences, beneficial and adverse of each degree class (Shalaby et al., 2017). Likewise with land use planning for liberica coffee. Different land evaluation methods have different data requirements and varying quality of estimates, but there is no fixed rule that defines when and what method to use when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021).

Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North to 123°18'38.52" – 123°33'15.48" East covering an area of 2,804.28 ha with the elevation of 300 – 338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm and the monthly rainfall ranging from 19.00 mm to 408.18 mm, so the study area is included in the agro-climatic zone of C1 because the number of dry month (montly rainfall less than 100 mm) is only 1 month and the number of wet month (monthly rainfall more than 200 mm) is 6 months is wet. The monthly air temperature fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%, while the monthly wind speed is between 2 knots to 2.60 knots. The study area is the upstream of the Bone watershed which flows to Tomini Bay.

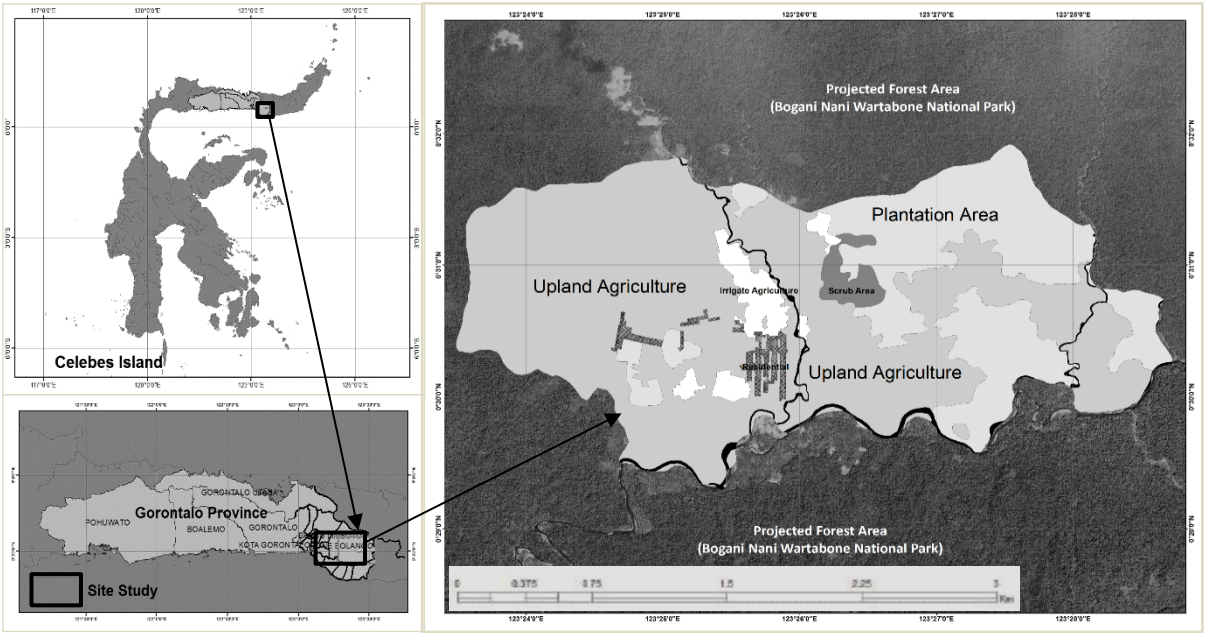
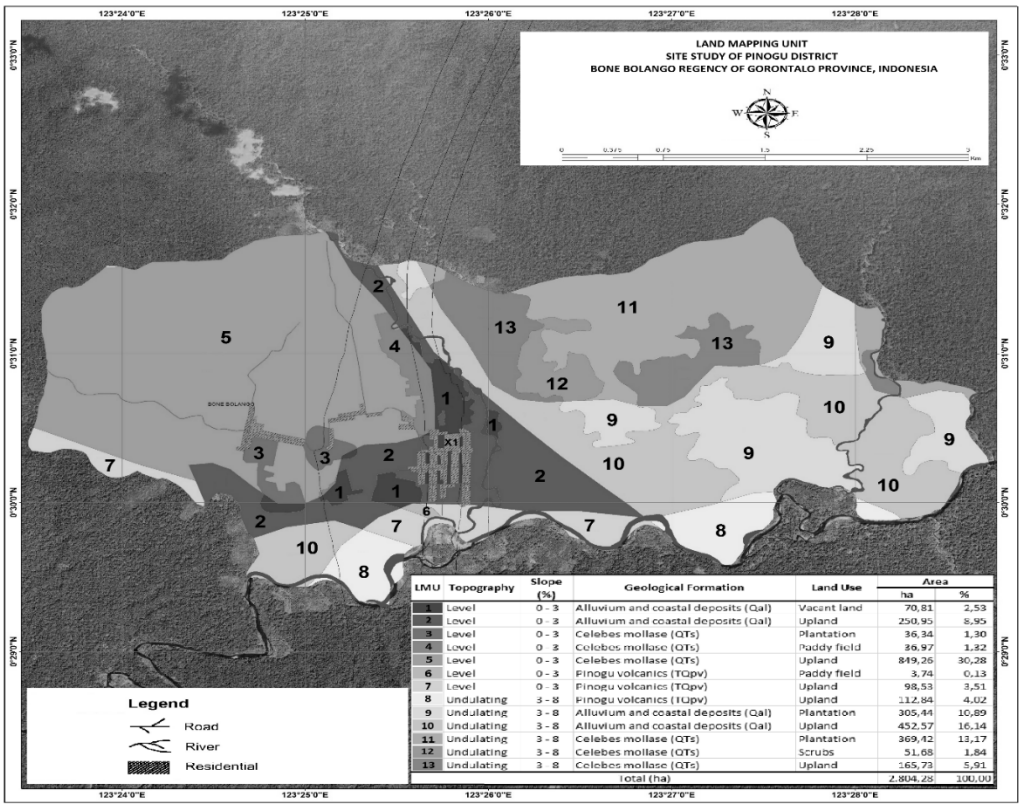


Figure 1. Research Location Map

Land Mapping Unit

Before carrying out soil survey and land observations, it begins with making a map of the land unit at a scale of 1: 12,000 (Fig. 2). This map contains of 13 land units which were the result of basic map overlays that has been adjusted to map scale, included: landform maps, slope maps, geological maps and maps of existing land use. Furthermore, this land unit map becames a reference in carrying out of soil survey and land observations, especially in determining soil observation points.



LMU	Topography	Slope (%)	Geological Formation	Land Use	Area ha	Area %
1	Level	0 - 3	Alluvium and coastal deposits (Qal)	Vacant land	70,81	2,53
2	Level	0 - 3	Alluvium and coastal deposits (Qal)	Upland	250,95	8,95
3	Level	0 - 3	Celebes mollase (QTs)	Plantation	36,34	1,30
4	Level	0 - 3	Celebes mollase (QTs)	Paddy field	36,97	1,32
5	Level	0 - 3	Celebes mollase (QTs)	Upland	849,26	30,28
6	Level	0 - 3	Pinogu volcanics (TQpv)	Paddy field	3,74	0,13
7	Level	0 - 3	Pinogu volcanics (TQpv)	Upland	98,53	3,51
8	Undulating	3 - 8	Pinogu volcanics (TQpv)	Upland	112,84	4,02
9	Undulating	3 - 8	Alluvium and coastal deposits (Qal)	Plantation	305,44	10,89
10	Undulating	3 - 8	Alluvium and coastal deposits (Qal)	Upland	452,57	16,14
11	Undulating	3 - 8	Celebes mollase (QTs)	Plantation	369,42	13,17
12	Undulating	3 - 8	Celebes mollase (QTs)	Scrubs	51,68	1,84
13	Undulating	3 - 8	Celebes mollase (QTs)	Upland	165,73	5,91
			Total (ha)		2.804,28	100,00

Figure 2. Land Mapping Unit

Soil Survey and Land Observation

A set of soil survey tools, included: soil knife, pH meter, soil belt, hoe, spade, clinometer and permanent spidol. Meanwhile, the materials used: soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory analysis. This field research used a soil survey method on a scale of 1: 12,000 by observing the soil properties on 13 land units (Fig.2). Furthermore, field observations were carried out to determine the land characteristics such as elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a

solution of 1:2.5 soil and water. Organic carbon content were determined with the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in spreasheet.

Land Suitability Assesment

The land suitability assessment was carried out based on the parameters of selected land characteristics which were the same between the limiting factor method and the parametric method. The assessment of land suitability classes used the limiting factor method followings the land evaluation framework (FAO, 1976). Land characteristics and quality were compared with the selected land suitability criteria (Table 1) from the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. Furthermore, the limiting factor of the actual land suitability class was carried out improvement efforts, in order to obtain a potential land suitability class.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Simbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes	sl	%	0 – 8	8 – 25	25 – 45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (*Walkley & Black*)		%	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10 – 15	5 – 10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20-35	<20	-
Nutrient availability:	na					
P-availability (*Olsen*)		ppm	>16	10 – 15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modifed.
Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea level, ppm = part per million.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the productivity (Y) of coffee uses several equations (Simbolon, 2018) namely:

Y = -2.672 + 0.026 Elevation ..... (1)

Y = 17,190 - 0.090 Slope ..... (2)

Y = 3.055 + 0.005 pH H_2O ..... (3)

Y = 4.050 - 0.019 C organic ..... (4)

Y = -28.796 + 0.621 P Olsen ..... (5)

Y = 32.450 - 0.109 Cation exchange capacity ..... (6)

Y = 0.457 - 0.002 Base saturation ..... (7)

In this case, Y = estimated production (ton ha^{-1}). The assumption of the liberica coffee optimal productivity used of 0.75 ton ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC = land characteristic; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

The determination of land suitability class based on land index (LI) was calculated from all LC values that affect of the liberica coffee productivity. The LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and N class (not suitable) with value 0 – 25.

The formulation recommendations of land management for liberica coffee was determined based on the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the land with land suitability of S2 class and recommendation III was the land with land suitability of S3 class. Meanwhile, not recommended was the land with land suitability of N class. All data and information obtained were described and presented in tabular form, while their spatial distribution was presented in map form.

RESULTS

Land Suitability Class Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 3. It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02

9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
								Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

The potential land suitability class was dominatly of S1 that covering an area of 1,980.30 ha or 70.62% of total area and the rest including S2 class covering an area of 823.98 ha or 29.38% of total area. After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were improved with the addition of organic matter, while the limiting factor for available nutrients of low P availability was improved with the addition of P fertilizer.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

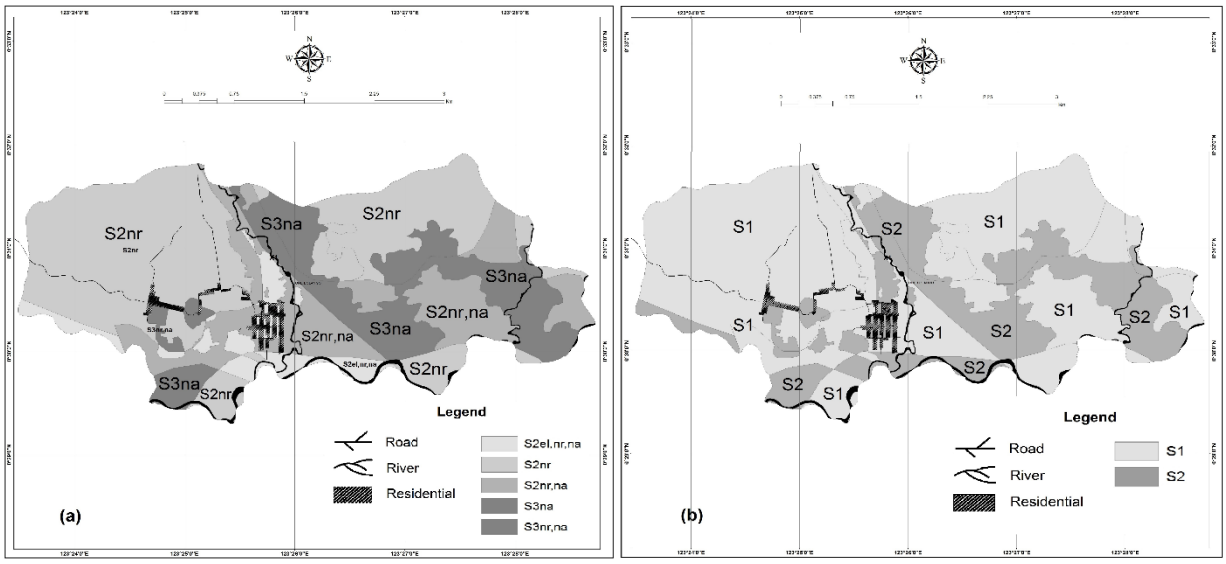


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Class Based on Parametric Method

Table 4 show that the highest productivity of liberica coffee was obtained on the slope characteristics with an average of 1.69 ton ha^{-1}, while the lowest was on the P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of productivity for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which the averaged value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50. The remaining LMUs get land index values ranged from 50 – 71. The varous of land index values will greatly affect the land suitability class for liberica coffee later.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		$\bar{Y}$ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remark: LMU = land mapping unit, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m asl = mean above sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% of total area (Table 5). Meanwhile, the S1 class was 7.21% of total area and the S3 class was 4.02% of total area without not suitable class (N).

Table 5. Value of Land Characteristics Rating, Land Index and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13

7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
								Total (ha)									2.804,28	100

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Table 6 show that the comparison between the two methods shows the similarity of the land suitability class (S2 : S2) of 22.18% of total area (LMU 1, 7 and LMU 10). But the most dominant class differences (S1 : S2) of 66.59% of total area (LMU 2, 4, 5, 6, 9, 11, and LMU 12), class S2 : S1 of 7.21% of total area (LMU 3, and LMU 13), while the lowest was the class (S1 : S3) of 4.02% of total area (LMU 8).

Based on land suitability class of the limiting factor method, the land that was included in recommendation I (S1) was 70.62% of the total area, while recommendation II (S2) was 29.38% of the total area, without land recommendation III (S3) and recommendation IV (N). In contrast to the parametric method, where land that was included in recommendation I (S1) was 7.21% of the total area, recommendation II (S2) was 88.77% of the total area, while land with recomendation III (S3) was 4.20% of the total area without land recommendation IV (N).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

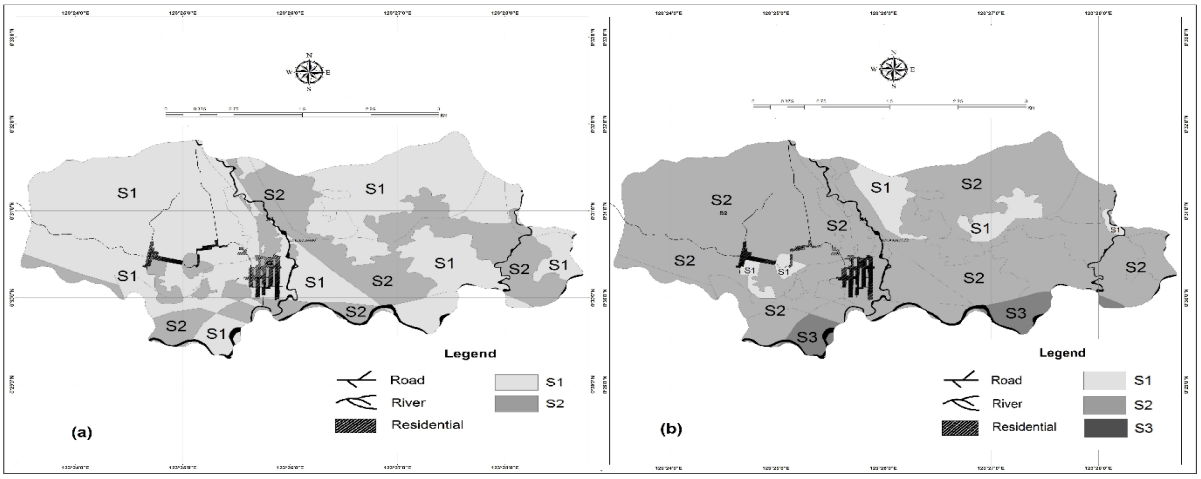


Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

DISCUSSION

The land suitability for liberica coffee with the limiting factor method and the parametric method was different, both in terms of class and areas. This study shown that, by limiting factor method, the dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class is moderately suitable (S2). Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all with the productivity of liberica coffee. The limiting factor method has weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018).

In contrast to the land suitability class with the parametric method, besides being based on the performance of land characteristics, it has also been directly related to the productivity of liberica coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), the precision and reliability of parametric methods more greater than other land evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map. This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it evidently that there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index should be improved so that the plant grows optimally (Israminanti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be done by adding organic matter and fertilizing according to the recommended dose of fertilizer. The addition of organic matter can increase soil pH and C organic (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use were irrigated rice fields and swamps that often inundated was classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were without further specifications (Abbasi et al., 2019). Meanwhile, with the parametric method, LMU 4 and LMU 6 are included in the quite appropriate class (S2) which is more realistic with the conditions of land use. The parameteric method in principle assigns values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). On the parametric method, the most limiting factor will reduce its effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method following the class pattern S2 > S1 > S3. The advantage of the parametric method in addition to calculating land suitability classes based on soil properties is also calculating all factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the parametric method was closer to the real conditions in the field, where the average of liberica coffee productivity in the Pinogu Plateau ranges from 0.51 to 0.61 ton ha^{-1}, while the productivity of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there was a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes also increases quantitatively. Diagnostic criteria in the parametric method were assessed numerically and mathematically to obtain land suitability classes (Marbun et al., 2019), so as to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

The land for liberica coffee with the limiting factor method was dominated by recommendation I followed by recommendation II because the land with class of S1 was wider than class of S2. Meanwhile, the parametric method was more dominant by recommendation II followed by recommendation I and III because the land with class of S2 was wider than class of S1 and S3. In order to optimize land use for liberica coffee, it was necessary to improve the cultivation system including through fertilization (Nugroho, 2015). In addition, the position of liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed needs to implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2015). The distribution of land suitability classes and land recommendations for liberica coffee in Plato Pinogu were very important for developing this coffee. According to Saidi & Suryani (2021), the existence of land suitability maps was very important to providing information on the suitability of various agricultural commodities, limiting factors, widely and it distribution in an area.

CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low P nutrients. The land for liberica coffee with the limiting factor method consist of recommendation I and II. Meanwhile, the parametric method consist of recommendation I, II and III for liberica coffee. Land suitability assessment using the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.

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THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

ABSTRACT

Coffee is a national strategic commodity that contributes to the country's foreign exchange but these productivity is still low due to cultivation on low potential land. Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability classes (LSC) was implemented using the limiting factor and the parametric methods. Meanwhile, the land management were referred to recommendation I or equal to very suitable (S1), II or equal to moderately suitable (S2), III or equal to marginaly suitable (S3) and recommendation IV or equal to not suitable (N). The results showed that the actual LSC for liberica coffee using the limiting factor method were consisted of S2 and S3 classes. After improvement of LSC, the potentialof LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method consisted of S1, S2 and S3 classes. The land for liberica coffee with the limiting factor method consist of recommendation I and II, while the parametric method consist of recommendation I, II and III. The results revealed that the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.

Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

INTRODUCTION

Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica coffee in the world because of its limited area, so that publications are also relatively limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or an increase of 2.62% from the previous year with a value of 809,158,900 US$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km^2) at an altitude of > 300 m above sea level, and is surrounded by hills and mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and become an endemic plant because this species only exists and grows in Pinogu District for the northern part of Celebes. Liberica coffee has the advantage of good taste (Gusfarina, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 ton ha^{-1} (Indonesian Industrial and Beverage Crops Research Institute, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 ton (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not in accordance with the potential of the land.

Until now there is no available information about the potential of land for the development of Liberica Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable (S3) class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the moderately suitable class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica coffee itself, because differences in land potential will be responded by variously by plants according to growing conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment so that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is an important contribution in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (Abdelrahman et al., 2016) and efficient use in agriculture land (Zakarya et al., 2021). Information of the land use potential forms were presented on the output of the land evaluation, including of their consequences, beneficial and adverse of each degree class (Shalaby et al., 2017). Likewise with land use planning for liberica coffee. Different land evaluation methods have different data requirements and varying quality of estimates, but there is no fixed rule that defines when and what method to use when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021).

Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North to 123°18'38.52" – 123°33'15.48" East covering an area of 2,804.28 ha with the elevation of 300 – 338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm and the monthly rainfall ranging from 19.00 mm to 408.18 mm, so the study area is included in the agro-climatic zone of C1 because the number of dry month (montly rainfall less than 100 mm) is only 1 month and the number of wet month (monthly rainfall more than 200 mm) is 6 months is wet. The monthly air temperature fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%, while the monthly wind speed is between 2 knots to 2.60 knots. The study area is the upstream of the Bone watershed which flows to Tomini Bay.

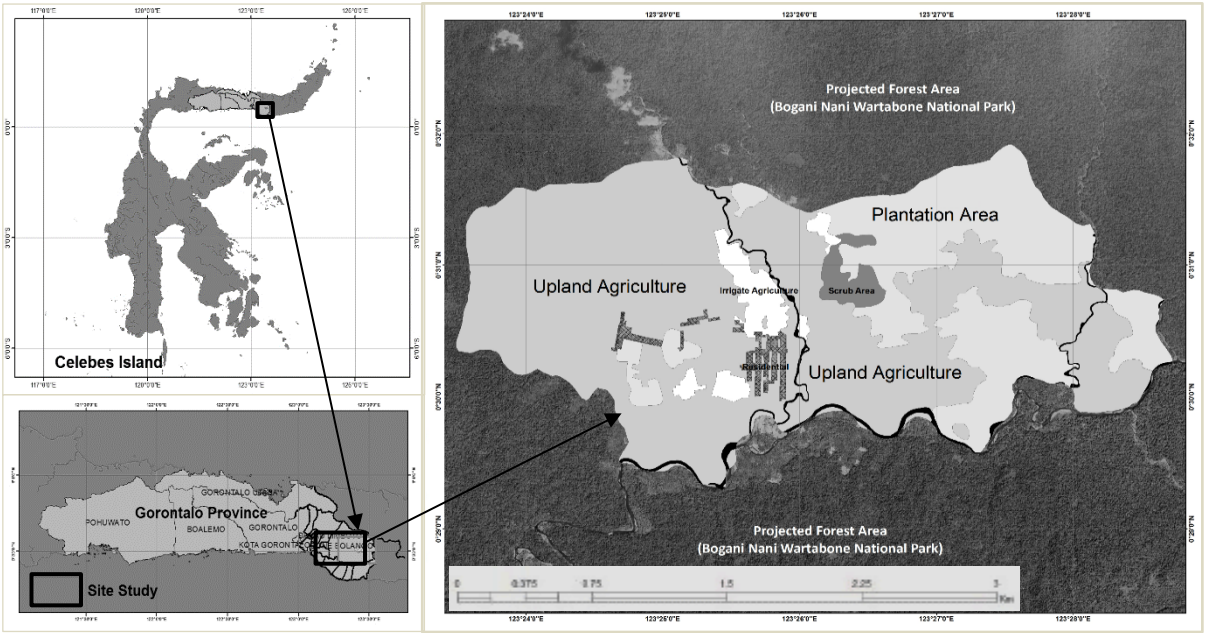
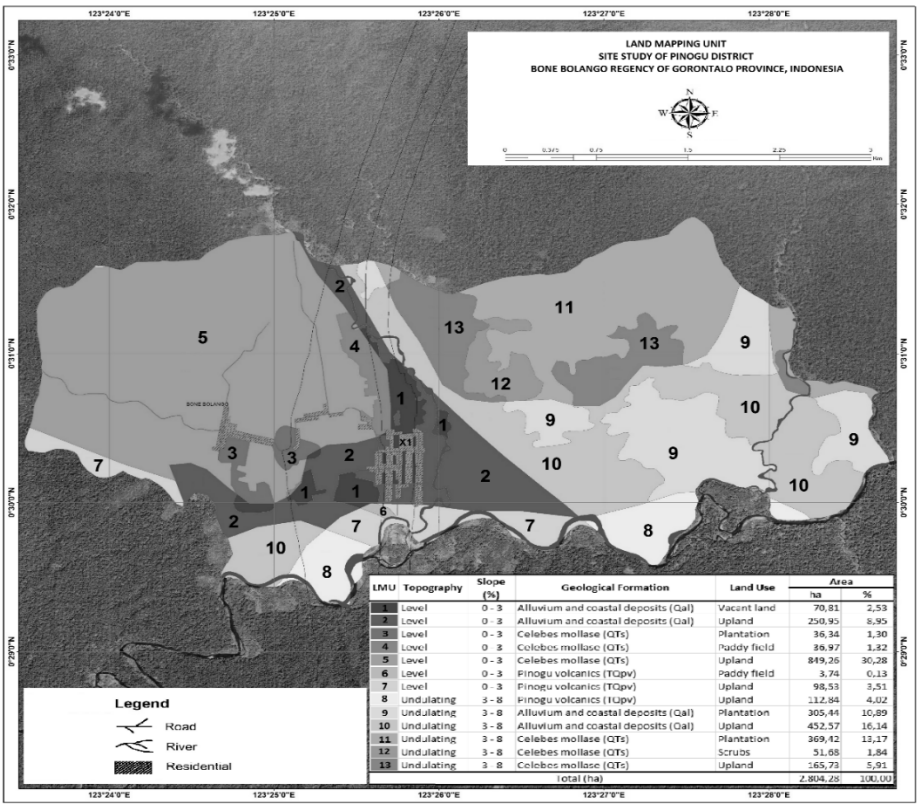


Figure 1. Research Location Map

Land Mapping Unit

Before carrying out soil survey and land observations, it begins with making a map of the land unit at a scale of 1: 12,000 (Fig. 2). This map contains of 13 land units which were the result of basic map overlays that has been adjusted to map scale, included: landform maps, slope maps, geological maps and maps of existing land use. Furthermore, this land unit map becames a reference in carrying out of soil survey and land observations, especially in determining soil observation points.



LMU	Topography	Slope (%)	Geological Formation	Land Use	Area	
					ha	%
1	Level	0 - 3	Alluvium and coastal deposits (Qal)	Vacant land	70,81	2,53
2	Level	0 - 3	Alluvium and coastal deposits (Qal)	Upland	250,95	8,95
3	Level	0 - 3	Celebes mollase (QTs)	Plantation	36,34	1,30
4	Level	0 - 3	Celebes mollase (QTs)	Paddy field	39,97	1,42
5	Level	0 - 3	Celebes mollase (QTs)	Upland	849,26	30,28
6	Level	0 - 3	Pinogu volcanics (TQpv)	Paddy field	3,74	0,13
7	Level	0 - 3	Pinogu volcanics (TQpv)	Upland	98,53	3,51
8	Undulating	3 - 8	Pinogu volcanics (TQpv)	Upland	112,84	4,02
9	Undulating	3 - 8	Alluvium and coastal deposits (Qal)	Plantation	305,44	10,89
10	Undulating	3 - 8	Alluvium and coastal deposits (Qal)	Upland	452,57	16,14
11	Undulating	3 - 8	Celebes mollase (QTs)	Plantation	369,42	13,17
12	Undulating	3 - 8	Celebes mollase (QTs)	Scrubs	51,68	1,84
13	Undulating	3 - 8	Celebes mollase (QTs)	Upland	165,73	5,91
			Total (ha)		2.804,28	100,00

Figure 2. Land Mapping Unit

Soil Survey and Land Observation

A set of soil survey tools, included: soil knife, pH meter, soil belt, hoe, spade, clinometer and permanent spidol. Meanwhile, the materials used: soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory analysis. This field research used a soil survey method on a scale of 1: 12,000 by observing the soil properties on 13 land units (Fig.2). Furthermore, field observations were carried out to determine the land characteristics such as elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a

solution of 1:2.5 soil and water. Organic carbon content were determined with the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was determined by calculation. All soil data and selected land characteristic data are input in spreasheet.

Land Suitability Assesment

The land suitability assessment was carried out based on the parameters of selected land characteristics which were the same between the limiting factor method and the parametric method. The assessment of land suitability classes used the limiting factor method followings the land evaluation framework (FAO, 1976). Land characteristics and quality were compared with the selected land suitability criteria (Table 1) from the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. Furthermore, the limiting factor of the actual land suitability class was carried out improvement efforts, in order to obtain a potential land suitability class.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Simbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300 – 500	600 – 800; 0 – 300	800 – 1.000	>1,000
Slopes	sl	%	0 – 8	8 – 25	25 – 45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5 – 6.0	6.1 – 7.0	7.1 – 8.0	>8.0
C-organic (*Walkley & Black*)		%	2 – 5	1 – 2; 5 – 10	0.5 – 1.0; 10 – 15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10 – 15	5 – 10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20-35	<20	-
Nutrient availability:	na					
P-availability (*Olsen*)		ppm	>16	10 – 15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modifed.
Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea level, ppm = part per million.

Meanwhile, in assessing land suitability using the parametric method, it is estimated that the productivity (Y) of coffee uses several equations (Simbolon, 2018) namely:

Y = -2.672 + 0.026 Elevation ..... (1)

Y = 17,190 - 0.090 Slope ..... (2)

Y = 3.055 + 0.005 pH H_2O ..... (3)

Y = 4.050 - 0.019 C organic ..... (4)

Y = -28.796 + 0.621 P Olsen ..... (5)

Y = 32.450 - 0.109 Cation exchange capacity ..... (6)

Y = 0.457 - 0.002 Base saturation ..... (7)

In this case, Y = estimated production (ton ha^{-1}). The assumption of the liberica coffee optimal productivity used of 0.75 ton ha^{-1} (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC = land characteristic; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

The determination of land suitability class based on land index (LI) was calculated from all LC values that affect of the liberica coffee productivity. The LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and N class (not suitable) with value 0 – 25.

The formulation recommendations of land management for liberica coffee was determined based on the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the land with land suitability of S2 class and recommendation III was the land with land suitability of S3 class. Meanwhile, not recommended was the land with land suitability of N class. All data and information obtained were described and presented in tabular form, while their spatial distribution was presented in map form.

RESULTS

Land Suitability Class Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 3. It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02

9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
								Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

The potential land suitability class was dominatly of S1 that covering an area of 1,980.30 ha or 70.62% of total area and the rest including S2 class covering an area of 823.98 ha or 29.38% of total area. After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, both pH, C-organic, and low base saturation were improved with the addition of organic matter, while the limiting factor for available nutrients of low P availability was improved with the addition of P fertilizer.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

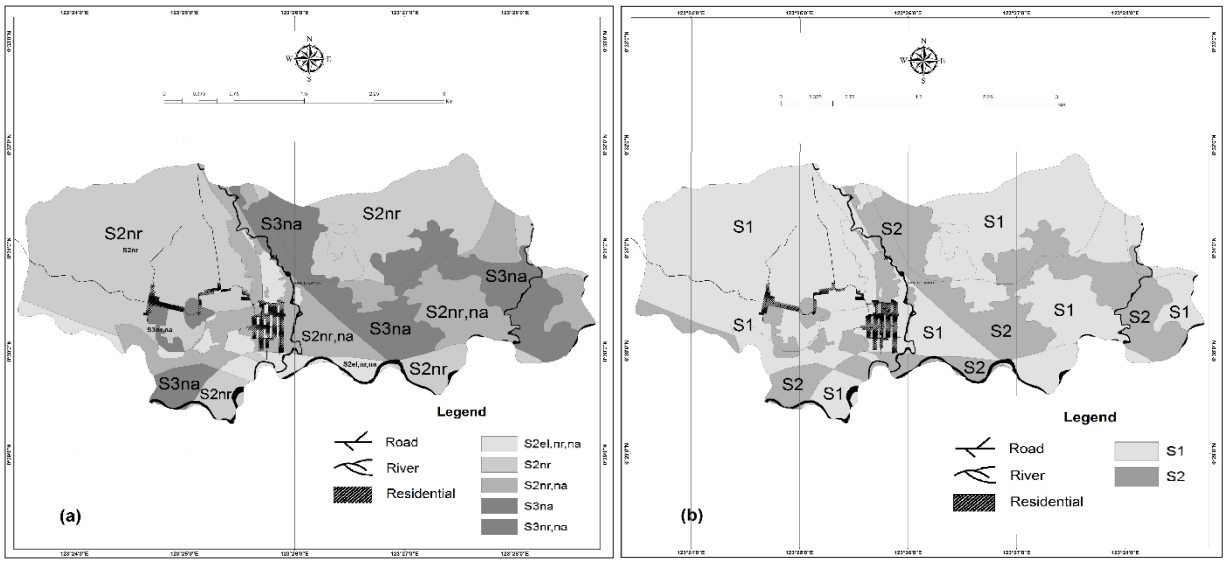


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Class Based on Parametric Method

Table 4 show that the highest productivity of liberica coffee was obtained on the slope characteristics with an average of 1.69 ton ha^{-1}, while the lowest was on the P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately determine the land index and land suitability class for liberica coffee.

It seems that the relative land characteristic index values follow the pattern of productivity for liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which the averaged value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability index of 26.39. The remaining land characteristics are relatively diverse but the average value of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50. The remaining LMUs get land index values ranged from 50 – 71. The varous of land index values will greatly affect the land suitability class for liberica coffee later.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		$\bar{Y}$ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remark: LMU = land mapping unit, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m asl = mean above sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% of total area (Table 5). Meanwhile, the S1 class was 7.21% of total area and the S3 class was 4.02% of total area without not suitable class (N).

Table 5. Value of Land Characteristics Rating, Land Index and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13

7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
								Total (ha)									2.804,28	100

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Table 6 show that the comparison between the two methods shows the similarity of the land suitability class (S2 : S2) of 22.18% of total area (LMU 1, 7 and LMU 10). But the most dominant class differences (S1 : S2) of 66.59% of total area (LMU 2, 4, 5, 6, 9, 11, and LMU 12), class S2 : S1 of 7.21% of total area (LMU 3, and LMU 13), while the lowest was the class (S1 : S3) of 4.02% of total area (LMU 8).

Based on land suitability class of the limiting factor method, the land that was included in recommendation I (S1) was 70.62% of the total area, while recommendation II (S2) was 29.38% of the total area, without land recommendation III (S3) and recommendation IV (N). In contrast to the parametric method, where land that was included in recommendation I (S1) was 7.21% of the total area, recommendation II (S2) was 88.77% of the total area, while land with recomendation III (S3) was 4.20% of the total area without land recommendation IV (N).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

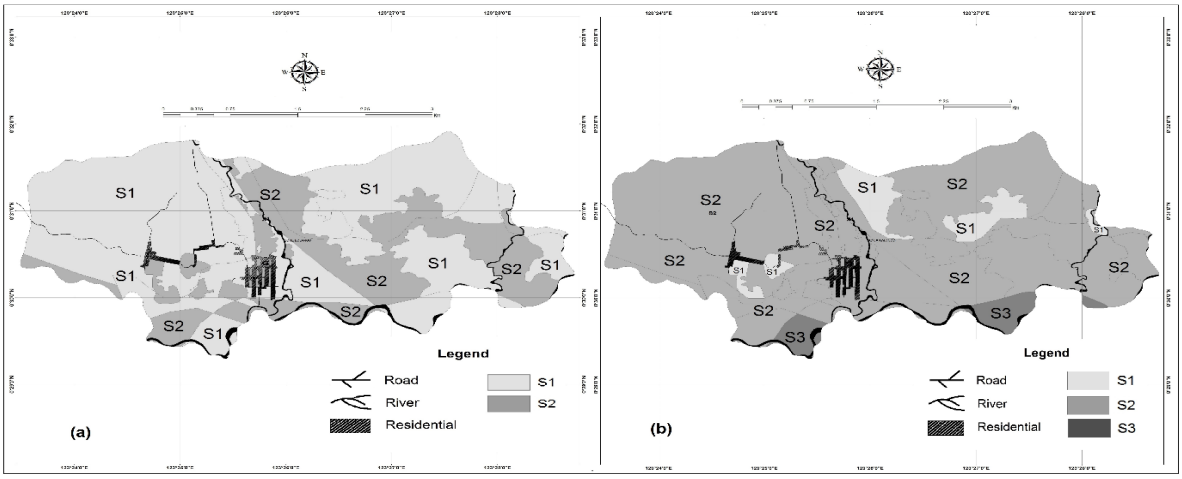


Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

DISCUSSION

The land suitability for liberica coffee with the limiting factor method and the parametric method was different, both in terms of class and areas. This study shown that, by limiting factor method, the dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class is moderately suitable (S2). Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all with the productivity of liberica coffee. The limiting factor method has weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018).

In contrast to the land suitability class with the parametric method, besides being based on the performance of land characteristics, it has also been directly related to the productivity of liberica coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), the precision and reliability of parametric methods more greater than other land evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority of this parametric method is not only calculating land suitability classes based on soil properties but also taking into account all factors and mapping them in one land suitability map. This parametric method with the square root of the land index uses a minimum rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it evidently that there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index should be improved so that the plant grows optimally (Israminanti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be done by adding organic matter and fertilizing according to the recommended dose of fertilizer. The addition of organic matter can increase soil pH and C organic (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use were irrigated rice fields and swamps that often inundated was classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were without further specifications (Abbasi et al., 2019). Meanwhile, with the parametric method, LMU 4 and LMU 6 are included in the quite appropriate class (S2) which is more realistic with the conditions of land use. The parameteric method in principle assigns values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). On the parametric method, the most limiting factor will reduce its effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method following the class pattern S2 > S1 > S3. The advantage of the parametric method in addition to calculating land suitability classes based on soil properties is also calculating all factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the parametric method was closer to the real conditions in the field, where the average of liberica coffee productivity in the Pinogu Plateau ranges from 0.51 to 0.61 ton ha^{-1}, while the productivity of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there was a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes also increases quantitatively. Diagnostic criteria in the parametric method were assessed numerically and mathematically to obtain land suitability classes (Marbun et al., 2019), so as to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

The land for liberica coffee with the limiting factor method was dominated by recommendation I followed by recommendation II because the land with class of S1 was wider than class of S2. Meanwhile, the parametric method was more dominant by recommendation II followed by recommendation I and III because the land with class of S2 was wider than class of S1 and S3. In order to optimize land use for liberica coffee, it was necessary to improve the cultivation system including through fertilization (Nugroho, 2015). In addition, the position of liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed needs to implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2015). The distribution of land suitability classes and land recommendations for liberica coffee in Plato Pinogu were very important for developing this coffee. According to Saidi & Suryani (2021), the existence of land suitability maps was very important to providing information on the suitability of various agricultural commodities, limiting factors, widely and it distribution in an area.

CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low P nutrients. The land for liberica coffee with the limiting factor method consist of recommendation I and II. Meanwhile, the parametric method consist of recommendation I, II and III for liberica coffee. Land suitability assessment using the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.

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We have edited your assignment for basic language and grammar, from the aspect of fluency, and would like to share our experience in editing your manuscript. Overall, we have made minor revisions to the manuscript in terms of language and grammar. We have also made a few revisions for accuracy and enhanced clarity.

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This is to certify that the following manuscript :

Title	:	COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA LIBERICA PINOGU HP. ACQUIRED USING DIFFERENT METHODS AND RECOMMENDATIONS FOR LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY, INDONESIA
Author	:	Nurdin*, Fauzan Zakaria, Muhammad Arief Azis, Yunnita Rahim, Rival Rahman, Mahmud Kasim
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Date: 17 February 2022

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Dr. Anthony Kent

~~THE~~ COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. ~~WITH~~ACQUIRED USING DIFFERENT METHODS~~,~~ AND ~~THEIR~~ RECOMMENDATIONS ~~OF~~FOR LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

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ABSTRACT

Coffee is a national strategic commodity that contributes to ~~the country's~~Indonesia's foreign exchange, but ~~these~~its productivity ~~is still~~remains low due to cultivation on low~~-~~ potential~~potential~~ land. ~~Study~~This study aimed to determine the land suitability ~~value~~ of endemic liberica coffee ~~with~~ using two different methods and ~~to~~ formulate recommendations for land management in Pinogu Plateau. ~~The 13~~Thirteen land units were surveyed, and soil samples were collected and analyzed ~~the soil samples~~ in the laboratory to ~~obtain data of~~identify the land ~~characteristic selected. Comparison of different land~~ characteristics. Land suitability classes (~~LSC) was implemented using the~~ LSCs) were compared by limiting factor and ~~the~~ parametric methods. ~~Meanwhile, the land management were referred to~~Land managements were classified as follows: recommendation I or ~~equal to~~ very suitable (S1), II or ~~equal to~~ moderately suitable (S2), III or ~~equal to marginaly~~marginally suitable (S3~~)~~), and ~~recommendation~~ IV or ~~equal to~~ not suitable (N). ~~The results~~ Analysis using the limiting factor method showed that the actual LSC for liberica coffee ~~using the limiting factor method were~~ consisted of S2 and S3 classes. ~~After~~Efforts for ~~-~~improvement ~~of LSC,~~could increase the ~~potentialof~~ potential of LSC to became ~~of~~ S1 and S2 classes. ~~Coversely~~Meanwhile, the ~~LSC using~~ assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. ~~The land for liberica coffee with the limiting factor method consist of recommendation I and II, while the parametric method consist of recommendation I, II and III. The~~These results revealed that the parametric method ~~was~~provides more realistic ~~on~~ land characteristics ~~in relation to liberica coffee productivity~~ than the limiting factor method.

Commented [Editor2]: Remark: In American English, a comma (called serial or Oxford comma) is inserted before "and" in a series of three or more items.

Keywords: ~~Land~~land, suitability, coffee, liberica, endemic, Pinogu~~.~~

INTRODUCTION

Coffee has long been recognized as a refreshing drink ~~in the world. The~~. Its global distribution is composed of ~~world~~arabica coffee ~~includes Arabica~~at 80%, robusta coffee ~~with a distribution area of 80%, Robusta~~at 20%, and liberica coffee ~~by 20% and Liberica coffee with a distribution area of~~at only <1% (Nillian et al., 2020). ~~It is relatively difficult to get research references~~ References and publications on liberica coffee ~~in the world~~are scarce because of its limited planting area~~, so that publications are also relatively limited. It is predicted that by~~. By 2050, the land suitable for robusta coffee cultivation ~~is~~will reach 83%, ~~while~~and that for arabica coffee ~~is~~will only be 17% ~~in the world~~ (Magrach & Ghazoul, 2015). ~~However, according to~~ Claude et al. (2019)~~, liberica coffee~~ reported that based on pedoclimatic zoning ~~is more~~, liberica coffee shows higher potential ~~to be cultivated~~for cultivation than robusta and arabica ~~coffee~~ because agro-climatic zoning ~~shows an increase in the potential for this coffee~~increases its production potential in the coming years.

Coffee ~~in Indonesia~~ is ~~still~~ a strategic commodity in Indonesia because ~~it is able to contribute~~its

export value contributes to the country's foreign exchange ~~from the export value of the commodity. Until 2020, national~~. National coffee production and export in 2020 separately reached 753,941 ~~tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached~~and 375,555.9 tons ~~or an increase of 2.62% from the previous year with a (~~value of 809,158,900 US~~$)~~ with increases of 0.19% and 2.62%, respectively, from the previous year (Indonesian Central Bureau of Statistics, 2020). ~~From this achievement of national coffee production, the contribution of~~ Gorontalo Province ~~is~~contributed only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in ~~the~~ Bone Bolango Regency, Gorontalo Province ~~which~~. This area is relatively flat and wide (496 km^2) ~~at~~with an altitude of > 300 m above sea level~~,~~ and is surrounded by hills and mountains ~~so that it can be called~~, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even ~~since~~during the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). ~~According to~~ Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi ~~(~~, 2018)~~, almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use pesticides, herbicides or other chemical fertilizers in coffee~~. Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020)~~, so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee~~. This coffee is processed from robusta and liberica varieties (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and ~~become an~~is now classified as endemic ~~plant~~in the northern part of Celebes because ~~this species~~it only exists and grows in Pinogu District ~~for the northern part of Celebes. Liberica coffee~~. This variety has the ~~advantage~~advantages of good taste (Gusfarina, 2014)~~,~~ and ~~a~~ distinctive ~~taste of~~ jackfruit flavor (Saidi & Suryani, 2021)~~. This condition makes pinogu~~, which make Pinogu coffee ~~an icon of the~~a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have ~~so far~~ encountered several obstacles, one of which is ~~the~~ low productivity ~~of the coffee.~~. Martono (2018) ~~reports~~reported that although Pinogu ~~Coffee~~coffee has ~~become~~reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} year^{-1}. ~~In fact~~By comparison, the productivity of liberica coffee can reach 1.69 ~~–~~ 1.98 ton ha^{-1} (Indonesian Industrial and Beverage Crops Research Institute, 2015). ~~Pinogu sub-district has a coffee~~Coffee plantation area ~~of 282.63 ha or~~accounts for the largest proportion in this district at 282.63 ha (66.21%) ~~with~~and new production of 36.34 ~~ton~~tons (Humola et al., 2021). Such conditions ~~will~~ affect the availability of coffee raw materials to meet market demand ~~later~~. The ~~low~~ coffee productivity ~~of coffee~~ is ~~thought to be~~low possibly because ~~coffee cultivation~~it is ~~carried out~~being cultivated on land ~~that is not in accordance~~ with ~~the~~low potential ~~of the land~~.

~~Until now there is no available information~~Information about the land potential ~~of land for the development of Liberica Coffee~~ in ~~the~~ Pinogu Plateau ~~area, except for the potential of land for robusta coffee because it is more~~is available only for the highly developed~~.~~ robusta coffee but not for liberica coffee. Land suitability ~~for robusta coffee~~ in Bone Bolango Regency is classified as marginally

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Commented [Editor4]: **Remark**: Minus sign is used to indicate negative values.

suitable (S3) ~~class~~for robusta coffee (Taslim, 2018; Indrianti, 2020)~~. Meanwhile,~~ and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla~~ are included in the moderately suitable class in Bone Bolango Regency~~ (Taslim, 2018). Liberica coffee is ~~not only~~ endemic, ~~it is also more~~highly resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust, and ~~somewhat~~slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters ~~regarding land potential will~~ greatly affect the productivity of liberica coffee ~~itself, because differences in~~; land potential ~~will be responded by variously by plants~~varies for every plant according to ~~growing~~growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment ~~so~~to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is ~~an~~ important ~~contribution~~ in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (Abdelrahman et al., 2016), and efficient ~~use in~~ agriculture land use (Zakarya et al., 2021). Information ~~of the~~ on land use potential ~~forms were~~is presented ~~on~~ as the output of ~~the~~ land evaluation, including ~~of~~ their consequences, beneficial, and ~~adverse~~severity of each degree class (Shalaby et al., 2017). ~~Likewise with~~ This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have ~~different~~ varying data requirements and ~~varying quality of estimates, but there is~~ estimate qualities; to date, no ~~fixed~~ rule ~~that defines~~has been imposed to define when and what evaluation method to use and when ~~there~~ is ~~a need for more~~ complex ~~analyzes~~analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) ~~Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based on~~to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). ~~In the parametric method, there is a combination of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore,~~ Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups ~~and separated from each other~~ with different ~~and~~but consistent ranges. Differences in land suitability values due to the use of ~~different~~varying methods ~~on a land will~~ have an impact on ~~differences in~~ land management. Therefore, ~~the aim of the~~this study ~~was~~aimed to determine the land suitability ~~value~~ of endemic liberica coffee ~~with~~by using two different methods and ~~to~~ formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

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MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. ~~Geographically, the research~~Its geographical location is ~~located~~ at 0°24'5.4"–~~–~~0°38'29.04" ~~North~~north to 123°18'38.52"–~~–~~123°33'15.48" ~~East~~east covering an area of 2,804.28 ha with ~~the~~ elevation of 300 –~~–~~338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall

~~ranging~~ranges from 19.00 mm to 408.18 mm~~, so the~~. The study area is included in the agro-climatic zone of C1 because the number of dry ~~month (monthly~~months (monthly rainfall less than 100 mm) is only 1~~ month~~, and the number of wet ~~month~~months (monthly rainfall more than 200 mm) is 6 ~~months is wet.~~. The monthly air temperature fluctuates between 24.34 °C ~~to~~ and 25.79 °C ~~while~~, and the relative humidity is between 78.60% ~~to~~and 84.40~~% and the duration of~~%. The monthly sunshine duration is between 44.52% ~~to~~and 70.50%, ~~while~~and the monthly wind speed is between 2 ~~knots to~~and 2.60 knots. The study area is ~~the~~ located upstream of ~~the~~ Bone watershed ~~which flows~~flowing to Tomini Bay.

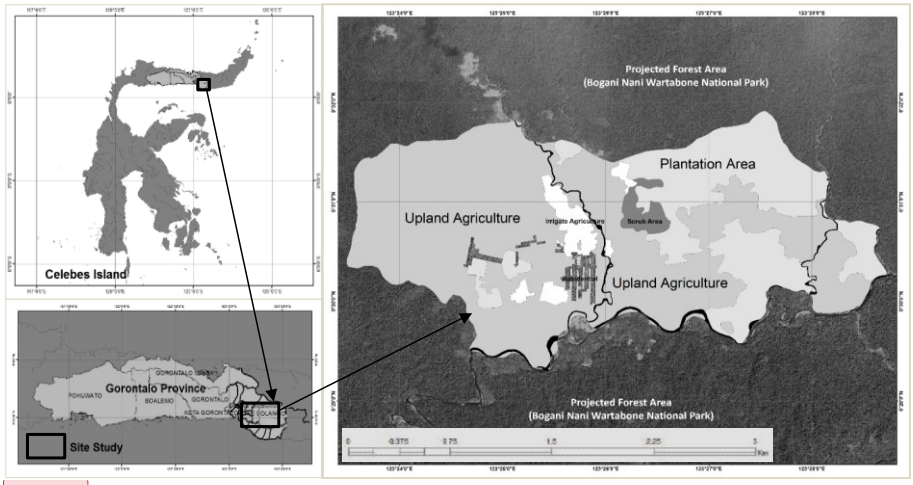

Figure 1. Research Location Map

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Land Mapping Unit

~~Before carrying out~~ Prior to soil ~~survey~~surveying and land observations, ~~it begins with making~~ a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains ~~of~~ 13 land units ~~which were the result of~~generated from basic map overlays ~~that has been adjusted to map scale, included:~~, namely, landform maps, slope maps, geological maps, and maps of existing land use~~. Furthermore, this~~, which were adjusted to the map scale. This land unit map ~~becames~~served as a reference in ~~carrying out of~~ soil survey and land observations, especially in determining soil observation points.

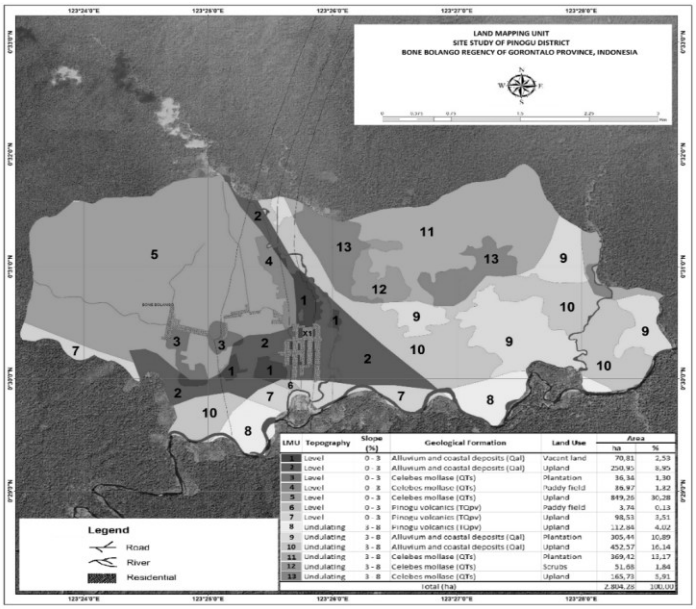

Figure 2. Land Mapping Unit

Soil Survey and Land Observation

~~A set of~~The following soil survey tools~~, included~~ were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker~~spidol. Meanwhile, the~~. The materials ~~used:~~included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015~~–~~2021~~)~~), and soil samples for laboratory analysis. ~~This field research used a~~A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). ~~Furthermore, field~~Field observations were carried out to determine ~~the~~ land characteristics, such as elevation and slope. ~~After that,~~Approximately 1 kg of soil samples were taken for ~~analysis in the~~ laboratory analysis.

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Soil Laboratory Analysis

~~Soil~~ The soil samples were air-dried for 3 days~~,~~ and then ~~sieved~~filtered through a 2 mesh sieve. ~~The analysis of selected soil~~ Soil properties ~~based on research parameters refers to~~were analyzed following the ~~soil analysis procedure according to~~method of Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content ~~were determined with~~was measured using the Walkley and Black method. ~~The~~Available P content was ~~available~~computed using the Olsen method, ~~while the~~ cation exchange capacity (CEC) was ~~extracted~~evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of ~~105°C, while~~ 105°C, and base saturation was ~~determined by calculation.~~calculated. All soil data and selected land characteristic data ~~are input~~were inputted in ~~spreasheet~~a spreadsheet.

Land Suitability ~~Assesment~~Assessment

~~The land~~Land suitability assessment was ~~-~~carried out ~~based on~~using the ~~parameters of~~ selected land characteristics ~~which were the same between~~for both methods. For the limiting factor method ~~and the parametric method. The assessment of land suitability classes used the limiting factor method followings~~, the land evaluation framework was adopted (FAO, 1976)~~. Land –~~, and the land characteristics and ~~quality~~qualities were compared ~~with~~according to the ~~selected land suitability~~ criteria (Table 1) selected from the Indonesian Directorate General of Plantations (2014)~~, in order~~ to ~~obtain~~choose the actual land suitability class ~~along with the~~and limiting factors for land use. ~~Furthermore,~~Optimization was further performed on the limiting factor of the actual land suitability class ~~was carried out improvement efforts, in order~~ to obtain a potential land suitability class.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	~~Simbol~~ Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300—500	600—800; 0—300	800—1.000	>1,000
Slopes	sl	%	0—8	8—25	25—45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)	nr		5.5—6.0	6.1—7.0	7.1—8.0	>8.0
C-organic (*Walkley & Black*)		%	2—5	1—2; 5—10	0.5—1.0; 10—15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)		cmol kg^{-1}	>15	10—15	5—10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20—35	<20	-
Nutrient availability:						
P availability (*Olsen*)	na	ppm	>16	10—15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), ~~modifed.~~modified.
Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea level, ppm = part per million.

~~Meanwhile, in assessing land suitability using the~~ For the parametric method, ~~it is estimated that~~ the productivity (Y) of coffee ~~uses several~~was estimated using the following equations (Simbolon, 2018) ~~namely:~~

:

Y = ~~-~~2.672 + 0.026 Elevation ~~-~~ ..... (1)

Y = 17,190 ~~-~~ ~~-~~0.090 Slope ..... (2)

Y = 3.055 + 0.005 pH H_2O ..... (3)

Y = 4.050 ~~-~~ ~~-~~ 0.019 C ~~-~~organic ~~-~~ ..... (4)

Y = -28.796 + 0.621 P Olsen ..... (5)

Y = 32.450 ~~-~~ ~~-~~ 0.109 Cation exchange capacity ..... (6)

Y = 0.457 ~~-~~ ~~-~~ 0.002 Base saturation ..... (7)

~~In this case,~~where Y = estimated production (ton ha^{-1}). The ~~assumption of the liberica coffee~~ optimal productivity ~~used of~~of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). ~~In order to assess the~~The accuracy of the estimated ~~productivity of the~~ liberica coffee~~, it~~ productivity was analyzed using the r~~R~~oot m~~M~~ean s~~S~~quare e~~E~~rror (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where: RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the value of the RMSE is, the more accurate the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses aA land index (LI) of root mean square (Khiddir, 1986), namely: was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where: LI = land index; LC = land characteristic; LC_{min} = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC.

The determination of land suitability class based on land index (LI) was calculated from all LC values that affect ofaffecting the liberica coffee productivity. The LI score criteria and scored using the following LI value criteria (Sys et al., 1991), namely:: S1 class (very suitable) with a value of 75 – 100, S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and N class (not suitable) with a value 0 – 25.

The formulation recommendationsRecommendations of land management for liberica coffee was determined basedwere formulated on the basis of the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the land with land suitability of S2 class, and recommendation III was the land with land suitability of S3 class. Meanwhile, notNot recommended was the land with land suitability of N class. All data and information obtained were described and presented in tabular form, whileand their spatial distribution was presented in map form.

RESULTS

Land Suitability Class Based on Limiting Factor Method

The resultresults of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau wasare shown to in Table 2 and Figure 3. It seems that theThe actual land suitability class was moderately suitable (S2)), which was more dominant in andominated a total area of 2,149.64 ha or 76.66% compared to%. By comparison, the marginally suitable class (S3) which was only accounted for 654.64 ha or only 23.34%. Meanwhile the veryVery suitable class (S1) and not suitable (N) has were not found in the results of obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrientsnutrient availability (P availability). In addition, there was an elevation limiting factor at LMUwas identified in LMUs 1 and LMU 7.

Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P			Area	
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual LSC	ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32

5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
								Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation ~~axchange~~exchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

The potential land suitability class was ~~dominatly of~~dominated by S1~~ that~~ covering an area of 1,980.30 ha or 70.62~~% of total area~~%, and the ~~rest including~~remaining part was classified as S2 ~~class~~ covering an area of 823.98 ha or 29.38~~% of total area.~~%. After ~~making efforts to improve~~the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for ~~LMU~~LMUs 1 and ~~LMU~~ 7 ~~which~~that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, ~~both~~namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter~~, while~~. Meanwhile, the limiting factor for available ~~nutrients of~~nutrient, that is, low P availability, was ~~improved~~enhanced with the addition of P fertilizer.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	~~Can not~~Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

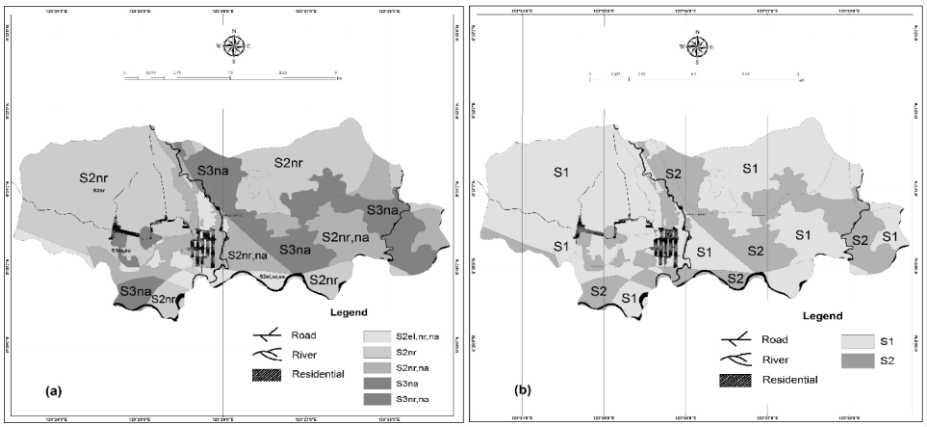

Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Class Based on Parametric Method

Table 4 ~~show that~~shows the highest ~~productivity of~~ liberica coffee ~~was obtained on the~~productivity for slope characteristics with an average of 1.69 ton ha^{-1}~~, while~~ and the lowest ~~was on the~~for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics ~~has~~had an average productivity 0.30. ~~The results of the~~ RMSE ~~analysis~~ values on the alleged productivity of liberica coffee were all close to 0~~, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to~~ ; LMU 8 ~~which is~~had the highest ~~(0.53).~~value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs ~~has an~~had a RMSE ~~value~~ of 0.52 (Table 4). The productivity of liberica coffee ~~will affect~~affects the land characteristic index, which ~~will~~ ultimately ~~determine~~determines the ~~land index~~LI and land suitability class for liberica coffee.

~~It seems that the~~The relative land characteristic index values ~~follow~~followed the pattern of ~~productivity for~~ liberica coffee productivity in ~~the~~ Pinogu Plateau. The highest ~~land characteristic index value and reaching the~~ and optimal ~~value was the~~land characteristic index was acquired for slope characteristic ~~which the averaged value~~with an average of 100 (Table 5), ~~while~~ and the lowest ~~land characteristic index value~~ was obtained for ~~the~~ available P ~~which~~with an average of P availability index of 26.39. The remaining land characteristics ~~are~~were relatively diverse, but the average ~~value of the~~ land characteristic index was 30 in the remaining LMUs in ~~the~~ Pinogu Plateau. The land characteristic index value affects the ~~land index value which results in LMU~~LI. Hence, LMUs 3 and ~~LMU~~ 13 ~~obtaining~~ obtained the highest ~~land index~~Lis at 76 and 80, respectively ~~76 and 80~~. Meanwhile, ~~the~~ LMU 8 ~~as~~had the lowest ~~land index value which was~~ LI of 50. The remaining LMUs ~~get land index values ranged~~achieved a LI ranging from 50 ~~–~~ to 71. The ~~varous of land index values will~~variation in LI greatly ~~affect~~affects the land suitability class for liberica coffee ~~later~~.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		$\bar{Y}$ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remark: LMU = land mapping unit, C-Org = C-organic, Exc. = exchangeable, CEC = cation ~~exchange~~exchange capacity, BS = base saturation, Ava-P = P availability, m asl = mean above sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

~~Based on~~On the ~~land index values~~basis of Lis, the land suitability class for liberica coffee was ~~more dominant~~dominated by S2 ~~with~~ covering ~~an area of~~ 88.77% of total area (Table 5). Meanwhile, ~~the~~ S1

class was 7.21% of total area and the S3 class wasclasses accounted for 7.21% and 4.02% of total area without not %, respectively. Not suitable class (N).) was not detected.

Table 5. Value of Land CharacteristicsCharacteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha⁻¹)	LC	Y (ton ha⁻¹)	LC	Y (ton ha⁻¹)	LC	Y (ton ha⁻¹)	LC	Y (ton ha⁻¹)	LC	Y (ton ha⁻¹)	LC	Y (ton ha⁻¹)	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
Total (ha)																	2.804,28	100

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 show shows that the comparison between the two methods shows theexhibit similarity of in the land suitability class (S2 ÷ :S2) of comprising 22.18% of total area (LMULMUs 1, 7, and LMU 10). ButHowever, the most dominant class differences (difference was S1 ÷ :S2) of accounting for 66.59% of total area (LMULMUs 2, 4, 5, 6, 9, 11, and LMU 12), followed by class S2 ÷ :S1 ofat 7.21% of total area (LMU(LMUs 3, and LMU 13), while) and the lowest was the class (S1 ÷ :S3) of at 4.02% of total area (LMU 8).

Commented [Editor8]: **Remark**: To create an easy flow of ideas, transition words such as however, therefore, moreover, etc. can be used. This usage enhances coherence of ideas in the paragraph and the manuscript on the whole.

Based on On the basis of the land suitability class offrom the limiting factor method, the land that was included in recommendation I (S1) wasaccounted for 70.62% of the total area, whileand that in recommendation II (S2) was comprised 29.38% of the total area, without%. No land recommendationrecommendations III (S3) and recommendation IV (N). In contrast to) were noted. For the parametric method, where the land that was included in recommendation I (S1) wasaccounted for 7.21% of the total area, that in recommendation II (S2) wascomprised 88.77% of the total area, while land with recomendation %, and that in recommendation III (S3) wasconstituted 4.20% of the total area without land%. Land recommendation IV (N).) was not detected.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
Total (ha)					2,804.28	100.00

Remark: LMU = land mapping unit.

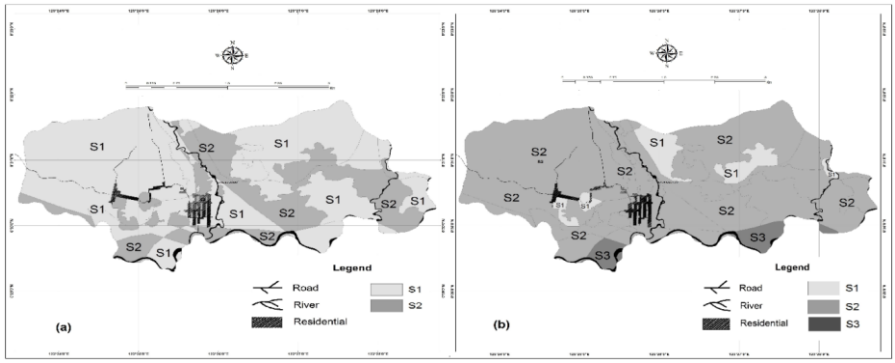

Figure 3. Comparison of Land Suitability Classes ~~with~~for Liberica Coffee in Pinogu Plateau obtained using Limiting ~~Factors~~Factor (a) and Parametric (b) Methods ~~(b) for Liberica Coffee in Pinogu Plateau~~

DISCUSSION

The land suitability for liberica coffee ~~with~~ vary between the ~~limiting factor method and the parametric method was different, both~~two methods in terms of class and areas. ~~This study shown that, by limiting factor method, the~~ The dominant ~~suitability~~ class ~~is~~ was very suitable (S1~~). Yet, by parametric method, the dominat suitability class is~~) based on the limiting factor method but moderately suitable (S2~~).~~) according to the parametric method. Although the land suitability class ~~using this limiting factor method~~from the former technique appears to be of a ~~higher~~high class and ~~wider~~wide distribution, it ~~was~~ is only based on the land characteristics ~~of the land~~ and has not been linked ~~at all~~ with ~~the productivity of~~ liberica coffee~~.~~ productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics ~~that are difficult to explain~~ (Elsheikh et al., 2013; Hartati, et al., 2018).

~~In~~By contrast ~~to~~, the land suitability class ~~with~~from the parametric method~~, besides being~~ is based on the performance of land characteristics~~, it has also been~~ and directly related to the productivity of liberica coffee in the research area~~, so that~~. Hence, the interactions ~~in it~~ are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability ~~of parametric methods more greater~~ than other land evaluation methods. ~~The~~Its advantage ~~of the parametric method~~ is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). ~~Furthermore,~~ Marbun et al. (2019) also stated that the superiority of this ~~parametric method is not only~~technique is calculating LSCs~~land suitability classes~~ based on soil properties ~~but also taking into account~~and considering all factors and mapping them in one land suitability map. ~~This~~The parametric method with the square root of ~~the land index~~LI uses a minimum rating to assess LSCs~~land suitability classes~~ (Juita et al., 2020). ~~In fact,~~ Mathewos et al. (2018) ~~stated~~reported that the square root ~~land index value was~~LI is higher than the Storie index. ~~To improve the~~For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee ~~using~~, the number of limiting factors was higher in the limiting factor method~~, it evidently that there were more limiting factors, while~~ than in the parametric method ~~most less~~. The only minimum rating value in the parametric method was ~~only~~ the

low P availability ~~of P nutrients.~~. A low land suitability index should be improved ~~so~~to ensure that the plant grows optimally (Isramiranti et al., 2020). ~~Land that has an~~A land with S3 suitability class ~~has the opportunity to~~ can be ~~improved~~enhanced through various land improvement efforts~~, so that it becomes a~~ to become class S2 ~~to class~~or even S1 (Refitri et al., 2016). Low nutrient availability ~~was improved~~can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be ~~done~~accomplished by adding organic matter and fertilizing according to the recommended ~~dose of~~ fertilizer dose. The addition of organic matter can increase soil pH and C ~~-~~organic content (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between LSCs~~land suitability classes~~ and their real productivity. ~~In fact, at LMU~~At LMUs 4 and ~~LMU~~ 6, the existing land ~~use were~~uses, which are irrigated rice fields and swamps that are often inundated~~ was~~, were classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role~~, so that~~; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment ~~were without~~do not have further specifications (Abbasi et al., 2019). ~~Meanwhile, with~~With the parametric method, ~~LMU~~LMUs 4 and ~~LMU~~ 6 ~~are~~ were included in the ~~quite appropriate~~moderately suitable class (S2~~)~~), which is ~~more realistic~~in accordance with the conditions of land use. ~~The parameteric method in~~ In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale ~~with~~from a maximum ~~value~~ of 100 to a minimum ~~value~~ of 0 (Juita et al., 2020). ~~On the parametric method~~In this case, the effect of the most limiting factor ~~will reduce its effect~~is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method ~~following~~followed the class pattern S2 > S1 > S3. ~~The advantage of the parametric method in~~In addition to calculating LSCs~~land suitability classes~~ based on soil properties ~~is also calculating~~, this technique calculates all factors and ~~mapping~~places them in one land suitability map (Marbun et al., 2019). ~~It seems that the~~The land index obtained by the parametric method was ~~closer~~close to the ~~real~~actual field conditions ~~in the field, where~~; the average ~~of~~ liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, ~~while the productivity~~and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii ~~&~~and Fariabi (2014) ~~state that there was~~stated a significant relationship between land index and production, ~~where as the land index increases~~that is, the yield based on the range of LSCs~~land suitability classes~~ ~~also~~ increases ~~quantitatively~~with the land index. Diagnostic criteria ~~in the parametric method~~ were assessed numerically and mathematically in the parametric method to obtain LSCs~~land suitability classes~~ (Marbun et al., 2019)~~, so as to~~ and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

~~The land for liberica coffee with~~With the limiting factor method~~-~~, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class ~~of S1~~ was wider than that with S2 class ~~of S2. Meanwhile,~~. With the parametric method, the land was ~~more dominant~~dominated by recommendation II, followed by ~~recommendation~~ I and III because the land with S2 class ~~of S2~~ was wider than ~~class of~~those with S1 and S3~~. In order to optimize land use for~~ classes. For optimal liberica coffee~~, it was necessary to improve~~ land use, the cultivation system

~~including~~must be improved, such as through fertilization (Nugroho, 2015). In addition, the ~~position of~~ liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed ~~needs to~~must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2015). The distribution of LSCs~~land suitability classes~~ and the land recommendations for liberica coffee in Plato Pinogu ~~were very~~are important for ~~developing this coffee.~~its development. According to Saidi & Suryani (2021), ~~the existence of~~ land suitability maps ~~was very important to providing~~provide information on the suitability of various agricultural commodities~~, limiting factors, widely~~ and ~~it~~ the distribution of limiting factors in an area.

CONCLUSION

The actual land suitability ~~class~~ for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable ~~class~~ (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by ~~adding~~ organic matter addition and fertilization~~,~~ could upgrade it ~~has the potential became very~~ to suitable ~~class~~ (S1) and moderately suitable (S2 ~~class.~~) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee ~~with~~consists of recommendations I and II according to the limiting factor method ~~consist~~but is composed of ~~recommendation~~recommendations I, II, and ~~II. Meanwhile,~~III according to the parametric method ~~consist of recommendation I, II and III for liberica coffee.~~. Land suitability assessment using the parametric method ~~was~~provides more realistic ~~on~~ land characteristics in relation to liberica coffee productivity than the limiting factor method.

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COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC *COFFEA LIBERICA PINOGU* HP. ACQUIRED USING DIFFERENT METHODS AND RECOMMENDATIONS FOR LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY, INDONESIA

ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Land managements were classified as follows: recommendation I or very suitable (S1), II or moderately suitable (S2), III or marginally suitable (S3), and IV or not suitable (N). Analysis using the limiting factor method showed that the actual LSC for liberica coffee consisted of S2 and S3 classes. Efforts for improvement could increase the potential of LSC to became S1 and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method.

Keywords: land, suitability, coffee, liberica, endemic, Pinogu

INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (Indonesian Central Bureau of Statistics, 2020). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its

highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Indonesian Industrial and Beverage Crops Research Institute, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Taslim, 2018; Indrianti, 2020) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2018). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (Abdelrahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of

varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

MATERIAL AND METHODS

Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34 °C and 25.79 °C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

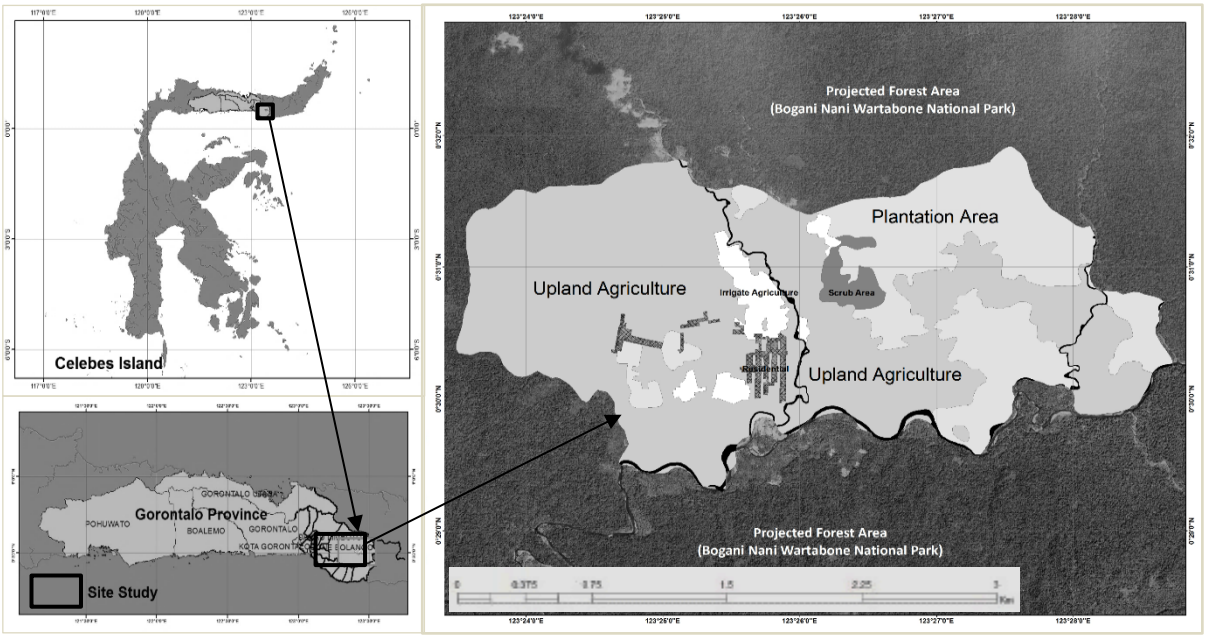
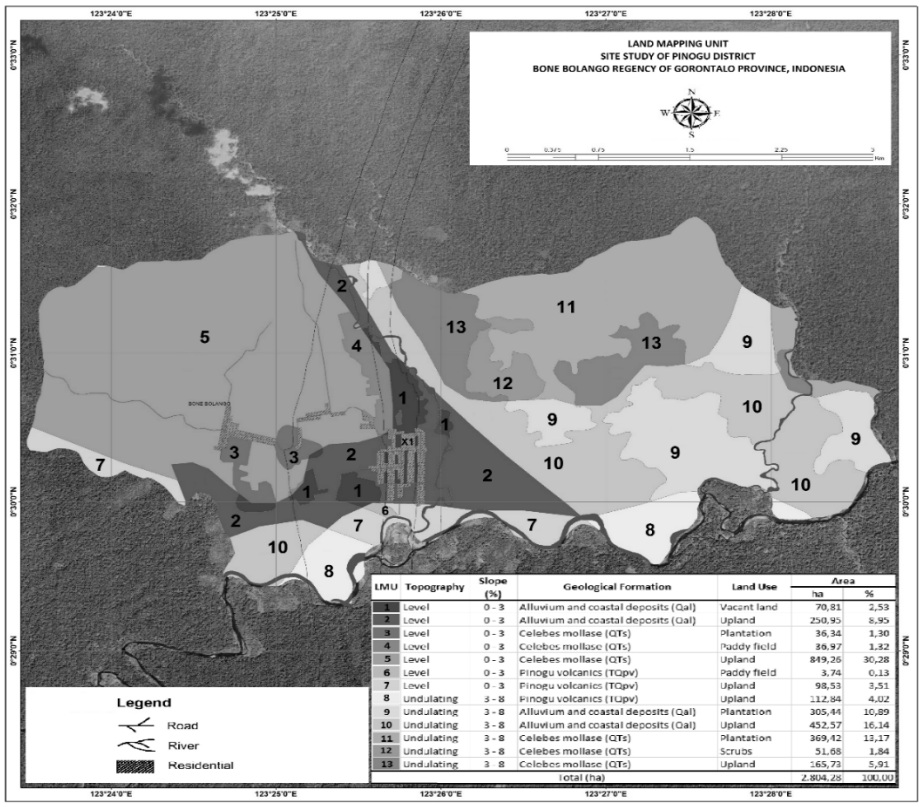


Figure 1. Research Location Map

Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.



LMU	Topography	Slope (%)	Geological Formation	Land Use	Area ha	Area %
1	Level	0 - 3	Alluvium and coastal deposits (Qal)	Vacant land	70,81	2,53
2	Level	0 - 3	Alluvium and coastal deposits (Qal)	Upland	250,95	8,95
3	Level	0 - 3	Celebes mollase (QTs)	Plantation	36,34	1,30
4	Level	0 - 3	Celebes mollase (QTs)	Paddy field	38,97	1,32
5	Level	0 - 3	Celebes mollase (QTs)	Upland	849,26	30,28
6	Level	0 - 3	Pinogu volcanics (TQpv)	Paddy field	3,74	0,13
7	Level	0 - 3	Pinogu volcanics (TQpv)	Upland	98,53	3,51
8	Und.ulating	3 - 8	Pinogu volcanics (TQpv)	Upland	112,84	4,02
9	Und.ulating	3 - 8	Alluvium and coastal deposits (Qal)	Plantation	305,44	10,89
10	Und.ulating	3 - 8	Alluvium and coastal deposits (Qal)	Upland	452,57	16,14
11	Und.ulating	3 - 8	Celebes mollase (QTs)	Plantation	369,42	13,17
12	Und.ulating	3 - 8	Celebes mollase (QTs)	Scrubs	51,68	1,84
13	Und.ulating	3 - 8	Celebes mollase (QTs)	Upland	165,73	5,91
			Total (ha)		2.804,28	100,00

Figure 2. Land Mapping Unit

Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviyati & Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the

land characteristics and qualities were compared according to the criteria (Table 1) selected from the Indonesian Directorate General of Plantations (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:						
P availability (*Olsen*)	na	ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.
Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea level, ppm = part per million.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

Y = −2.672 + 0.026 Elevation ..... (1)

Y = 17,190 − 0.090 Slope ..... (2)

Y = 3.055 + 0.005 pH H_2O ..... (3)

Y = 4.050 − 0.019 C-organic ..... (4)

Y = -28.796 + 0.621 P Olsen ..... (5)

Y = 32.450 − 0.109 Cation exchange capacity ..... (6)

Y = 0.457 − 0.002 Base saturation ..... (7)

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad \text{..... (8)}$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x \ldots x\ \frac{N}{100}} \quad \text{..... (9)}$$

where LI = land index; LC = land characteristic; LC_{min} = minimum LC rating; A, B, C, …, N = other LC in

beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (very suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

RESULTS

Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Very suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
									Area (ha)							2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remark: LMU = land mapping unit, LSC = land suitability class.

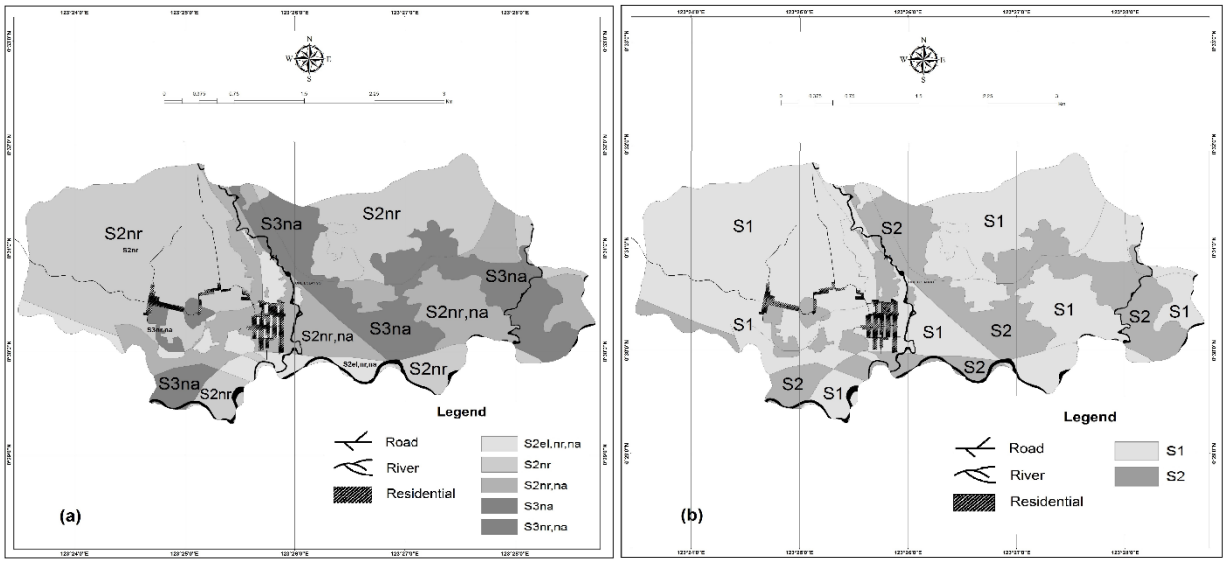


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land

characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		$\bar{Y}$	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})	(ton ha^{-1})		
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remark: LMU = land mapping unit, C-Org = C-organic, Exc. = exchangeable, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, m asl = mean above sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
								Total (ha)									2.804,28	100

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric

method, the land included in recommendation I (S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
Total (ha)					2,804.28	100.00

Remark: LMU = land mapping unit.

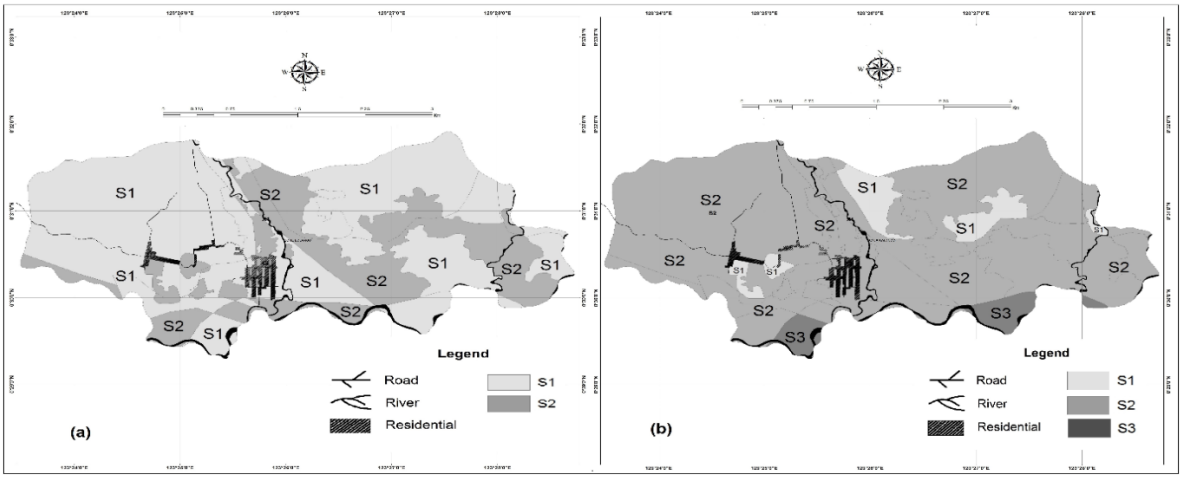


Figure 3. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was very suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati, et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method

with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and

upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2015). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi & Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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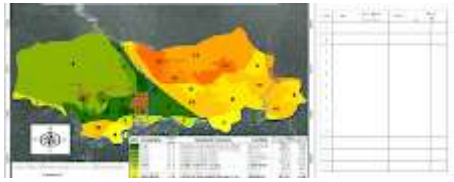

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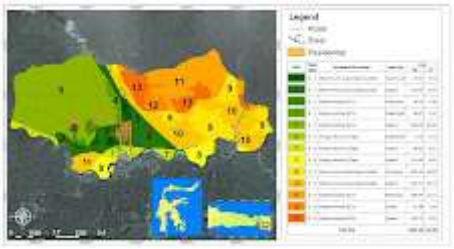

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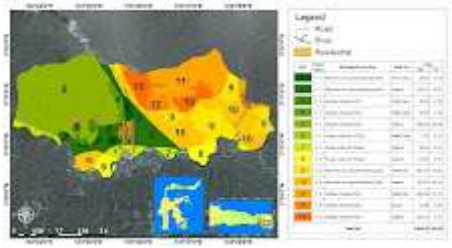

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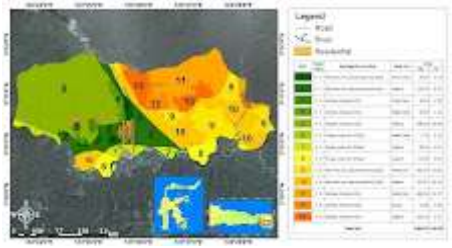

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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Determination of land management recommendations consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of limiting factors but can still be improved, while recommendation IV was a lot of limiting factors and cannot be improved for the liberica coffee development. Analysis using the limiting factor method showed that the actual LSC for liberica coffee consisted of moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to became highly suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II turned out to be more dominant with the recommendation of adding P and organic fertilizer.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

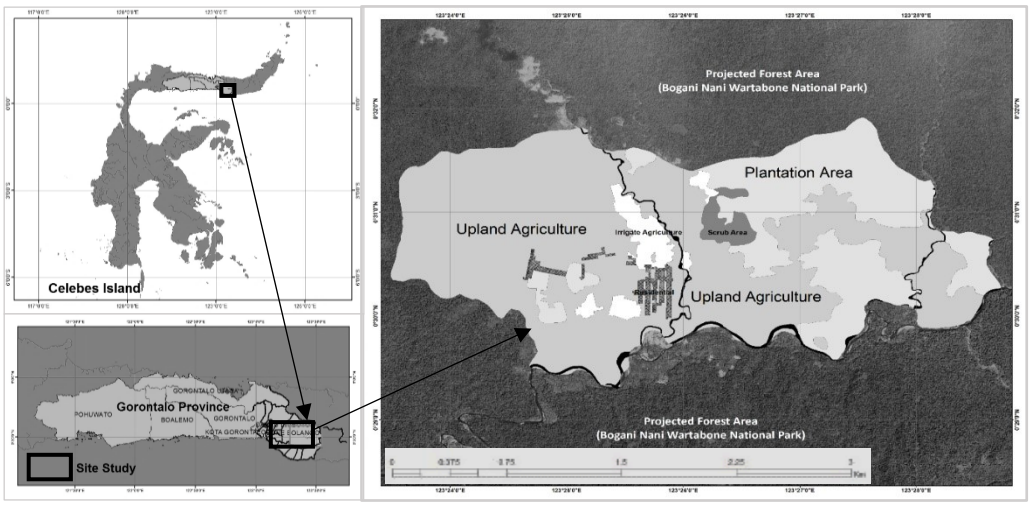
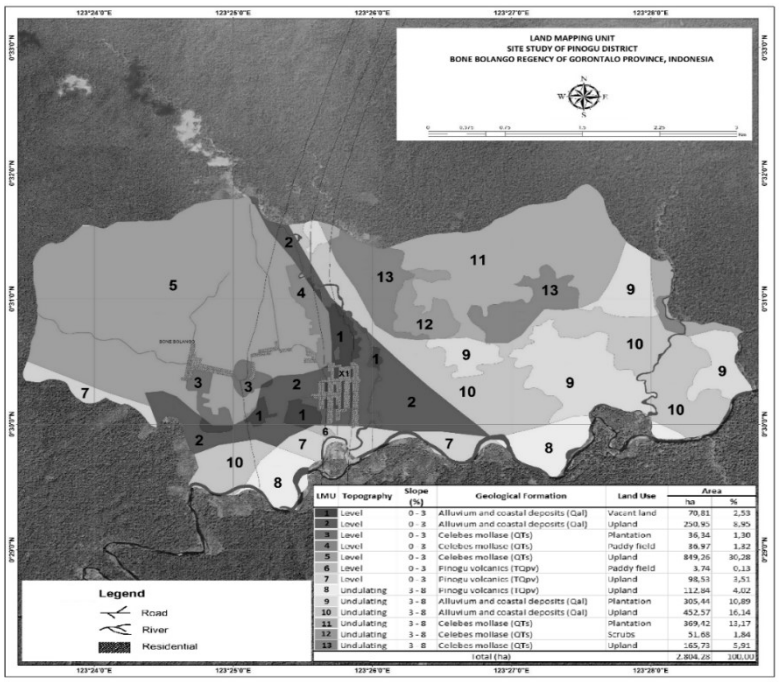


Figure 1. Research Location Map



LMU	Topography	Slope (%)	Geological Formation	Land Use	Area ha	Area %
1	Level	0 - 3	Alluvium and coastal deposits (Qal)	Vacant land	70,81	2,53
2	Level	0 - 3	Alluvium and coastal deposits (Qal)	Upland	250,95	8,95
3	Level	0 - 3	Celebes mollase (QTs)	Plantation	36,34	1,30
4	Level	0 - 3	Celebes mollase (QTs)	Paddy field	38,97	1,82
5	Level	0 - 3	Celebes mollase (QTs)	Upland	849,26	30,28
6	Level	0 - 3	Pinogu volcanics (TQpv)	Paddy field	3,74	0,13
7	Level	0 - 3	Pinogu volcanics (TQpv)	Upland	98,53	3,51
8	Undulating	3 - 8	Pinogu volcanics (TQpv)	Upland	112,94	4,02
9	Undulating	3 - 8	Alluvium and coastal deposits (Qal)	Plantation	305,44	10,89
10	Undulating	3 - 8	Alluvium and coastal deposits (Qal)	Upland	452,57	16,14
11	Undulating	3 - 8	Celebes mollase (QTs)	Plantation	369,42	13,17
12	Undulating	3 - 8	Celebes mollase (QTs)	Scrubs	51,68	1,84
13	Undulating	3 - 8	Celebes mollase (QTs)	Upland	165,73	5,91
			Total (ha)		2.804,25	100,00

Figure 2. Land Mapping Unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:	na					
P availability (*Olsen*)		ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = meters above sea level, ppm = part per million.

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

Y = −2.672 + 0.026 Elevation [1]
Y = 17,190 − 0.090 Slope [2]
Y = 3.055 + 0.005 pH H_2O [3]
Y = 4.050 − 0.019 C-organic [4]
Y = -28.796 + 0.621 P Olsen [5]
Y = 32.450 − 0.109 Cation exchange capacity [6]
Y = 0.457 − 0.002 Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sl= meters sea level, ppm = part per million.

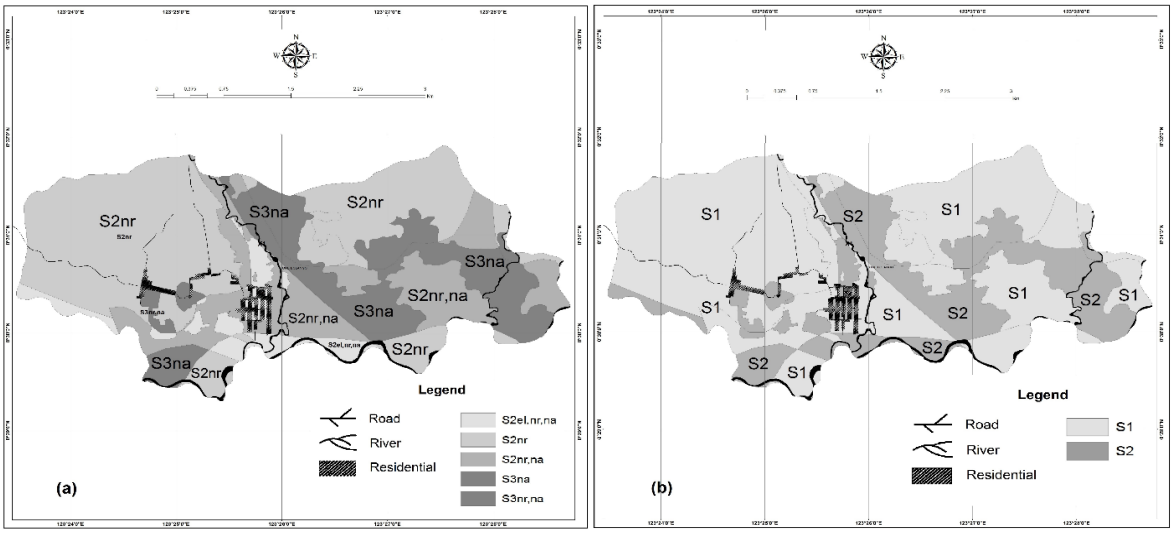


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class.

3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 and Figure 4 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I accounted for 70.62% of the total area, and that in recommendation II comprised 29.38%. No land recommendations III and IV were noted. For the parametric method, the land included in recommendation I accounted for 7.21% of the total area, that in recommendation II comprised 88.77%, and that in recommendation III constituted 4.20%. Land recommendation IV was not detected.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		Ȳ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
								Total (ha)									2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

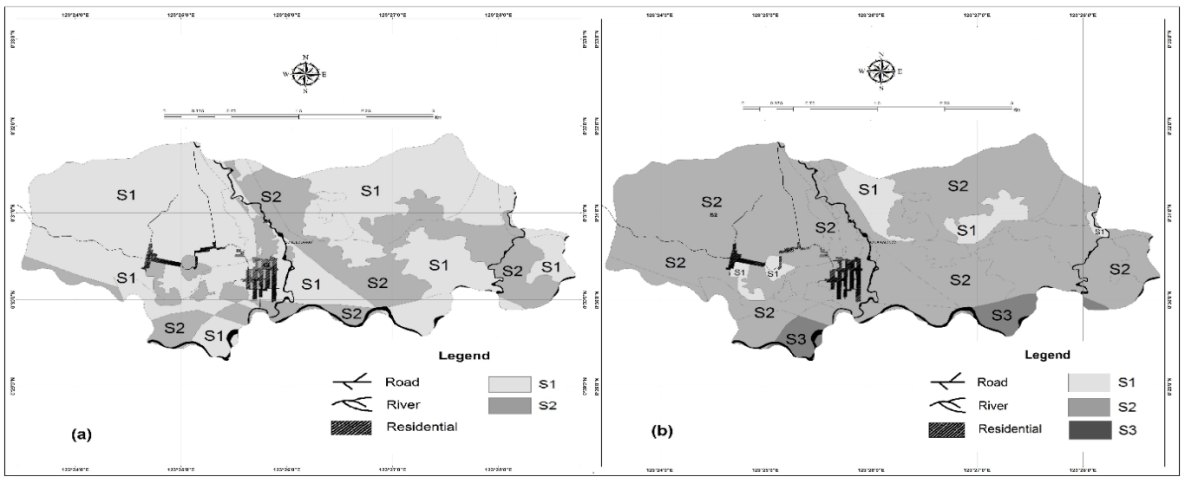


Figure 4. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric Methods (b)

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. ~~Land managements were classified as follows: recommendation I or highly suitable (S1), II or moderately suitable (S2), III or marginally suitable (S3), and IV or not suitable (N).~~ Determination of land management recommendations consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of limiting factors but can still be improved, while recommendation IV was a lot of limiting factors and cannot be improved for the liberica coffee development. Analysis using the limiting factor method showed that the actual LSC for liberica coffee consisted of S2 and S3 classes. Efforts for improvement could increase the potential of LSC to became S1 and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II turned out to be more dominant with the recommendation of adding P and organic fertilizer.

Commented [h1]: This classification is improper. Highly suitable (S1), S2, etc. are not "land management classification". If land management classification, please specifically mention the recommendation, not only recommendation I, II or III. But mention the managements in detail briefly.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not

use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

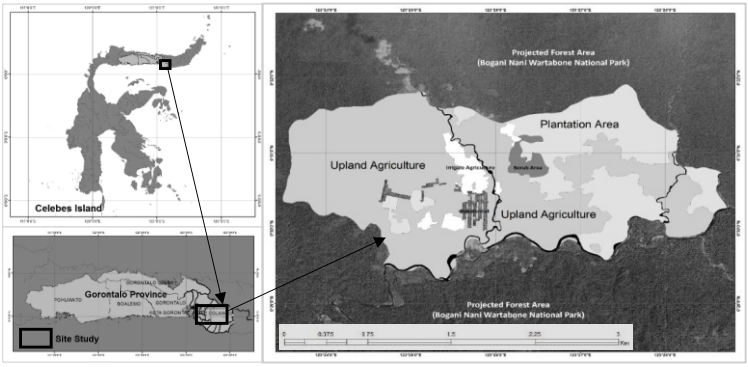

Figure 1. Research Location Map

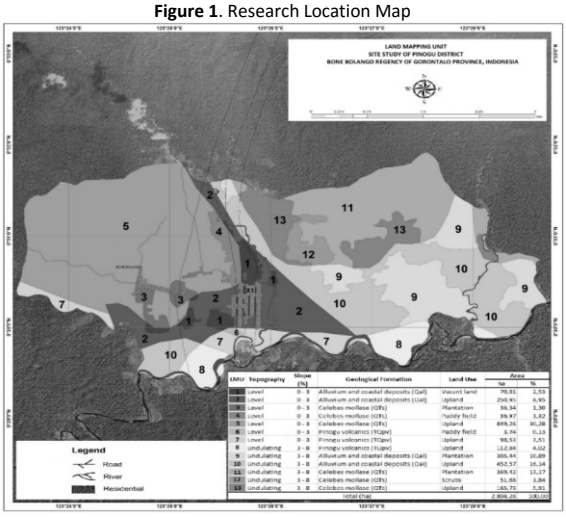

Figure 2. Land Mapping Unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)	nr		5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)		cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:	na					
P availability (*Olsen*)		ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = meters above sea level, ppm = part per million.

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

Y = −2.672 + 0.026 Elevation [1]
Y = 17,190 − 0.090 Slope [2]
Y = 3.055 + 0.005 pH H_2O [3]
Y = 4.050 − 0.019 C-organic [4]
Y = -28.796 + 0.621 P Olsen [5]
Y = 32.450 − 0.109 Cation exchange capacity [6]
Y = 0.457 − 0.002 Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sl= meters sea level, ppm = part per million.

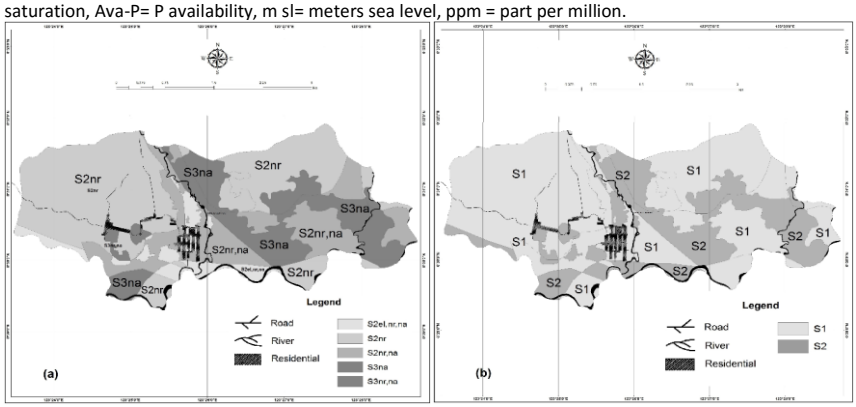

Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
Total (Ha)					2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class.

3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the

lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 and Figure 4 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I accounted for 70.62% of the total area, and that in recommendation II comprised 29.38%. No land recommendations III and IV were noted. For the parametric method, the land included in recommendation I accounted for 7.21% of the total area, that in recommendation II comprised 88.77%, and that in recommendation III constituted 4.20%. Land recommendation IV was not detected.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		$\bar{Y}$ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
Total (ha)																	2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
Total (ha)					2,804.28	100.00

Remark: LMU = land mapping unit.

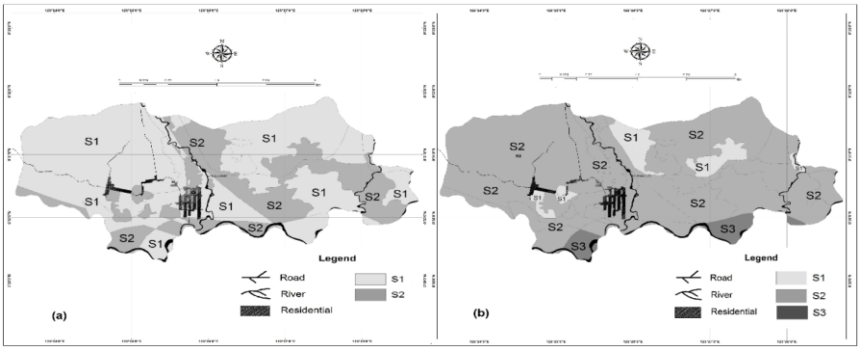

Figure 4. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique

calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Determination of land management recommendations consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of limiting factors but can still be improved, while recommendation IV was a lot of limiting factors and cannot be improved for the liberica coffee development. Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of S2 and S3 classes. Efforts for improvement could increase the potential of LSC to became S1 and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II turned out to be more dominant with the recommendation of adding P and organic fertilizer.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

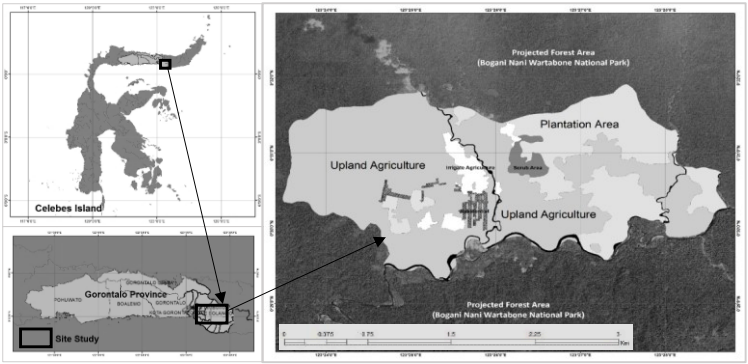

Figure 1. Research Location Map

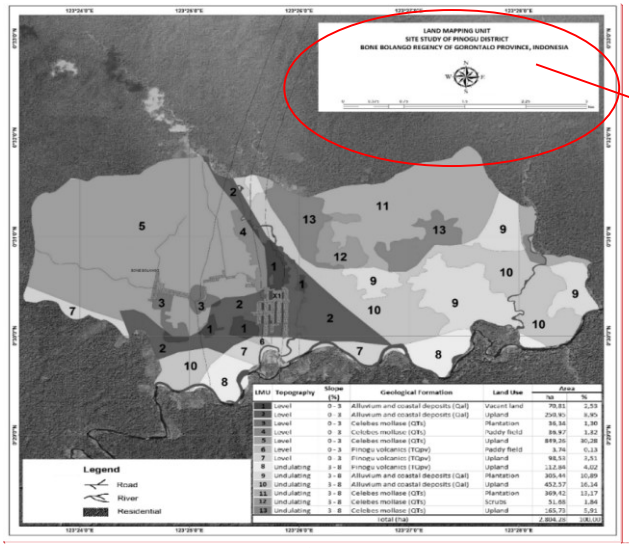

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Figure 2. Land Mapping Unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:						
P availability (*Olsen*)	na	ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = meters above sea level, ppm = part per million.

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

$Y = -2.672 + 0.026$ Elevation [1]

$Y = 17{,}190 - 0.090$ Slope [2]

$Y = 3.055 + 0.005$ pH H_2O [3]

$Y = 4.050 - 0.019$ C-organic [4]

$Y = -28.796 + 0.621$ P Olsen [5]

$Y = 32.450 - 0.109$ Cation exchange capacity [6]

$Y = 0.457 - 0.002$ Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sl= meters sea level, ppm = part per million.

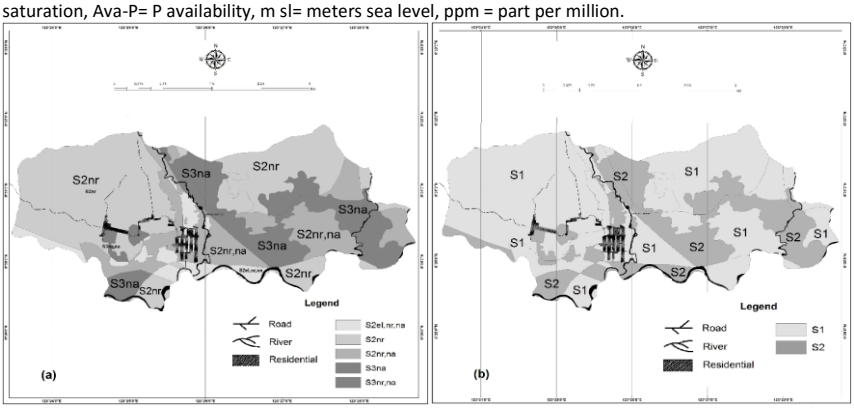

Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class.

3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric method, the land included in recommendation I

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(S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		Ȳ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

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Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
Total (ha)																	2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose.

The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

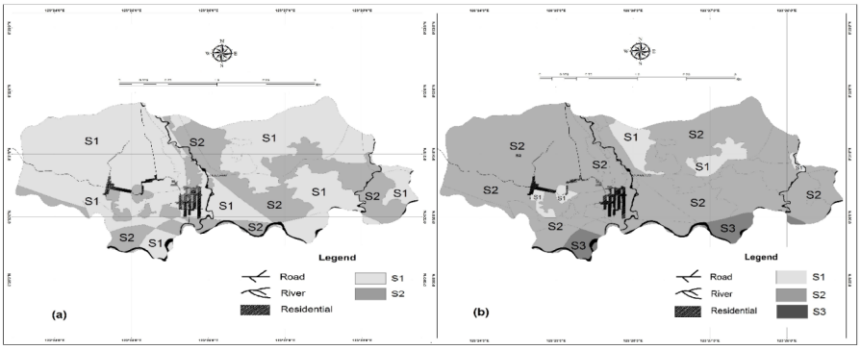

Figure 3. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016).

The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. ~~Determination of land management recommendations consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of limiting factors but can still be improved, while recommendation IV was a lot of limiting factors and cannot be improved for the liberica coffee development~~. Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to became very suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II for the land that had a little limiting factor turned out to be more dominant with the recommendation of adding P and organic fertilizer.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from

robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

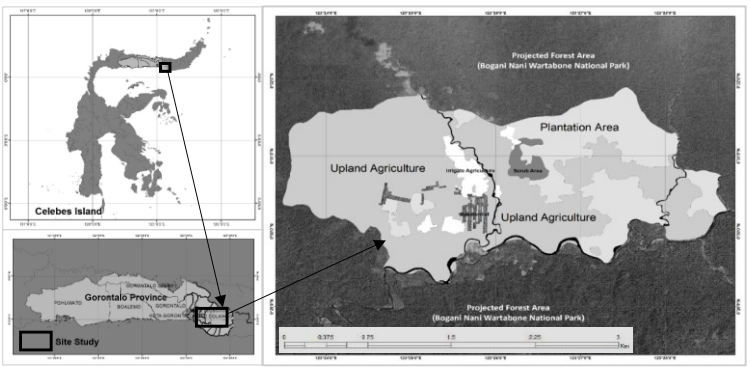
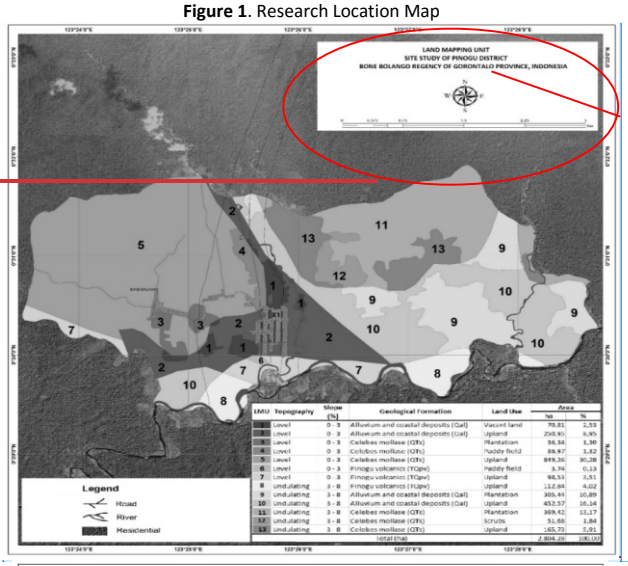


Figure 1. Research Location Map



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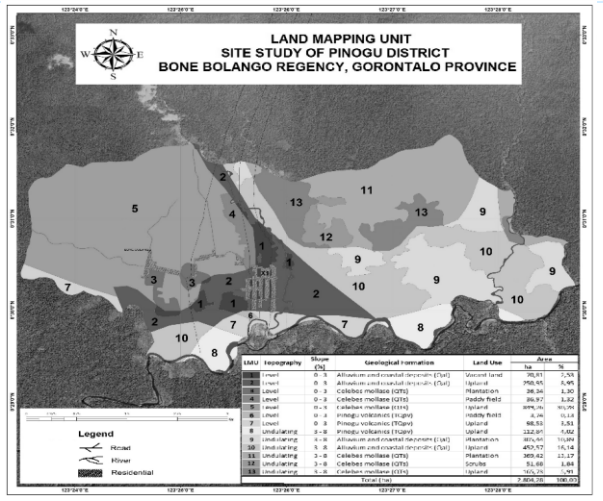

Figure 2. Land Mapping Unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)	nr		5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)		cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:	na					
P availability (*Olsen*)		ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, m asl = meters above sea level, ppm = part per million.

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

Y = −2.672 + 0.026 Elevation [1]
Y = 17,190 − 0.090 Slope [2]
Y = 3.055 + 0.005 pH H_2O [3]
Y = 4.050 − 0.019 C-organic [4]
Y = -28.796 + 0.621 P Olsen [5]
Y = 32.450 − 0.109 Cation exchange capacity [6]
Y = 0.457 − 0.002 Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x\ \ldots x\ \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH)

and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
								Area (ha)								2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= Phosphor availability, m sl= meters sea level, ppm = part per million, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient available.

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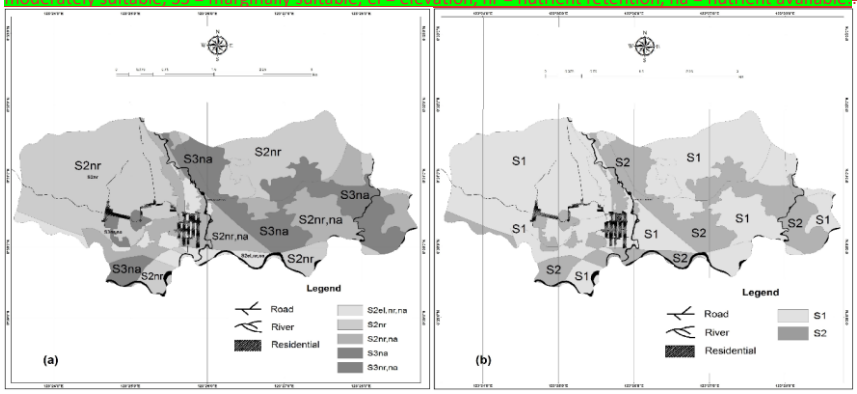

Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

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Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
			Total (Ha)		2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient available, C = carbon, P = phosphor.

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3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 and Figure 4 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric method, the land included in recommendation I (S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		$\bar{Y}$	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})	(ton ha^{-1})		
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, Y = productivity, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

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Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84

13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
																Total (ha)	2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

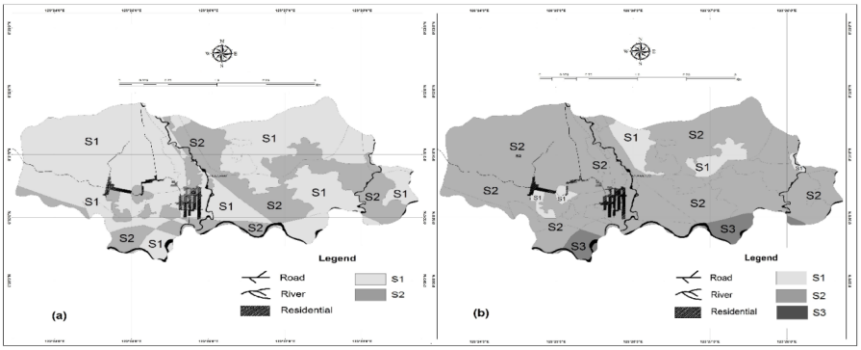

Figure ~~3~~4. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

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Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Determination of land management recommendations consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of limiting factors but can still be improved, while recommendation IV was a lot of limiting factors and cannot be improved for the liberica coffee development. Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of S2 and S3 classes. Efforts for improvement could increase the potential of LSC to became S1 and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II turned out to be more dominant with the recommendation of adding P and organic fertilizer.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

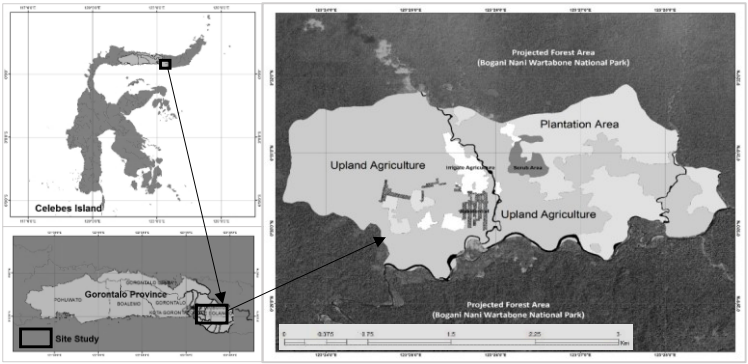

Figure 1. Research Location Map

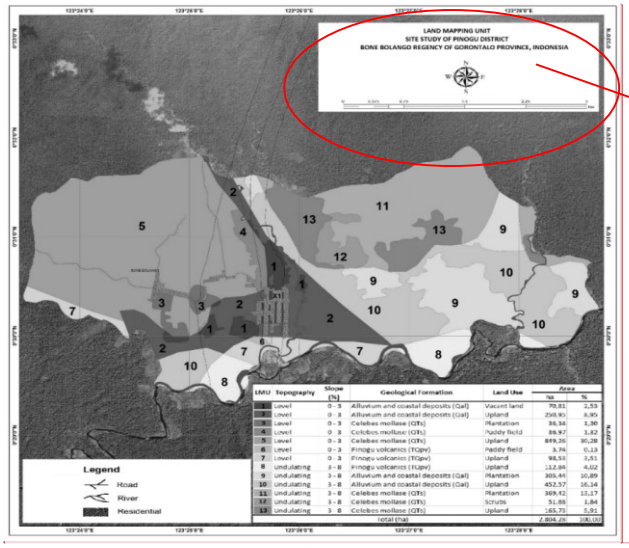

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Figure 2. Land Mapping Unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:						
P availability (*Olsen*)	na	ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = meters above sea level, ppm = part per million.

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

$Y = -2.672 + 0.026$ Elevation [1]

$Y = 17{,}190 - 0.090$ Slope [2]

$Y = 3.055 + 0.005$ pH H_2O [3]

$Y = 4.050 - 0.019$ C-organic [4]

$Y = -28.796 + 0.621$ P Olsen [5]

$Y = 32.450 - 0.109$ Cation exchange capacity [6]

$Y = 0.457 - 0.002$ Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sl= meters sea level, ppm = part per million.

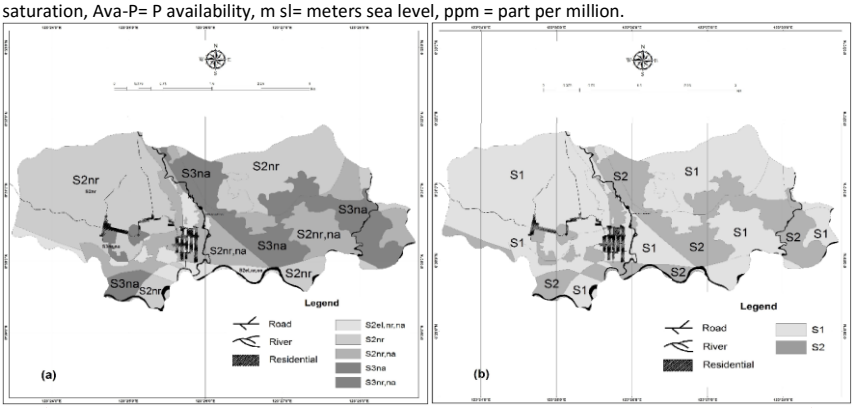

Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class.

3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric method, the land included in recommendation I

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(S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		Ȳ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

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Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
Total (ha)																	2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose.

The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

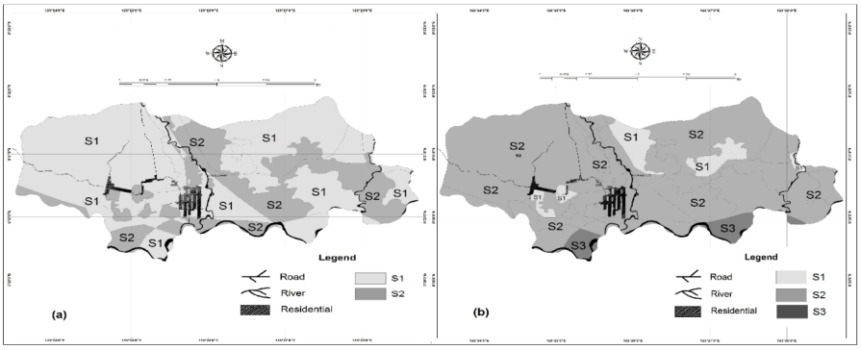

Figure 3. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016).

The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. ~~Determination of land management recommendations consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of limiting factors but can still be improved, while recommendation IV was a lot of limiting factors and cannot be improved for the liberica coffee development.~~ Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to became very suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II or the land that had a little limiting factor turned out to be more dominant with the recommendation of adding P and organic fertilizer ~~Land management II turned out to be more dominant with the recommendation of adding P and organic fertilizer~~.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not

use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

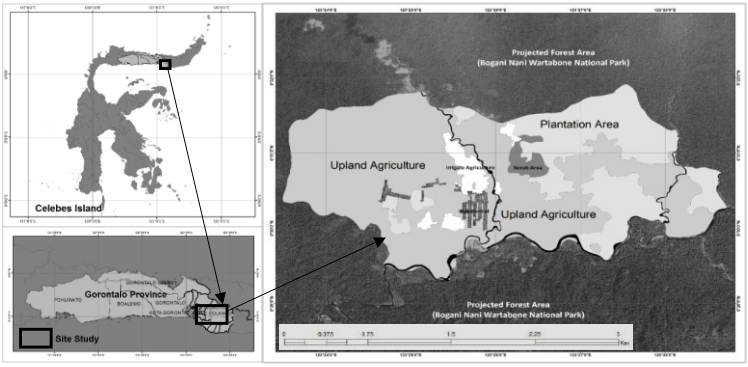

Figure 1. Research Location Map

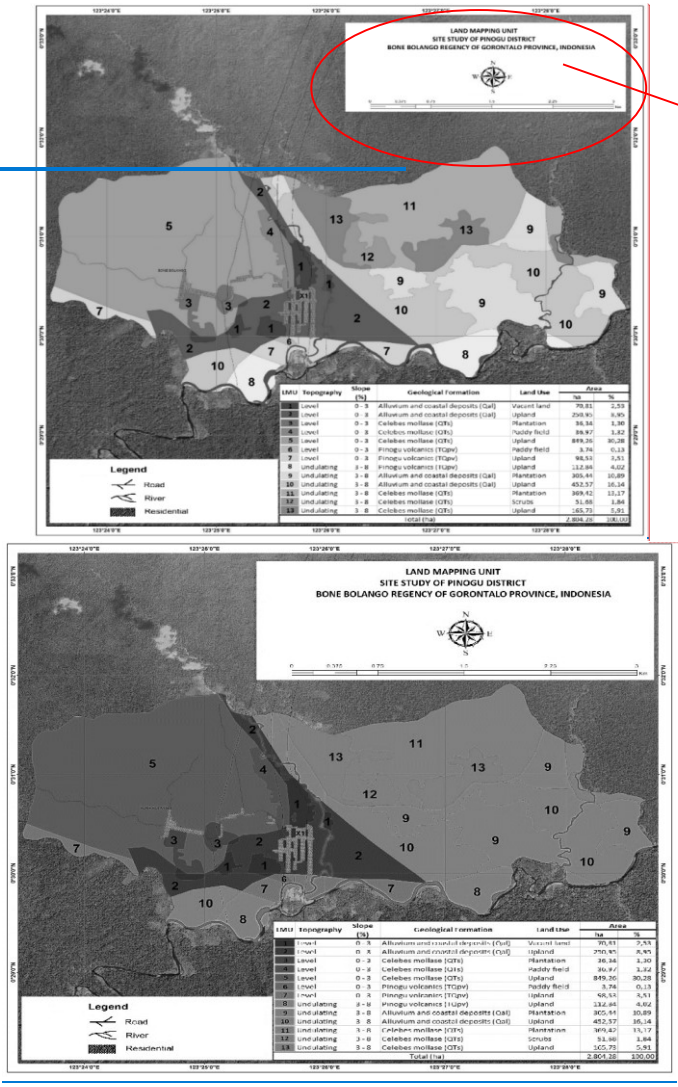

Figure 2. Land Mapping Unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

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2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:						
P availability (*Olsen*)	na	ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = meters above sea level, ppm = part per million.

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

$Y = -2.672 + 0.026$ Elevation [1]

$Y = 17{,}190 - 0.090$ Slope [2]

$Y = 3.055 + 0.005$ pH H_2O [3]

$Y = 4.050 - 0.019$ C-organic [4]

$Y = -28.796 + 0.621$ P Olsen [5]

$Y = 32.450 - 0.109$ Cation exchange capacity [6]

$Y = 0.457 - 0.002$ Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100}\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x\ \ldots\ x\ \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH)

and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sl= meters sea level, ppm = part per million.

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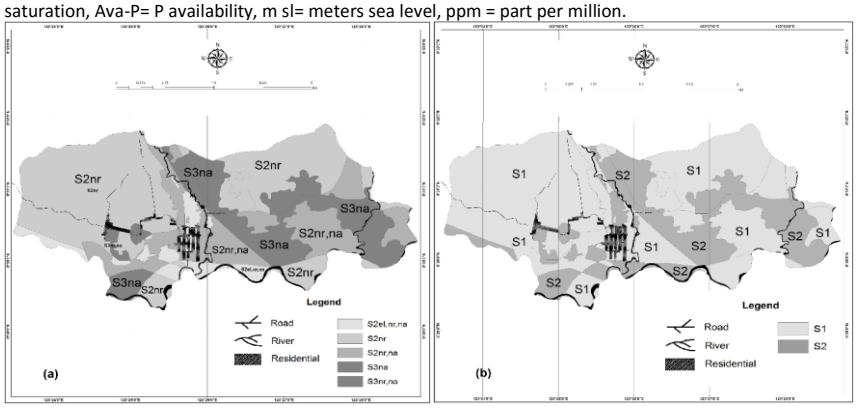

Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

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Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
Total (Ha)					2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class.

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3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and their Recommendations on Land Management

Comparison in Table 6 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric method, the land included in recommendation I (S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		Ȳ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m asl= meters above sea level, ppm= part per million, Y = productivity, Stdev= standard deviation, RMSE= root mean square error.

Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
Total (ha)																	2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
		Total (ha)			2,804.28	100.00

Remark: LMU = land mapping unit.

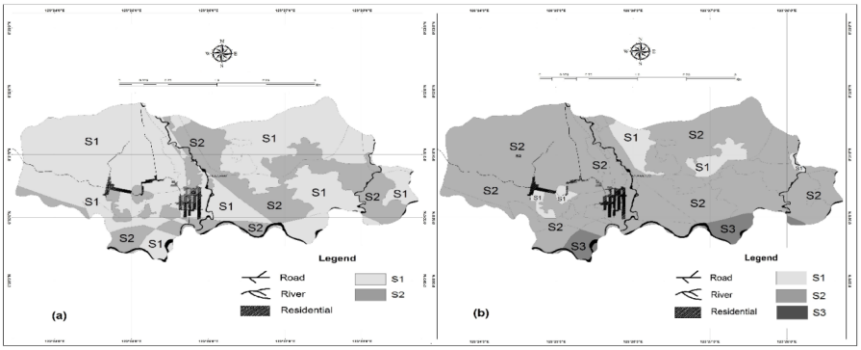

Figure 34. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

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Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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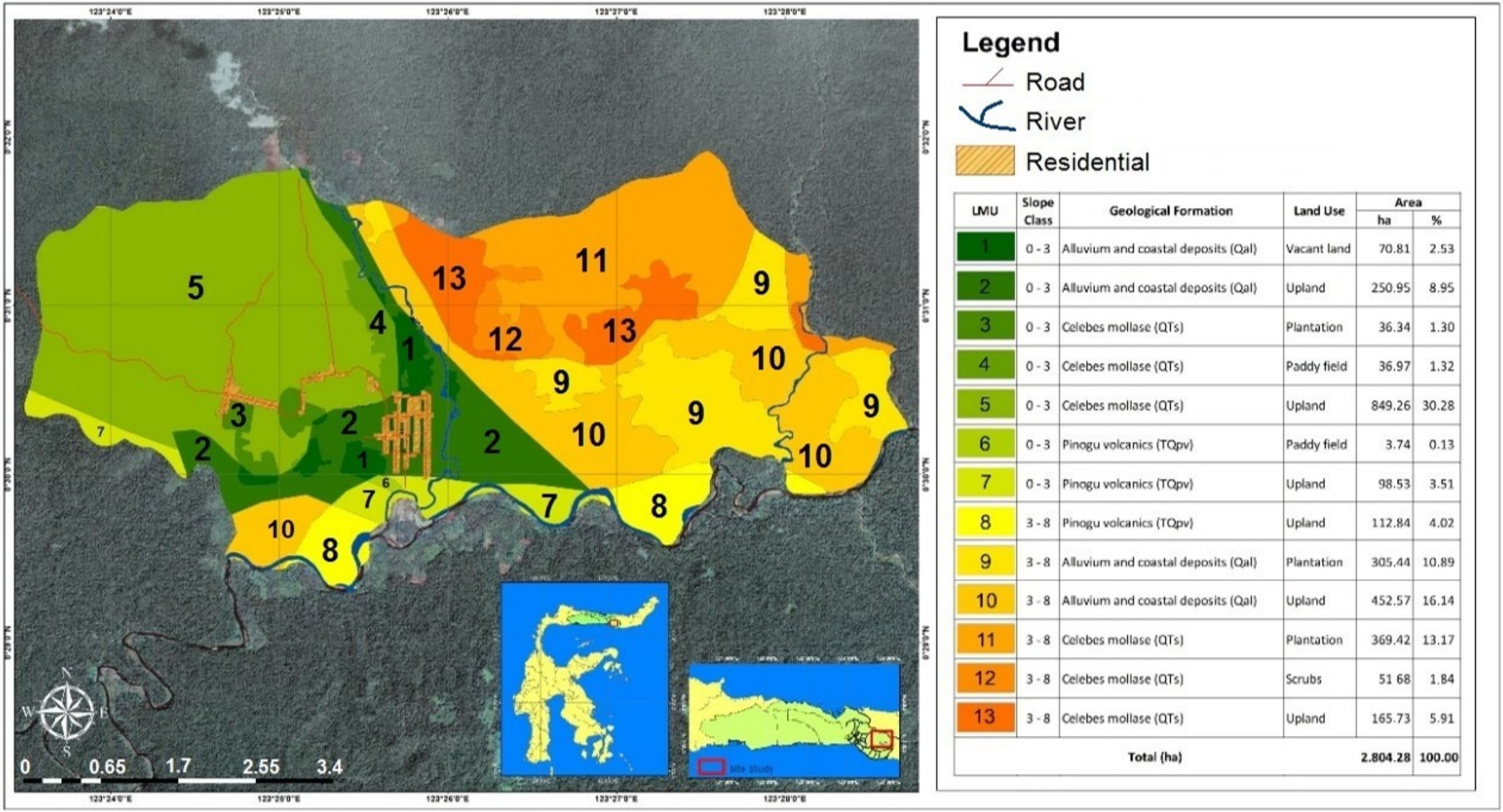
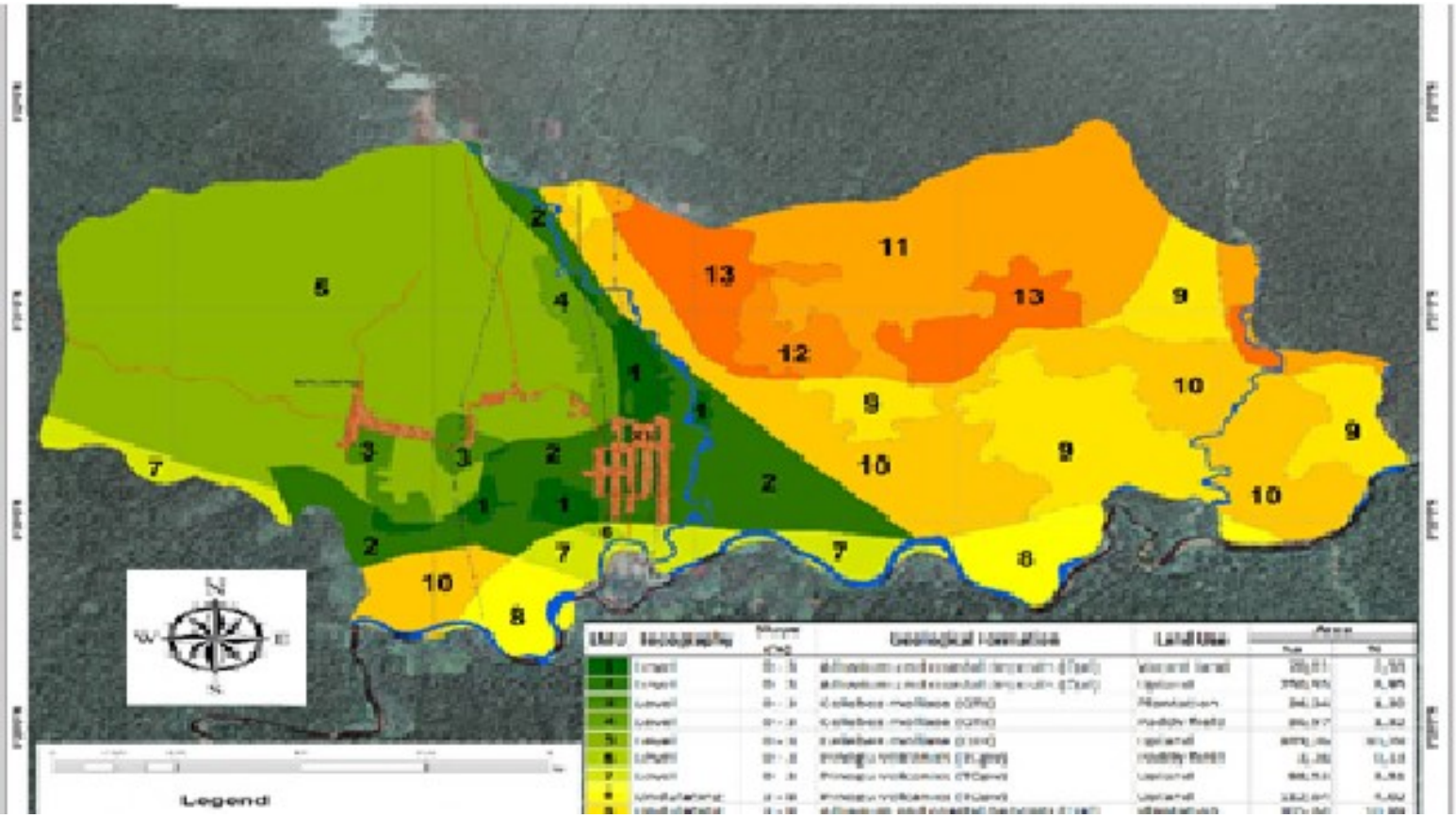


Legend

- Road
- River
- Residential

LMU	Slope Class	Geological Formation	Land Use	Area	
				ha	%
1	0 - 3	Alluvium and coastal deposits (Qal)	Vacant land	70.81	2.53
2	0 - 3	Alluvium and coastal deposits (Qal)	Upland	250.95	8.95
3	0 - 3	Celebes mollase (QTs)	Plantation	36.34	1.30
4	0 - 3	Celebes mollase (QTs)	Paddy field	36.97	1.32
5	0 - 3	Celebes mollase (QTs)	Upland	849.26	30.28
6	0 - 3	Pinogu volcanics (TQpv)	Paddy field	3.74	0.13
7	0 - 3	Pinogu volcanics (TQpv)	Upland	98.53	3.51
8	3 - 8	Pinogu volcanics (TQpv)	Upland	112.84	4.02
9	3 - 8	Alluvium and coastal deposits (Qal)	Plantation	305.44	10.89
10	3 - 8	Alluvium and coastal deposits (Qal)	Upland	452.57	16.14
11	3 - 8	Celebes mollase (QTs)	Plantation	369.42	13.17
12	3 - 8	Celebes mollase (QTs)	Scrubs	51 68	1.84
13	3 - 8	Celebes mollase (QTs)	Upland	165.73	5.91
Total (ha)				**2.804.28**	**100.00**



SMU	Name	Geological Formation	Area Ha	Area %
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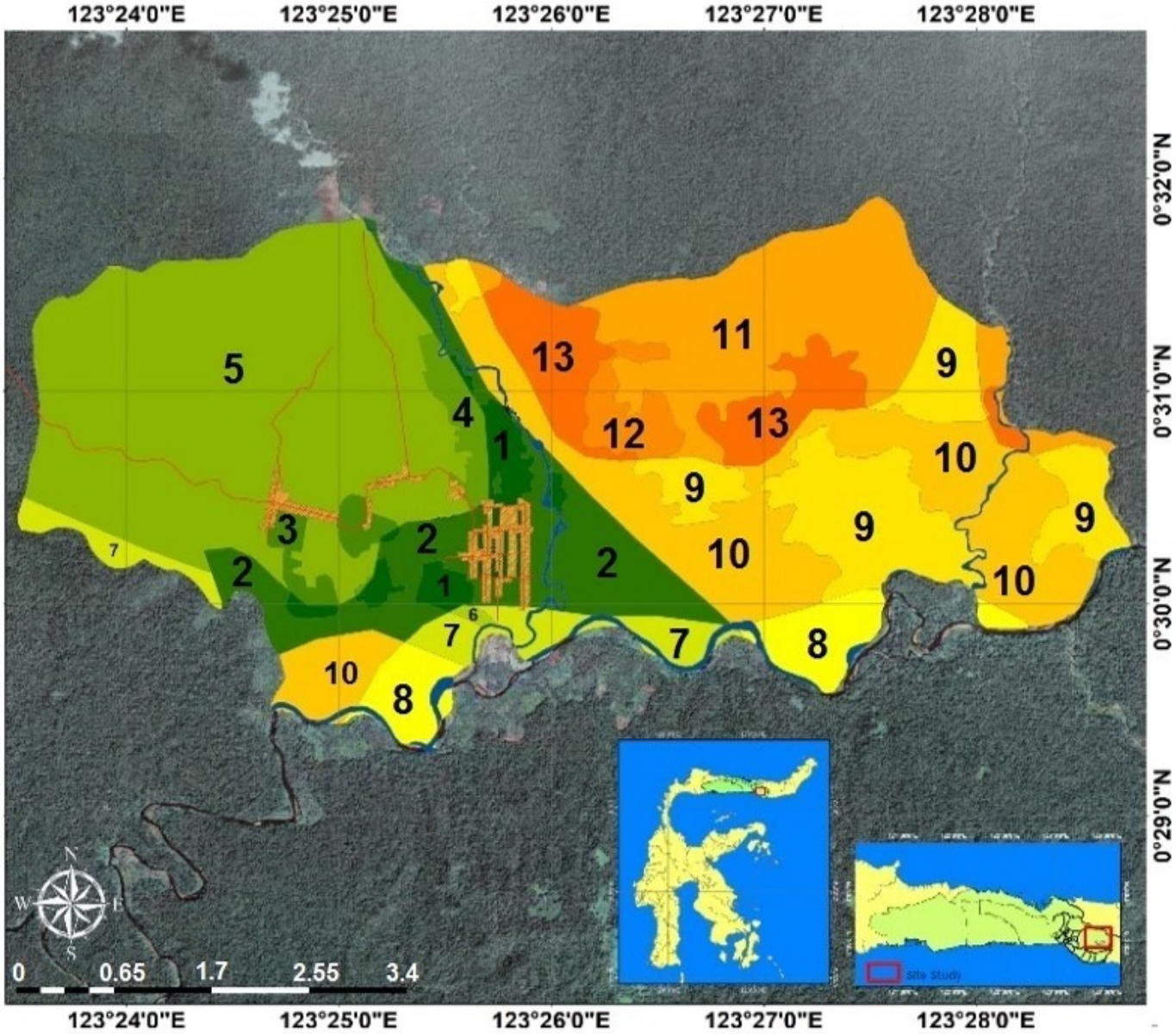

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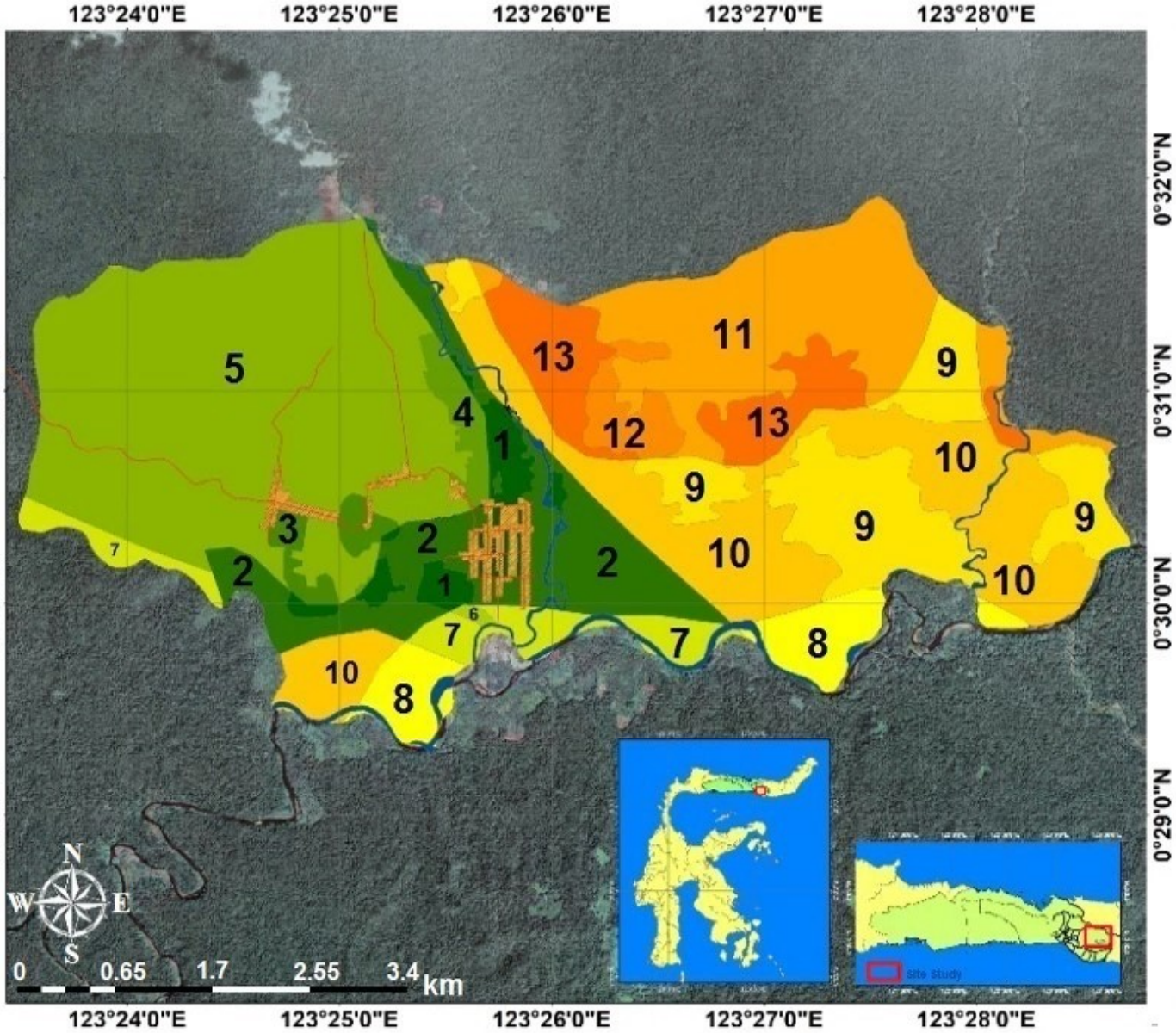

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After carefully reading our pre-published article with the title "Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia", we humbly I beg if you can correct some incorrect bibliography (bibliography attached), namely:

Written:
Gusfarina, D. S. (2014). Mengenal Kopi Liberika Tungkal Komposit (Libtukom). In: Balai Pengkajian eknologi Pertanian (BPTP) Jambi.
Should:
Gusfarina, D. S. (2014). Mengenal Kopi Liberika Tungkal Komposit (Libtukom). In: Balai Pengkajian Teknologi Pertanian (BPTP) Jambi.
Written:
Hartati, T. M., Sunarminto, B. H., & Nurudin, M. (2018). Evaluasi Kesesuaian Lahan untuk Tanaman Perkebunan di Wilayah Galela, Kabupaten Halmahera Utara, Propinsi Maluku Utara. , 33(1), 10 . https://doi.org/10.20961/carakatani.v33i1.19298
Should:
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Written:
Sancayaningsih, R. P., Suryanto, E., Reza, A., & Wiryawan, I. F. (2016). Community Empowerment Program in Pinogu Subdistrict, Bone Bolango Regency, Gorontalo Province, Indonesia: Concerning The Unique Local Biodiversity Conservation. 2016, 1(2), 193 -193. https://doi.org/10.22146/jpkm.10604
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Susilo, B., Fibrianto, K., Sunaryo, S., Ciptadi, G., Arwani, M., & Salsabila, A. N. (2021). Upaya Pengembangan Agroindustri Kopi Pinogu Melalui Introduksi Alat Pengolahan Kopi. 2021 , 7(1), 1184-1192.
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FINAL CORRECTION LIST of REFERENCE.docx
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J. Soil Sci. & Agric <sainstanah@mail.uns.ac.id> 19 Mei 2022 pukul 12.55
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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to become very suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II or the land that had a little limiting factor turned out to be more dominant with the recommendation of adding P and organic fertilizer.

How to Cite: Nurdin, Zakaria, F., Azis, M.A., Rahim, Y., Rahman, R., Kasim, M. (2022). Comparison of land suitability class for endemic *Coffea liberica* Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia. Sains Tanah Journal of Soil Science and Agroclimatology, 19(1): 42-51. https://dx.doi.org/10.20961/stjssa.v19i1.56441

1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including the consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. The parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4"–0°38'29.04" north to 123°18'38.52"–123°33'15.48" east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

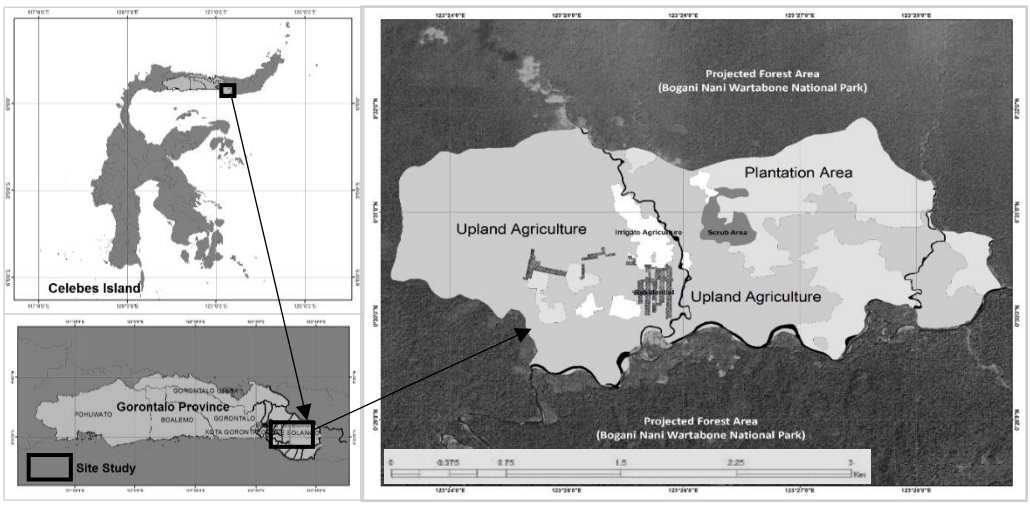
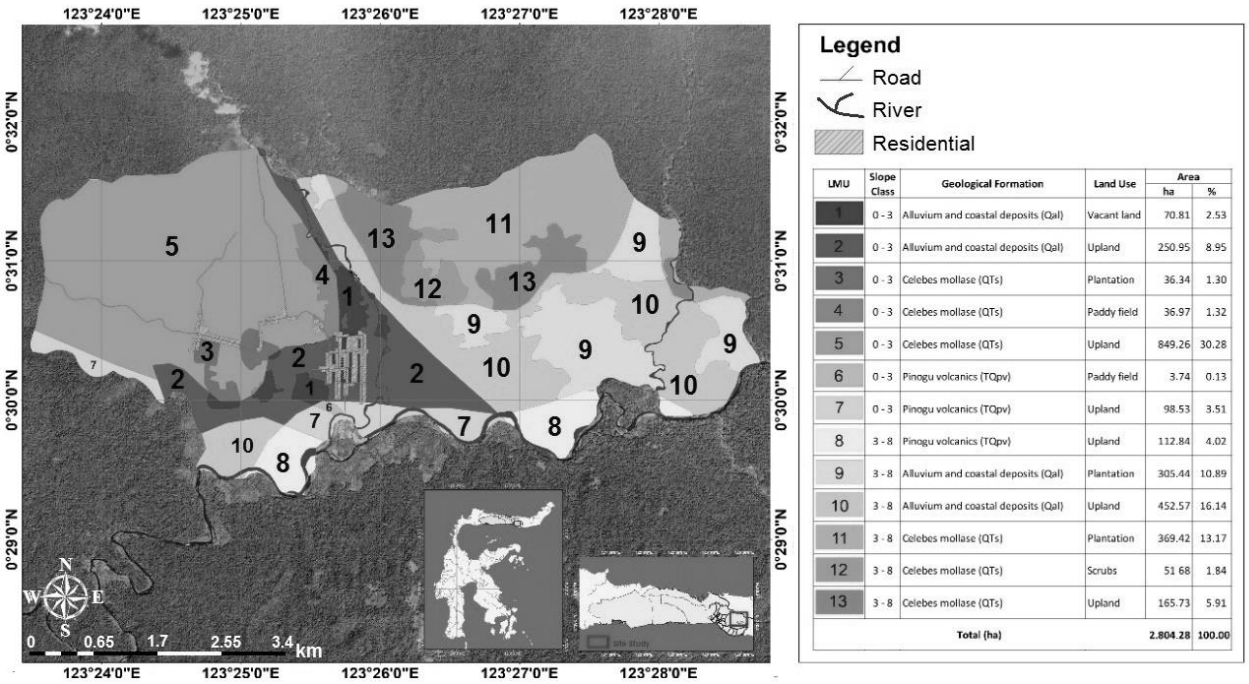


Figure 1. Research location map



LMU	Slope Class	Geological Formation	Land Use	Area ha	Area %
1	0 - 3	Alluvium and coastal deposits (Qal)	Vacant land	70.81	2.53
2	0 - 3	Alluvium and coastal deposits (Qal)	Upland	250.95	8.95
3	0 - 3	Celebes mollase (QTs)	Plantation	36.34	1.30
4	0 - 3	Celebes mollase (QTs)	Paddy field	36.97	1.32
5	0 - 3	Celebes mollase (QTs)	Upland	849.26	30.28
6	0 - 3	Pinogu volcanics (TQpv)	Paddy field	3.74	0.13
7	0 - 3	Pinogu volcanics (TQpv)	Upland	98.53	3.51
8	3 - 8	Pinogu volcanics (TQpv)	Upland	112.84	4.02
9	3 - 8	Alluvium and coastal deposits (Qal)	Plantation	305.44	10.89
10	3 - 8	Alluvium and coastal deposits (Qal)	Upland	452.57	16.14
11	3 - 8	Celebes mollase (QTs)	Plantation	369.42	13.17
12	3 - 8	Celebes mollase (QTs)	Scrubs	51 68	1.84
13	3 - 8	Celebes mollase (QTs)	Upland	165.73	5.91
Total (ha)				2.804.28	100.00

Figure 2. Land mapping unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected land suitability criteria for *Coffea liberica*

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)	nr		5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH_4.OAc pH 7 Extraction*)		cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH_4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:	na					
P availability (*Olsen*)		ppm	>16	10–15	<10	-

Source: (Kementan, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, m asl = meters above sea level, ppm = part per million

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

Y = −2.672 + 0.026 Elevation [1]
Y = 17.190 − 0.090 Slope [2]
Y = 3.055 + 0.005 pH H_2O [3]
Y = 4.050 − 0.019 C-organic [4]
Y = -28.796 + 0.621 P Olsen [5]
Y = 32.450 − 0.109 Cation exchange capacity [6]
Y = 0.457 − 0.002 Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, …, N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Fig. 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Fig. 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual land suitability class for *Coffea liberica* in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= Phosphor availability, m sl= meters sea level, ppm = part per million, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient availability

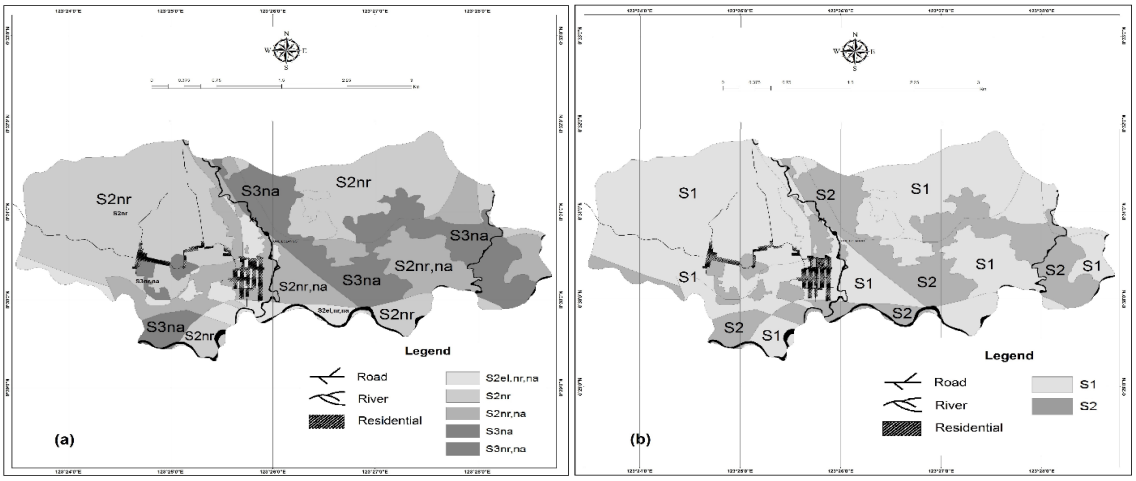


Figure 3. Actual (a) and potential (b) of land suitability class of *Coffea liberica* in Pinogu Plateau (Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient availability)

Table 3. Potential land suitability classes for *Coffea liberica* in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36.34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1,386.94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient available, C = carbon, P = phosphor

3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and Recommendations on Land Management

Comparison in Table 6 and Fig. 4 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric method, the land included in recommendation I (S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 4. Estimated value of *Coffea liberica* productivity in Pinogu Plateau

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		Ȳ (ton ha^{-1})	Stdev	RMSE
	Value (m sl)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (cmol)	Y (ton ha^{-1})	Value (%)	Y (ton ha^{-1})	Value (ppm)	Y (ton ha^{-1})			
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, Y = productivity, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

Table 5. Value of land characteristic rating, land index, and land suitability class for *Coffea liberica*

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		LI	LCS	Area	
	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC	Y (ton ha^{-1})	LC			ha	%
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
Total (ha)																	2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of land suitability classes with limiting factors and parametric methods for *Coffea liberica* in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
Total (ha)					2,804.28	100.00

Remark: LMU = land mapping unit; S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable

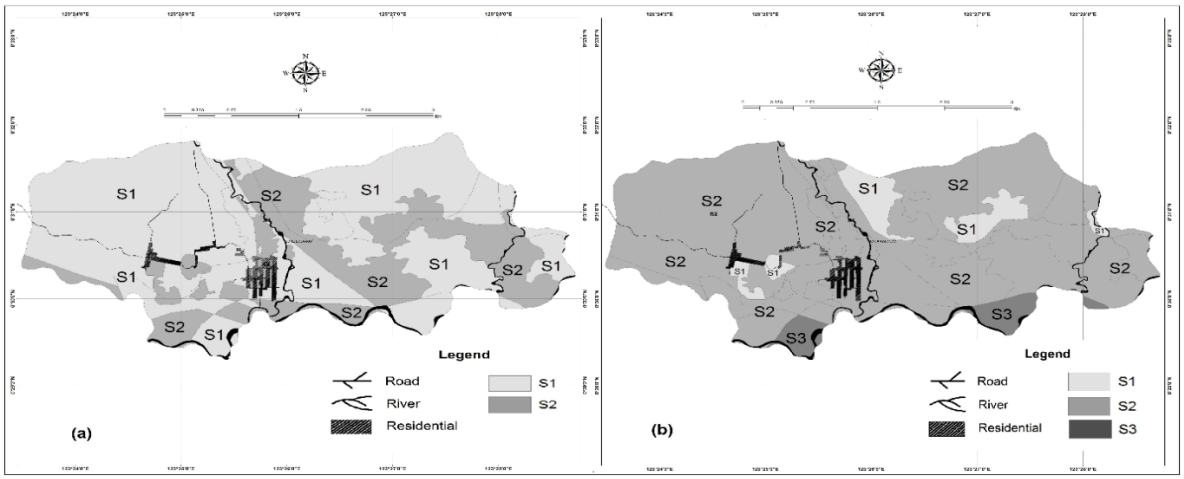


Figure 4. Comparison of land suitability classes for *Coffea liberica* in Pinogu Plateau obtained using limiting factor (a) and parametric methods (b) (Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable)

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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