



RESEARCH ARTICLE

Land capability and suitability evaluation for developing three major plantation crops in the Padang Ulak Tanding transmigration area, Rejang Lebong Regency, Bengkulu Province, Indonesia

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Abstract

Land suitability evaluation is crucial for sustainable plantation development, particularly in transmigration areas designated as emerging regional economic growth centers. These areas often exhibit heterogeneous land characteristics and management constraints that may limit agricultural productivity. This study assessed the actual and potential land suitability of three major plantation commodities: coffee, oil palm and rubber in the Padang Ulak Tanding Transmigration Area, Bengkulu Province, Indonesia. The study was conducted from August to December 2025 using an integrated approach combining field surveys, soil laboratory analyses and geographic information system (GIS) techniques. Land suitability classification followed the FAO framework adapted to the Indonesian Land Suitability Assessment System. Under actual conditions, most land units were classified as marginally suitable (S3), primarily due to shallow soil depth, acidic soil pH and steep slopes. The application of feasible land improvement measures, particularly soil fertility management and erosion control, improved land suitability to moderately suitable (S2) in most areas, although physical limitations remained in certain locations. These findings highlight the importance of site-specific land management and provide a scientific basis for sustainable plantation development in transmigration areas supporting regional economic growth.

Keywords: geographic information system; land suitability; plantation crops; transmigration area

Introduction

Plantation commodities such as coffee, oil palm and rubber play essential roles in Indonesia's agricultural economy, contributing significantly to rural livelihoods, employment and export earnings (1). However, sustainable expansion of these perennial crops requires systematic land suitability evaluation to ensure that land resources are used efficiently and do not degrade the environment or reduce long-term productivity. Land suitability assessment is a decision support tool that matches physical land characteristics with crop ecological requirements, thus guiding land use planning and management (2, 3). Studies in various Indonesian regions have applied land suitability methods for specific plantation crops, revealing that soil properties, climate and topography are major determinants of suitability classes and limiting factors (1). Despite this, there is limited research addressing land suitability for multiple plantation commodities simultaneously within transmigration areas, where land use history and socio-economic contexts vary considerably. The Padang Ulak Tanding Transmigration Area in Bengkulu Province contains diverse landscapes across 3 subdistricts, including Padang Ulak Tanding, Sindang Beliti Ilir and Kota Padang, making it an important case for multi-commodity land evaluation.

Therefore, this study seeks to address the knowledge gap by evaluating land suitability for coffee, oil palm and rubber in this specific transmigration context.

Land suitability research for coffee crops in Indonesia has demonstrated the necessity of identifying environmental limitations that affect production and recommendation of land management practices to improve suitability classes (1, 4). Similarly, field surveys combined with laboratory soil analyses have been used to assess suitability of coffee land in other regions, highlighting common limiting factors such as soil moisture and nutrient availability (4). Comparable research on oil palm plantations demonstrates that overlaying soil, slope and climate maps helps classify areas into suitability categories that inform land use decisions. These studies illustrate how land evaluation methods provide insights into both actual and potential suitability classes, enabling stakeholders to target interventions for improving land productivity. Despite these advances, multi-commodity suitability assessments that incorporate key plantation crops have rarely been applied at the transmigration area scale. This gap underscores the need for integrated land evaluation that supports balanced crop development and landscape planning.

The transmigration program in Indonesia has historically redistributed population and agricultural activities to less populated areas, significantly altering land use patterns and socio-economic dynamics (5). In areas like Padang Ulak Tanding, transmigration settlements have created mosaic landscapes of smallholder farms, mixed cropping systems and plantation plots that require nuanced understanding of land potential for various commodity crops. Unlike typical plantation zones dominated by one crop, transmigration areas often host multi-commodity production, which necessitates comprehensive evaluation to support diversified agricultural development. Moreover, evaluating land suitability in these contexts is crucial to inform not only production potential, but also environmental conservation, infrastructure planning and farmer support services. Agricultural planning in transmigration landscapes must consider both the physical capacity of the land and the socio-economic needs of local communities. By examining coffee, oil palm and rubber suitability simultaneously across 3 subdistricts, this study provides a more holistic view of land capability for plantation commodities. Such integrated assessment supports regional development strategies that aim to enhance livelihoods while maintaining ecological integrity.

Given the critical importance of plantation commodities and the strategic role of transmigration areas in rural development, there is a pressing need for evidence-based land use planning that aligns crop requirements with land potential. The evaluation results of multi-commodity land suitability can serve as a foundation for policy recommendations, investment decisions and land management practices tailored to each subdistrict's context. Additionally, this study contributes to the broader literature on land evaluation by demonstrating a framework that accommodates multiple perennial crops with distinct ecological needs. Understanding the spatial distribution of suitability classes enables stakeholders to prioritise areas for intensified cultivation, rehabilitation, or alternative use. Ultimately, this research supports sustainable plantation development in the Padang Ulak Tanding Transmigration Area, fostering balanced economic growth and environmental stewardship.

The objective of this study is to evaluate land suitability for coffee, oil palm and rubber plantation commodities in the Padang Ulak Tanding Transmigration Area, covering Padang Ulak Tanding, Sindang Beliti Ilir and Kota Padang subdistricts. This study aims to identify suitability classes and limiting factors for each commodity to support sustainable land use planning. The results are expected to provide a scientific basis for plantation development strategies in transmigration areas.

Materials and Methods

Study area and time

This research was conducted from August to December 2025 in the Padang Ulak Tanding Transmigration Area, Rejang Lebong Regency, Bengkulu Province, Indonesia, geographically located at approximately 3°22'31" S and 102°47'48" E. The study area covers three administrative subdistricts: Padang Ulak Tanding Subdistrict, Sindang Beliti Ilir subdistrict and Kota Padang subdistrict (Fig. 1). These areas represent major transmigration settlement units with dominant plantation commodities, including coffee, oil palm and rubber. The region exhibits diverse topography, soil types and land-use characteristics that are critical for land suitability evaluation. The

administrative boundary map used in this study was derived from the delineation of the transmigration area and serves as the spatial reference for subsequent land unit analysis (Fig. 1).

Data collection and sources

This study applied a spatial land suitability evaluation approach by integrating geospatial analysis, field surveys and laboratory analysis. Primary data were obtained through direct field observations, soil sampling and land characteristic measurements at representative land units. Soil samples were collected from the topsoil layer (0–30 cm) and analysed to determine key physical and chemical properties relevant to plantation crop requirements.

Secondary data included base maps such as administrative boundary maps, land-use/land-cover maps, soil type maps, slope maps, climate data and digital elevation models (DEM). Administrative and base spatial data were obtained from the Indonesian Geospatial Information Agency (BIG), statistical and regional data from the Central Bureau of Statistics (BPS) and supporting datasets from relevant local government agencies.

The methodological workflow began with the preparation of base maps, followed by spatial overlay analysis to delineate land units based on the combination of land use, soil type and slope. After overlaying, there were 7 land units for soil sampling (Fig. 2). Each land unit was then evaluated using a matching technique between land characteristics and crop growth requirements to determine actual land suitability. Potential land suitability was assessed by simulating reasonable land improvement measures, such as fertilisation, soil amendment and erosion control. All spatial analyses and map production were conducted using ArcGIS 10.8, resulting in land unit maps and land suitability evaluation outputs for coffee, oil palm and rubber commodities.

Field survey and soil analysis

Field surveys were conducted using purposive sampling to select representative land units based on land use, slope and soil type. Soil samples were collected manually using a soil auger to a depth of 0–60 cm, with additional field measurements including slope gradient, drainage condition and surface characteristics. Laboratory analyses were conducted to determine soil physical and chemical properties relevant to plantation crops, including soil texture, pH (H₂O), organic carbon, available phosphorus (P₂O₅), exchangeable potassium (K₂O), cation exchange capacity (CEC) and base saturation. These parameters were used as key indicators for assessing crop growth requirements.

Land suitability evaluation

Land suitability classification followed the FAO land evaluation framework, adapted through the Indonesian land suitability assessment system (SPKL). Suitability was evaluated for coffee, oil palm and rubber by matching land characteristics with crop growth requirements. Each land unit was classified into four suitability classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N) (Tables 1, 2 and 3). Both actual land suitability (current conditions) and potential land suitability (assuming feasible land improvements such as fertilization, organic matter application and slope management) were assessed to identify development opportunities and constraints (6).

Data analysis

Spatial analysis integrated soil, topography and land-use data to produce suitability maps for each plantation commodity. The

Table 1. Land suitability criteria for coffee cultivation

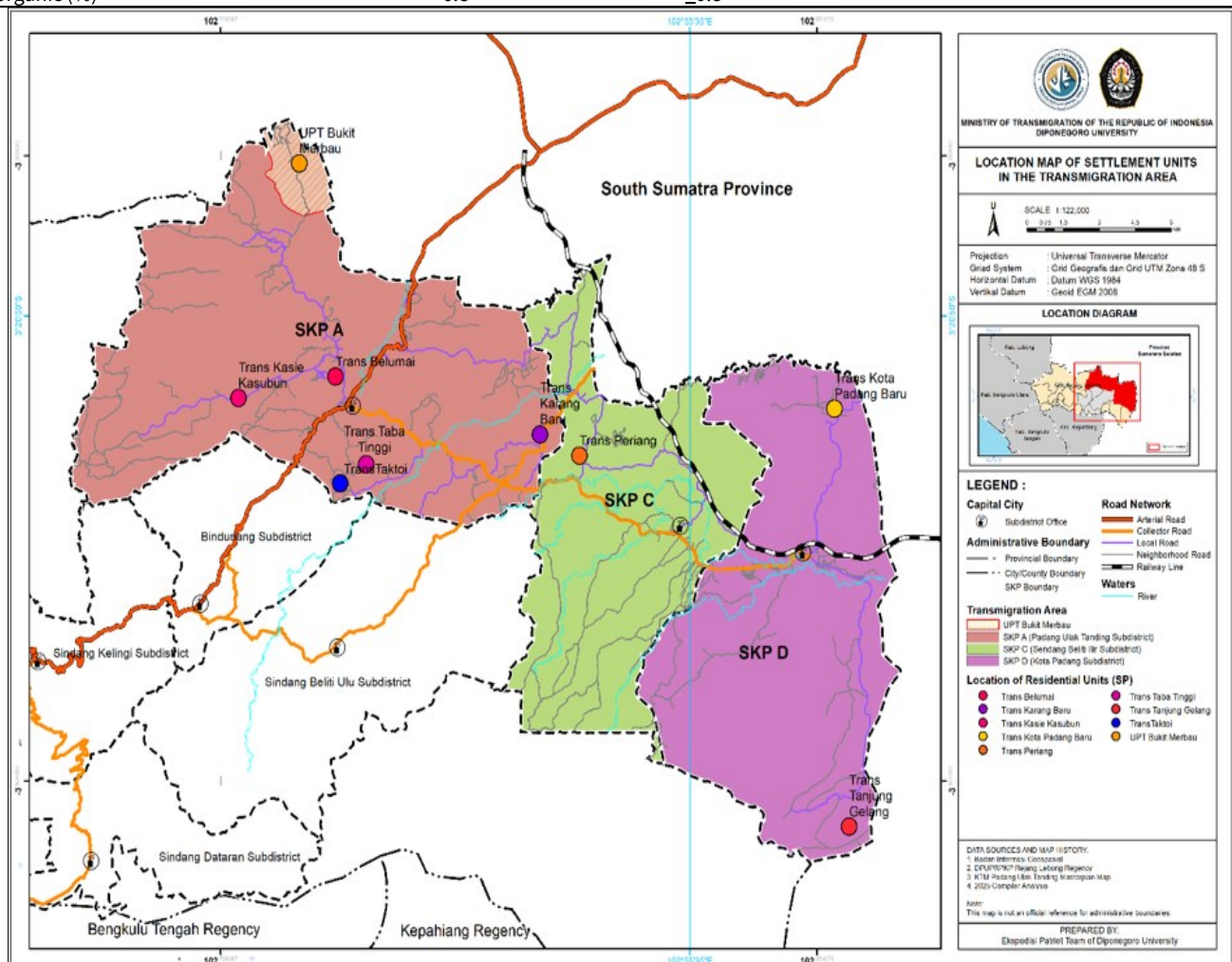
Land use requirements/Land characteristics	Land suitability class			
	S1	S2	S3	N
Temperature regime(tc) (°C)	22–25	25–28	28–32	< 19
Water availability (wa) (mm year ⁻¹)	2000–3000	1750–2000	1500–1750	< 1500
Humidity (%)	45–80	80–90; 35–45	> 90; 30–35	< 30
Drainage	Good	Moderate	Mod. Poor, mod. Rapid	Poor, very poor, rapid
Soil texture (surface)	Fine, slightly fine, medium	-	slightly coarse, very fine	Coarse, very fine
Soil depth (cm)	> 100	75–100	50–75	< 50
CEC-Clay (cmol (+) kg ⁻¹)	> 16	5–16	< 5	-
pH H ₂ O (1:1)	5.3–6.0	6.0–6.5	> 6.5	-
C-organic (%)	> 0.8	≤ 0.8	-	-

Table 2. Land suitability criteria for oil palm cultivation

Land use requirements/Land characteristics	Land suitability class			
	S1	S2	S3	N
Temperature regime(tc) (°C)	25–28	22–25	20–22	< 20
Water availability (wa) (mm year ⁻¹)	1700–2500	1450–1700	1250–1450	< 1250
Drainage	Good, Moderate	Mod. Poor	Poor, Mod. Rapid	Very poor, rapid
Soil texture (surface)	Fine, slightly fine, medium	-	Slightly coarse	Coarse
Soil depth (cm)	> 100	75–100	50–75	< 50
CEC-Clay (cmol (+) kg ⁻¹)	> 16	5–16	< 5	-
pH H ₂ O (1:1)	5.0–6.5	4.2–5.0	< 4.2	-
C-organic (%)	> 0.8	≤ 0.8	-	-

Table 3. Land suitability criteria for rubber cultivation (12)

Land use requirements/Land characteristics	Land suitability class			
	S1	S2	S3	N
Temperature regime(tc) (°C)	26–30	30–34	-	> 34
Water availability (wa) (mm year ⁻¹)	2500–3000	2000–2500	1500–2000	< 1500
Drainage	Good	Moderate	Mod. Poor,	very poor, rapid
Soil texture (surface)	Fine, slightly fine, medium	-	slightly coarse	Coarse
Soil depth (cm)	> 100	75–100	50–75	< 50
CEC-Clay (cmol (+) kg ⁻¹)	> 16	5–16	< 5	-
pH H ₂ O (1:1)	5.0–6.0	6.0–6.5	> 6.5	-
C-organic (%)	> 0.8	≤ 0.8	-	-



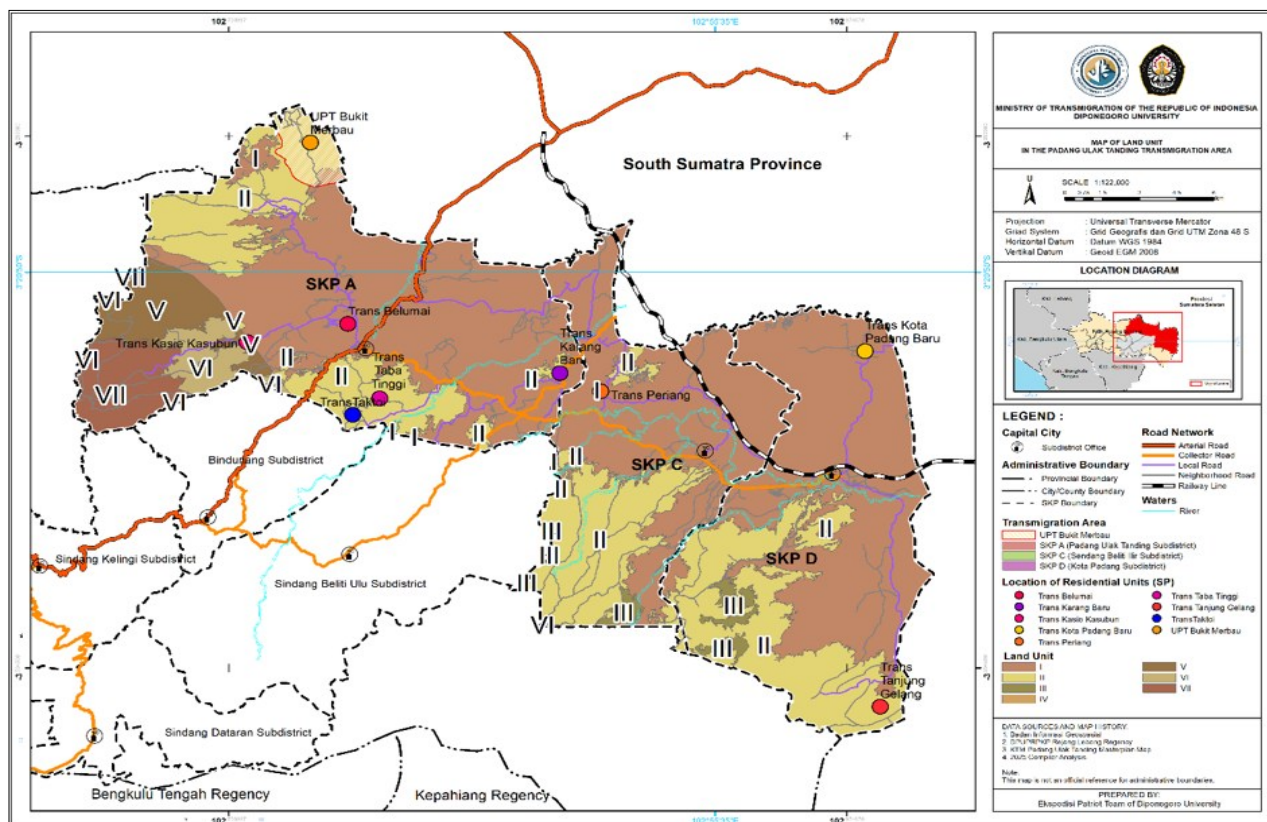


Fig. 2. Land unit map of the Padang Ulak Tanding transmigration area (BIG– Badan informasI Geospasial).

consistency and reliability of the results were ensured through cross-validation between field data, laboratory results and spatial datasets. The combined use of GIS-based spatial analysis and standardised land evaluation criteria provided a systematic and reproducible assessment of plantation land suitability in the transmigration area, supporting evidence-based land-use planning and commodity development strategies.

Results

Soil type conditions and climate data in Rejang Lebong Regency

The soil physicochemical properties in the study area were evaluated to know the existing environmental conditions. There are many factors that have been considered in assessing the suitability of land for farming purposes. According to results, the variability of soil property in the area can be observed based on its geologic and geographic past. The soil analysis of the study area is summarised in Table 4, which presents the key physical and chemical characteristics of soils in Rejang Lebong Regency.

From Table 4, it is evident that the soil characteristics of Rejang Lebong Regency exhibit considerable spatial heterogeneity. The area is dominated by diverse tropical soil types, including Andosol, Podsollic complexes, Latosol, Alluvial and Regosol soils, reflecting variations in parent material, weathering intensity and landscape development. Topographic conditions range from flat to steep slopes (0 % to > 30 %) with elevations between 100 and < 1000 m above sea level, indicating a predominantly highland agroecosystem. Such variability in topography may influence runoff dynamics, erosion susceptibility and nutrient redistribution across the landscape. The soils are generally characterised by acidic to near-neutral reactions (pH 4.5–7.5) and moderately coarse sandy loam texture. The sandy loam texture suggests relatively moderate soil permeability and favourable drainage conditions, which may support water movement, soil aeration and root-zone development within the study area. The soil type sandy loam is usually made up of soils that have an optimal balance between sand and other smaller particles, thus they can have proper drainage but still retain enough moisture for plant growth (7). However, hydraulic conductivity was not directly quantified in the present study and therefore is

Table 4. Soil analysis of Rejang Lebong Regency area

Sl. No.	Parameter	Criteria	Description	Dominant characteristics
1.	Soil type	Tropical soil complex	Andosol	Heterogeneous tropical soils with variable fertility, drainage capacity and nutrient retention characteristics
			Complex of podsollic brown, podzolic latosol	
			Complex of podsollic red-yellow, litosol and latosol	
			Podsollic red-yellow / latosol andosol	
			Latosol	
2.	Slope	Undulating –	Alluvial	Variable topography with moderate to high
			Regosol	
3.	Elevation	Highland	100 – < 1000 m above sea level	Highland agroecosystem with distinct
4.	Soil pH	Acidic	4.5–7.5	Slightly acidic to near-neutral soil reaction affecting nutrient availability
5.	Soil texture	Moderate	Sandy loam	Moderately coarse texture with good aeration and drainage capacity

interpreted qualitatively based on soil physical characteristics. The occurrence of Andosol and Regosol soils may further indicate relatively good porosity and drainage behavior, which are commonly associated with volcanic-derived upland soils. The soils known as volcanic soils, for example andosols, have good porosity, low bulk density and good aggregate stability (8). Overall, these environmental conditions are typical of tropical volcanic highland agroecosystems and may substantially influence soil water dynamics, nutrient availability and crop adaptability in the region (9).

The annual climate variability in the study area from 2021 to 2024 is presented in Fig. 3, which depicts the average trends in temperature, humidity and rainfall.

As can be seen from Fig. 2, the mean temperature recorded for the study site was recorded at 24.1°C in 2021 and rose steadily to reach 24.7°C in 2024. The level of humidity also increased steadily from 87 % to 92 %. The amount of rainfall was characterised by interannual variation, with a steep drop from 370.7mm in 2021 to 201.2mm in 2022, with a slight recovery to 295.3mm in 2024. The above variations in the recorded data have similarities with other climate trends in the Indonesian Maritime Continent, where nonstationarity in annual rainfall has been noted, particularly due to the influence of El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) climate modes (10).

Land unit map and characteristics

The spatial overlay analysis of soil type and slope resulted in the delineation of several homogeneous land units within the Padang Ulak Tanding Transmigration Area. The distribution of these land units is presented in Fig. 3, which illustrates the spatial variation of biophysical conditions across the study area. Each land unit represents a unique combination of topographic and soil characteristics that influence land suitability for plantation commodities. The overlay process enabled a systematic classification of the landscape into manageable analytical units. This approach ensures that land suitability evaluation is based on

spatially explicit and integrated land attributes. Consequently, the resulting land unit map serves as a fundamental basis for further suitability assessment.

The characteristics of each delineated land unit are summarised in Table 5, including slope gradient, effective soil depth, soil texture, drainage condition and soil chemical properties. The table highlights considerable variability among land units, particularly in terms of slope and soil depth, which are key limiting factors for plantation development. By integrating spatial patterns shown in Fig. 3 with the detailed attributes listed in Table 5, a comprehensive understanding of land characteristics is achieved to support subsequent land suitability classification.

Actual land suitability

The actual land suitability classification for plantation commodities in the Padang Ulak Tanding transmigration area was determined using a land evaluation method based on matching land characteristics with crop requirements. The evaluation revealed that most land units fell into the marginally suitable category (S3). Several significant limiting factors were identified that reduce the potential productivity of the land for plantation crops.

These limiting factors include soil depth (rc4), soil pH (nr3) and steep slope (eh1). These constraints affect plant root development, nutrient uptake, water retention and overall crop performance. The actual land suitability is shown in Table 6.

The results of the actual land suitability assessment indicate that most land units in the Padang Ulak Tanding transmigration area fall into the marginally suitable class (S3) for coffee (Fig. 4), oil palm (Fig. 5) and rubber cultivation (Fig. 6). This classification reflects the presence of significant limiting factors, particularly shallow effective soil depth (rc4) and acidic soil conditions (nr3), which restrict optimal root development and nutrient availability. Similar findings have been reported in tropical plantation systems, where soil depth and pH are consistently identified as dominant constraints affecting crop growth and yield

Table 5. Results of soil sample analysis in the Padang Ulak Tanding transmigration area

Village	Land Unit	Results of soil sample analysis					
		C (%)	N (%)	P (P ₂ O ₅ Bray (ppm))	K (cmol(P ⁺)/kg)	pH	KTK (cmol(P ⁺)/kg)
Periang	I	2.69	0.26	4.03	0.35	4.18	10.76
Kota Padang Baru	I	3.53	0.35	3.37	0.34	4.25	11.57
Belumai II	I	4.80	0.36	3.63	0.38	4.10	13.81
Taktoi	II	1.75	0.33	4.16	0.38	4.95	12.57
Taba Tinggi	II	3.42	0.28	7.52	0.40	4.00	14.58
Karang Baru	II	4.36	0.26	2.18	0.42	4.82	15.11
Tanjung Gelang	III	3.29	0.37	4.09	0.31	4.38	12.17
UPT B. Merbau	IV	3.33	0.34	4.14	0.36	4.01	15.48
Kasie Kasubun	V	3.35	0.27	5.30	0.50	4.00	18.77
	VI	3.98	0.33	4.15	0.42	4.44	16.09
	VII	2.15	0.24	3.26	0.42	4.00	14.11

C: carbon; N: nitrogen; P: phosphorus; K: potassium; pH: potential of hydrogen;; P₂O₅ Bray: phosphorus extracted using the Bray method. Land unit indicates the soil mapping unit used for land evaluation.

Table 6. The actual land suitability classification

Land unit	Village	Coffee	Oil palm	Rubber
I	Belumai II	S3–rc4/nr3	S3–rc4/nr3	S3–rc4/nr3
I	Kota Padang Baru	S3–rc4/nr3	S3–rc4	S3–rc4/nr3
I	Periang	S3–rc4/nr3	S3–rc4/nr3	S3–rc4/nr3
II	Taba Tinggi	S3–rc4/nr3	S3–rc4/nr3	S3–rc4/nr3
II	Taktoi	S3–rc4/nr3	S3–rc4	S3–rc4
II	Karang Baru	S3–rc4/nr3	S3–rc4	S3–rc4
III	Tanjung Gelang	S3–rc4/nr3/eh1	S3–rc4/nr3/eh1	S3–rc4/nr3/eh1
IV	Bukit Merbau	S3–rc4/nr3/eh1	S3–rc4/nr3/eh1	S3–rc4/nr3/eh1
V	Kasie Kasubun	S3–rc4/nr3	S3–rc4/nr3	S3–rc4/nr3
VI	Kasie Kasubun	S3–rc4/nr3	S3–rc4	S3–rc4/nr3
VII	Kasie Kasubun	S3–rc4/nr3/eh1	S3–rc4/nr3/eh1	S3–rc4/nr3/eh1

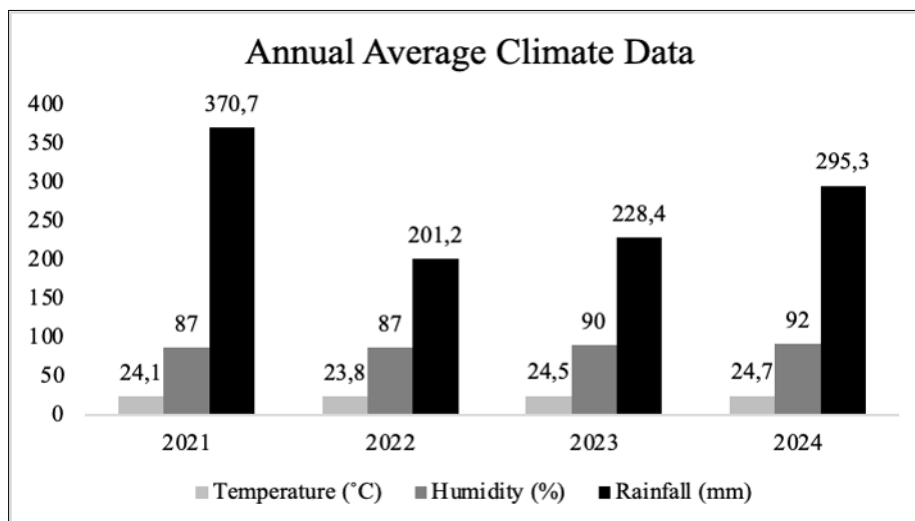


Fig. 3. Annual climate data for Rejang Lebong Regency (2021–2024).

potential. Acidic soils can reduce nutrient uptake efficiency, while shallow soil profiles limit root penetration and water storage capacity. Consequently, these limitations contribute to suboptimal plant performance despite favourable climatic conditions. This soil acidity condition can be improved by adding organic materials and providing dolomite (agricultural lime) (11, 12). A decrease in soil pH will reduce the solubility and availability of micronutrients (13).

In addition to soil-related constraints, steep slope conditions (eh1) were identified as an important limiting factor in several land units, particularly in upland and hilly areas (Fig. 4–6). Steep slopes increase the risk of erosion, reduce soil moisture retention and complicate mechanised farming practices, thereby lowering land productivity. Such topographic limitations are commonly observed in plantation development within transmigration areas, where land allocation often includes marginal terrains. Previous studies emphasise that slope gradients above critical thresholds significantly reduce land suitability unless appropriate conservation measures, such as terracing and erosion control, are implemented. Without these interventions, land degradation processes may intensify and further reduce long-term productivity. This pattern aligns with the land suitability which highlights slope and erosion risk as key determinants in evaluating plantation land suitability (14).

Potential land suitability

Land suitability potential represents the classification after implementing appropriate land improvements, such as soil improvement, fertilisation and erosion control. Compared to actual conditions, most land units in the Padang Ulak Tanding transmigration area improved to moderately suitable (S2) for coffee, oil palm and rubber. Improvements primarily addressed limiting factors such as low pH, poor nutrient retention, low nutrient

availability and soil depth. The potential land suitability is shown in Table 7.

The potential land suitability assessment indicates that land units in the Padang Ulak Tanding transmigration area generally improve from S3 to S2 after the implementation of appropriate land management measures (Fig. 7–9). Improvements such as soil pH correction, fertilisation and enhancement of soil nutrient availability play a crucial role in increasing land productivity for coffee, palm oil and rubber. These findings are consistent with studies showing that chemical soil constraints are among the most manageable limiting factors in plantation systems. Proper soil amendments can significantly enhance crop growth and yield potential when physical constraints are not dominant. Therefore, potential land suitability provides a more optimistic but realistic representation of land performance under improved management scenarios. Previous research has emphasised the importance of soil fertility improvement in land suitability upgrading (15).

Nevertheless, several land units remain constrained by inherent physical limitations such as shallow soil depth and slope-related erosion risk, which restrict further improvement beyond the S2 class (Fig. 7–9). These factors are difficult to mitigate through standard agronomic practices and often require long-term conservation interventions. Studies have shown that topographic constraints and rooting depth strongly influence perennial crop suitability and long-term sustainability. Without adequate soil conservation measures, these limitations may increase land degradation risks despite chemical improvements. Consequently, land management strategies should prioritise erosion control and slope stabilisation to maintain productivity. That terrain-related factors remain the primary limiting variables in plantation land suitability assessments (16).

Table 7. The potential land suitability classification

Land unit	Village	Coffee	Oil palm	Rubber
I	Belumai II	S2	S2	S2
I	Kota Padang Baru	S2	S2	S2
I	Periang	S2	S2	S2
II	Taba Tinggi	S2	S2	S2
II	Taktoi	S2	S2	S2
II	Karang Baru	S2	S2	S2
III	Tanjung Gelang	S2	S2	S2
IV	Bukit Merbau	S2	S2	S2
V	Kasie Kasubun	S2	S2	S2
VI	Kasie Kasubun	S2	S2	S2
VII	Kasie Kasubun	S2	S2	S2

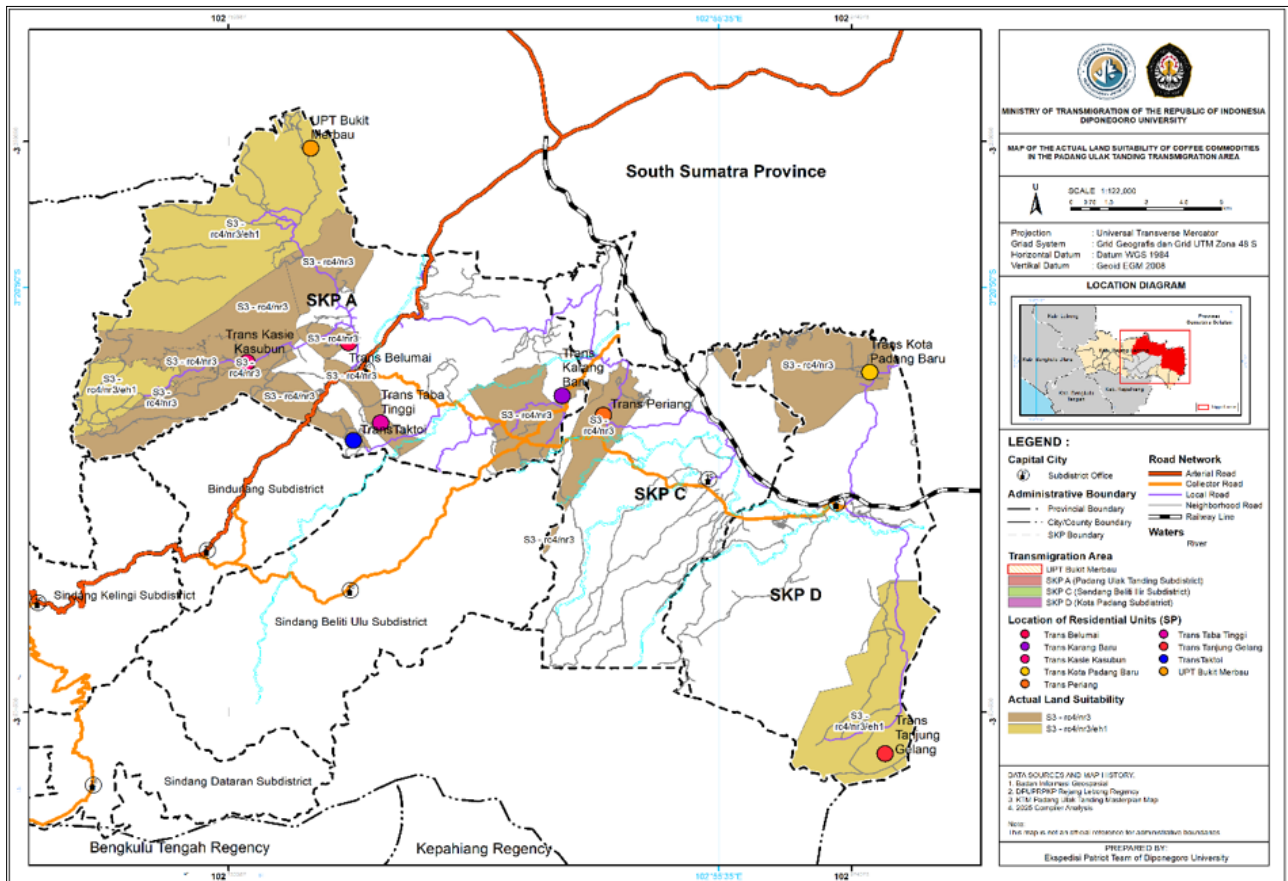


Fig. 4. Actual land suitability for coffee commodities (BIG– Badan informasi Geospasial).

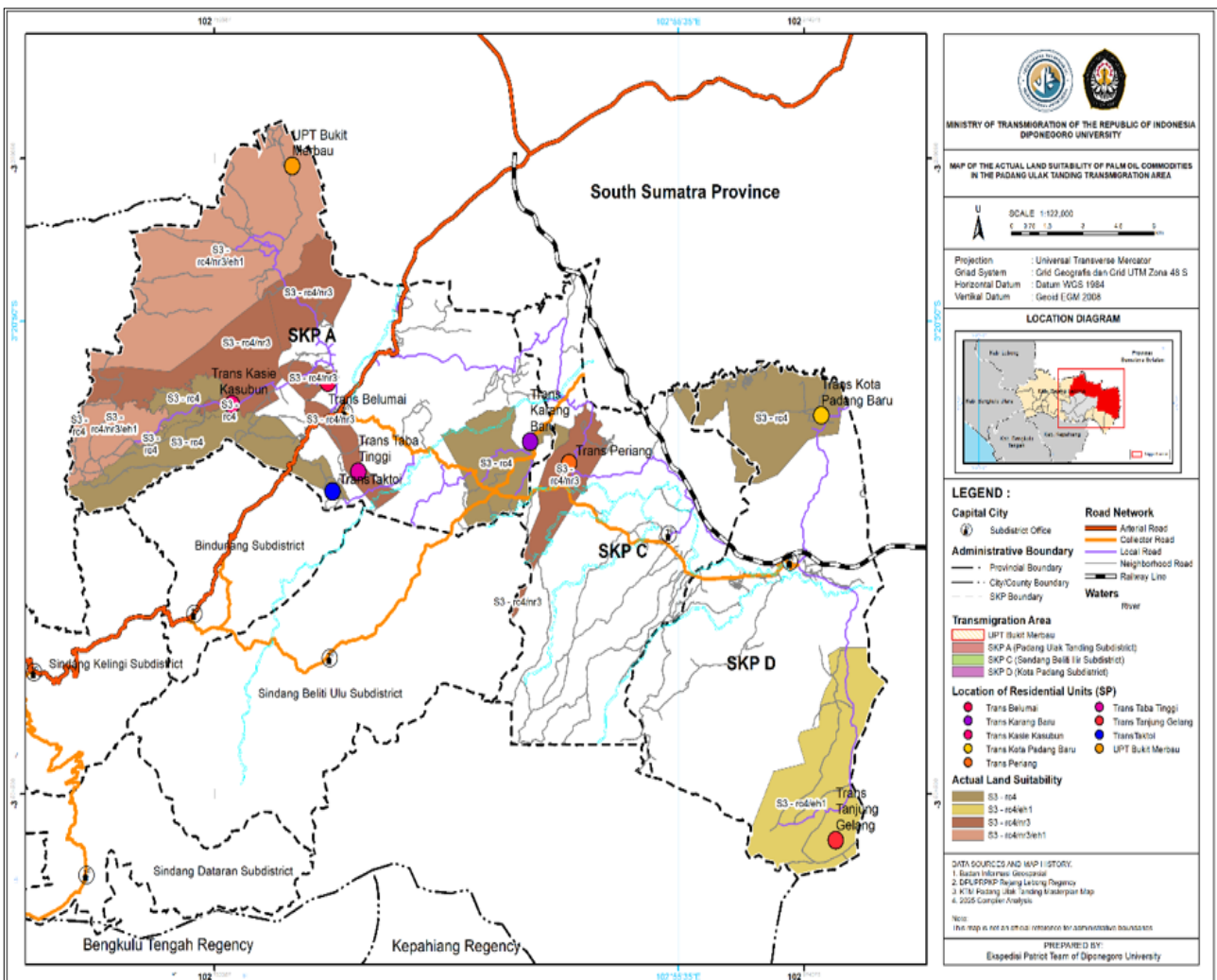


Fig. 5. Actual land suitability for oil palm commodities (BIG– Badan informasi Geospasial).

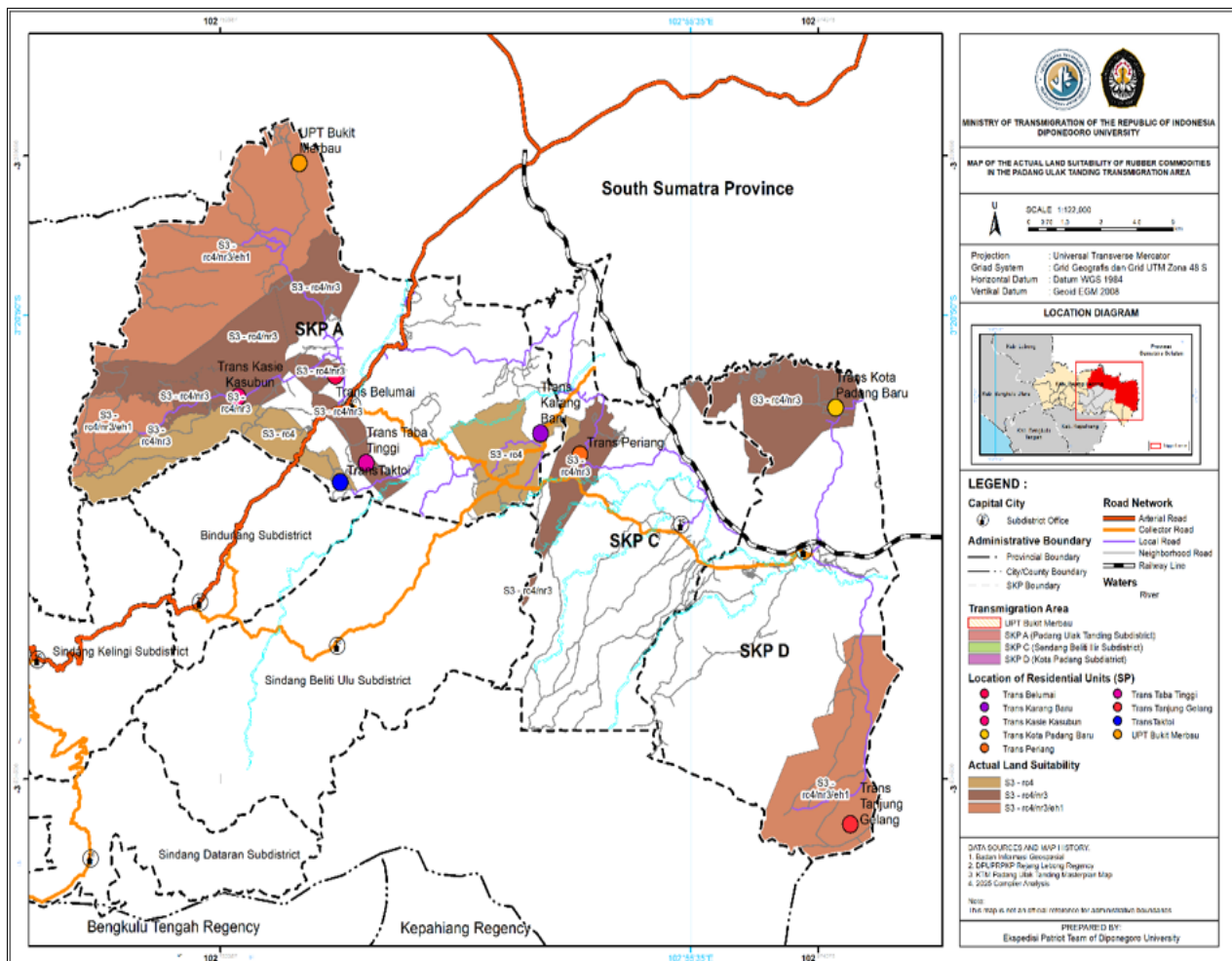


Fig. 6. Actual land suitability for rubber commodities (BIG– Badan informasi Geospasial).

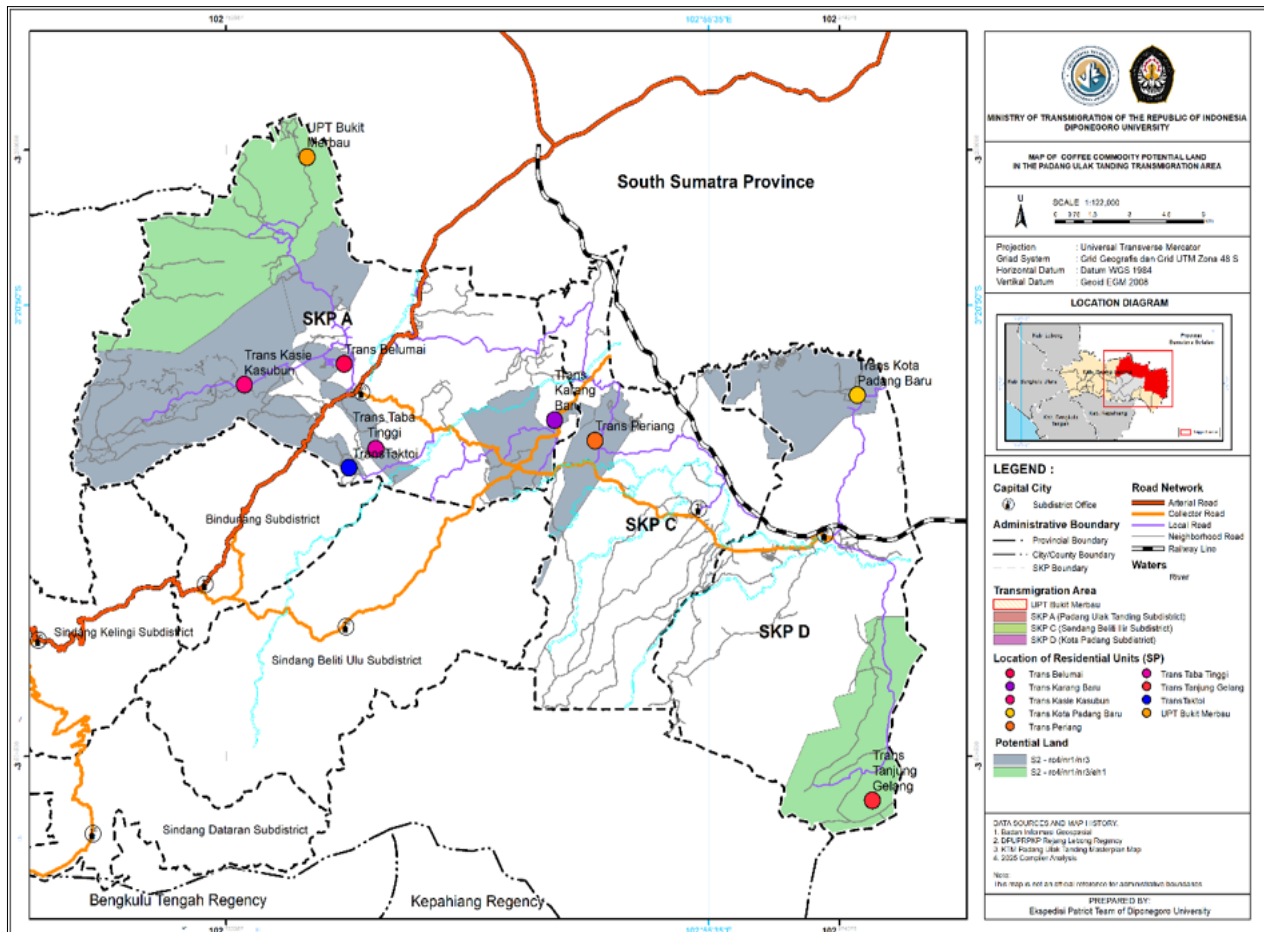


Fig. 7. Potential land suitability for coffee commodities (BIG– Badan informasi Geospasial).

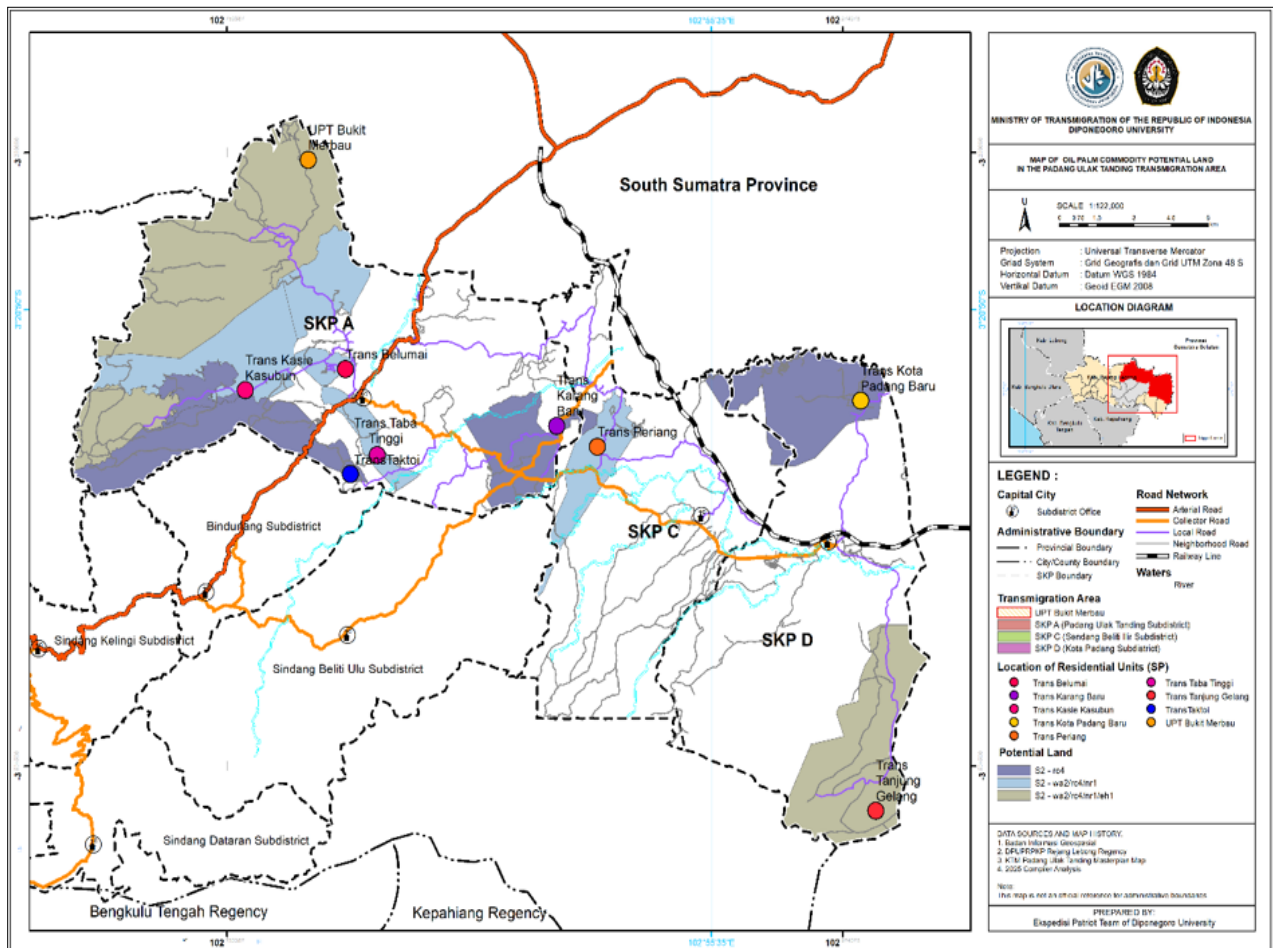


Fig. 8. Potential land suitability for oil palm commodities (BIG– Badan informasi Geospasial).

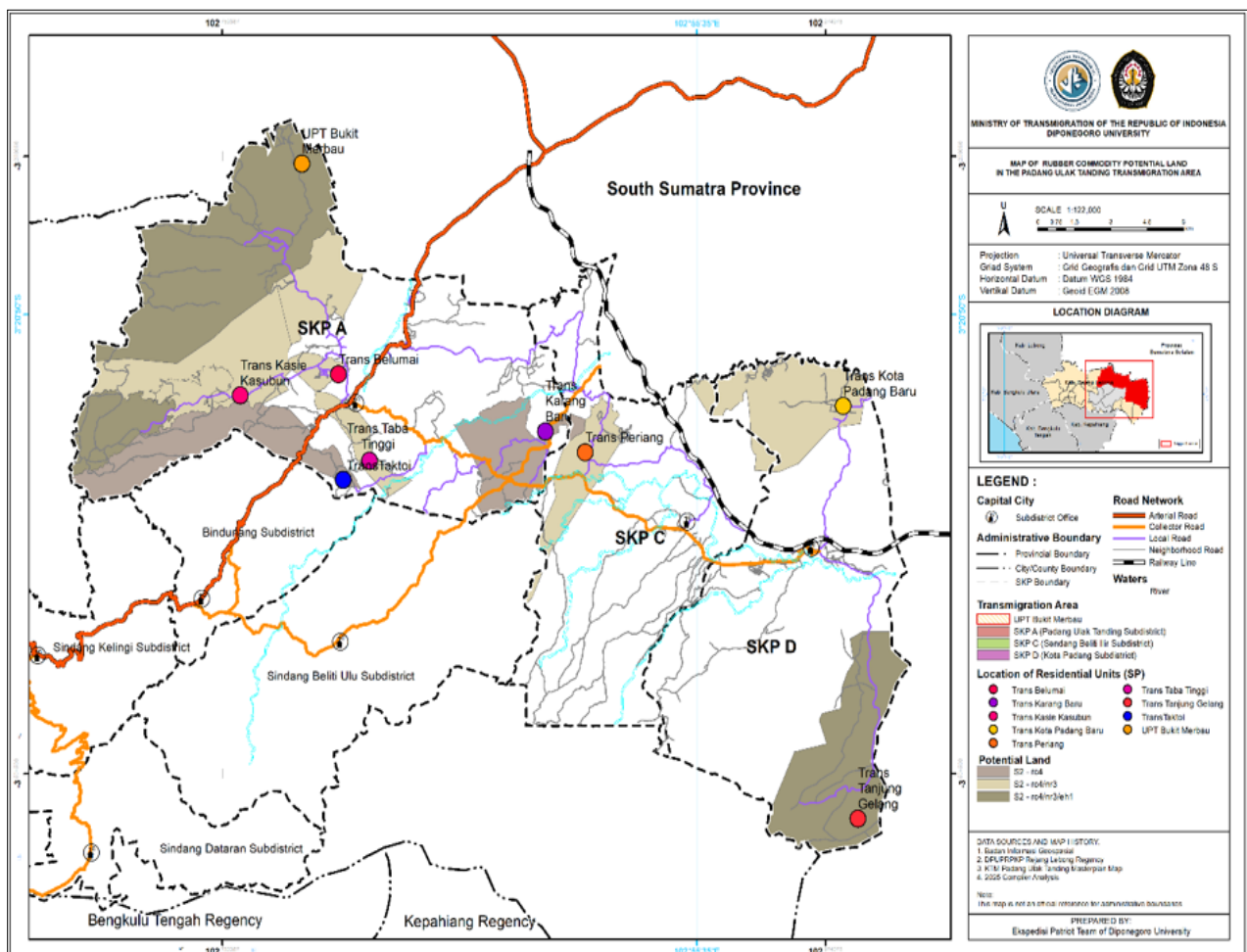


Fig. 9. Potential land suitability for rubber commodities (BIG– Badan informasi Geospasial).

Discussion

According to the actual assessment on land suitability, it shows that the majority of the land in the Padang Ulak Tanding transmigration area is categorised as S3 for growing coffee, oil palm and rubber. This is mainly due to limitations such as soil shallowness (rc4), acid soil reaction (nr3) and steep slope (eh1). Such limiting factors affect plant root growth, nutrient availability and soil moisture. Similar conclusions have been made by previous studies, such as those by (2,3) who stated that major limitations in upland and transmigration plantation systems include soil acidity, limited nutrient retention capacity and soil limitations associated with slope. However, while comparing the present study location to others in other parts of Indonesia, it can be observed that in lowland plantation systems, limitations related to soil fertility prevail, while limiting factors in relation to topography are less restrictive. Nevertheless, this does not apply to Padang Ulak Tanding transmigration area, where steep slopes coexist with shallow acidic soils.

The improvement of soil CEC can be considered one of the major techniques to improve nutrient retention and soil fertility within the respective regions. Organic amendments like compost and manure can be used for enhancing the amount of organic matter and CEC to promote the availability of nutrients in highly weathered soils (17). In addition, the use of biochar is known to improve CEC since it increases the surface area and functional groups, which serve as CEC sites (18). The use of liming within acidic soils is also beneficial since it can help to increase soil pH and availability of base cations, which will result in the increased effective CEC (19). The conservation agriculture including cover crops and mulching can be used for gradual CEC improvement (20).

Regarding socio-economic issues, the classification of the S2 land would have an impact on the small-scale farmers in the transmigration area. Even though the S2 land has the potential to support profitable plantation agriculture, it requires some amount of input and improved land management practices such as fertilising, liming and soil conservation measures. For farmers with limited capital, the adoption of these practices may be constrained, potentially limiting the realisation of the land's full productive potential. This highlights the importance of aligning land management recommendations with farmers' economic capacity, as well as the need for institutional support such as extension services, access to inputs and financial assistance

Similarly, comparable research studies have shown that whereas chemical limitations are capable of being effectively improved by management intervention, topographical limitations usually tend to remain the major limiting factor when attempting to realise higher land suitability classes (16). In general, the comparison of real land suitability and potential land suitability indicates that effective intervention strategies for the management of lands are very important for the improvement of plantations in transmigration areas. Consequently, this research study has provided evidence that the combination of soil improvement and erosion control can effectively enhance land productivity.

Conclusion

The results obtained from this study revealed that most land units within the Padang Ulak Tanding transmigration area possess a marginal (S3) suitability rating for the cultivation of coffee, oil palm

and rubber, based on actual circumstances, due to shallow soil depth, soil acidity and the presence of slopes. The aforementioned physical constraints negatively affect plantation crop productivity and reflect the low productivity of these land units under the current land management practices. On the other hand, the analysis of land suitability in terms of its potential indicated that with proper implementation of improvements, which include improving soil fertility and neutralising the soil pH value, it will be possible to make land units moderately suitable (S2).

In this regard, slope stabilisation needs to be given priority by practicing soil conservation methods such as terracing, contour farming and construction of vegetative barriers, for instance, use of grass strips and agroforestry systems that would help reduce run-off, improve water infiltration and slope stabilisation. At the same time, the process of improving soil cation exchange capacity (CEC) needs to be prioritised as a means of ensuring nutrients remain available; organic managements such as use of compost and manure, incorporation of biochar and adding of organic residues need to be practiced in order to ensure increased soil organic matter. Erosion prevention techniques such as mulching, crop cover and minimum tillage should also be practiced.

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Authors' contributions

R designed and planned the experiments. MAR analysed and interpreted the results and, together with R, prepared the manuscript. MSJM, EYS and DPP conducted the statistical analyses and prepared the figures and illustrations. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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