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Spatial Analysis of Available and Suitable Land for Oil Palm in Ketapang Regency

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ABSTRACT

Oil palm plantations are a primary sub-sector of Indonesia's agricultural economy and continue to expand rapidly. Ketapang Regency, which has the largest oil palm plantation area in West Kalimantan, holds significant potential for further development. This study assessed land suitability for oil palm expansion using a Multi-Criteria Decision-Making approach integrated with Geographic Information Systems. The Analytical Hierarchy Process was applied to assign weights to the following criteria: slope, land cover, spatial pattern, soil texture, adequate depth, drainage, temperature, rainfall, and road accessibility. The results show that 79.56% of the total area is classified as suitable (S1 and S2), comprising 3.17% as highly suitable (S1) and 67.11% as suitable (S2). Meanwhile, 7.62% was moderately suitable (S3) and 20.44% was not suitable (N). Overlay analysis revealed that the most suitable lands overlap with Other Use Areas and Conversion Production Forests, while some intersect with existing agricultural and plantation uses. Validation with existing plantation data confirmed that 98.34% of plantations are located in S1 and S2 zones, demonstrating the robustness of the model. Overall, Ketapang Regency has substantial land availability for oil palm expansion. However, the limited extent of highly suitable land (S1) and the predominance of suitable (S2) highlight the need for cautious interpretation of expansion opportunities. Sustainable development must align with spatial regulations, land conversion policies, and environmental safeguards. Future research should integrate socio-economic, ecological, and climate change considerations to support sustainable and resilient oil palm development.

Keywords: Analytical hierarchy process, geographic information system, multi-criteria decision making

INTRODUCTION

Oil palm plantations are a leading subsector of Indonesia's agriculture, experiencing rapid growth over the past few decades. Indonesia is one of the world's largest palm oil-producing countries (Danylo et al., 2021; Tan et al., 2022). Based on data from the Central Statistics Agency of Indonesia (2023), the area of oil palm plantations in Indonesia increased from 14.33 million hectares in 2018 to 15.34 million hectares in 2022. Of these, West Kalimantan Province accounts for about one-third of the total national oil palm plantation area, at around 5.06 million hectares. Oil palm plantations in this province are spread across almost all districts, with several areas having significant plantation areas, such as Landak, Sanggau, Sekadau, Sintang, and Ketapang (Sharma et al., 2019). Ketapang is the district with the largest oil palm plantation area in West Kalimantan, reaching 646,753 hectares. Palm oil production in this district is also the highest in the province, with a total production of 3,366,648 tons per year (Central Statistics Agency Ketapang Regency, 2024). The number of oil palm plantations is expected to increase. However, for the expansion of oil palm plantations, compliance with applicable regulations is necessary to avoid threatening the protected area (Zhao et al., 2024). The expansion of oil palm plantation land must comply with the land use plan and government permits, and must be supported by spatial analysis to determine land availability (Goenadi et al., 2021; Rustiadi et al., 2023). In addition, biophysical and environmental factors should be considered when conducting spatial analysis in a geographic information system to determine land suitability (Rendana et al., 2022).

One method for land suitability analysis is integrating a Geospatial Information System (GIS) with the Multi-Criteria Decision Making (MCDM) method, specifically the Analytical Hierarchy Process approach. This approach allows for determining the weight of the criteria and the value of the subcriteria that influence the analysis of land suitability. This method has been widely applied in research related to land suitability analysis, such as agricultural land assessment, vegetable commodity development in highlands, land suitability analysis for rice cultivation, and land suitability analysis for cocoa plants (Adrian et al., 2022; Singh et al., 2021; Widiatmaka et al., 2016; Yuniarti et al., 2022).

The integration of GIS and AHP offers innovative and effective solutions for optimizing land use and provides a more comprehensive information base for policymakers in planning and managing land resources. This method can provide planners with in-depth information to determine land development priorities and make recommendations (Ambarwulan et al., 2021; Hamdani et al., 2017). Therefore, this study aims to analyze the suitability of oil palm plantation land to assist stakeholders in considering the development of oil palm plantations in Ketapang Regency.

MATERIALS AND METHODS

Research location

This research was conducted in Ketapang Regency, West Kalimantan Province. Ketapang Regency is the largest district in West Kalimantan, covering 31,588 km2, and is located in the southern part of the province. Geographically, Ketapang Regency is located at 0° 19' 26.51" S and 3° 4' 16.59" S, and 109° 47' 36.55" E to 111° 21' 37.36" E. Ketapang Regency consists of a total of 20 sub-districts (Figure 1).

Data Source

This research relied on a combination of primary and secondary data to support the analysis. Primary data were collected through questionnaires and interviews. The secondary data used was spatial data which includes regional administration maps and road maps sourced from Imageoportal (RBI) scale 1:50.000, Regional Spatial Planning (SPR) maps for 2015-2035 sourced from the Ketapang Regency Bappeda, land use maps interpreted from Landsat imagery 8 United States Geological Survey

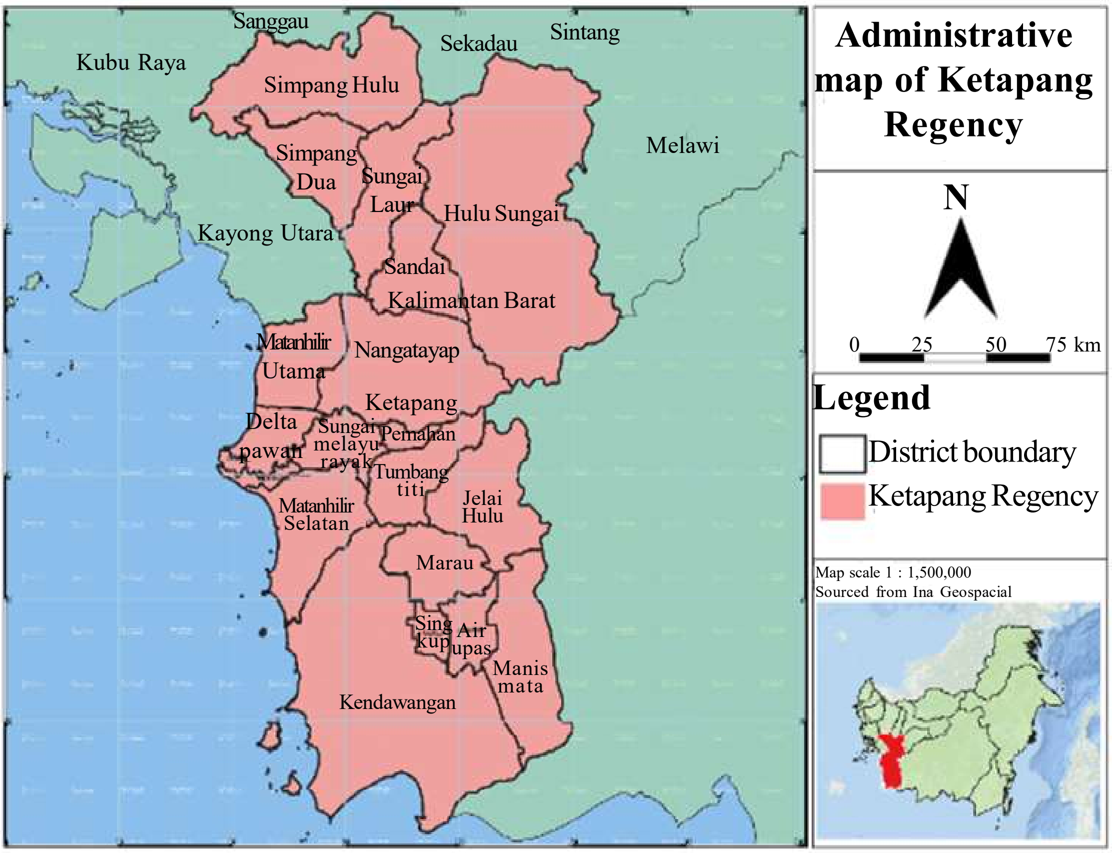

Figure 1. Administrative map of Ketapang Regency.

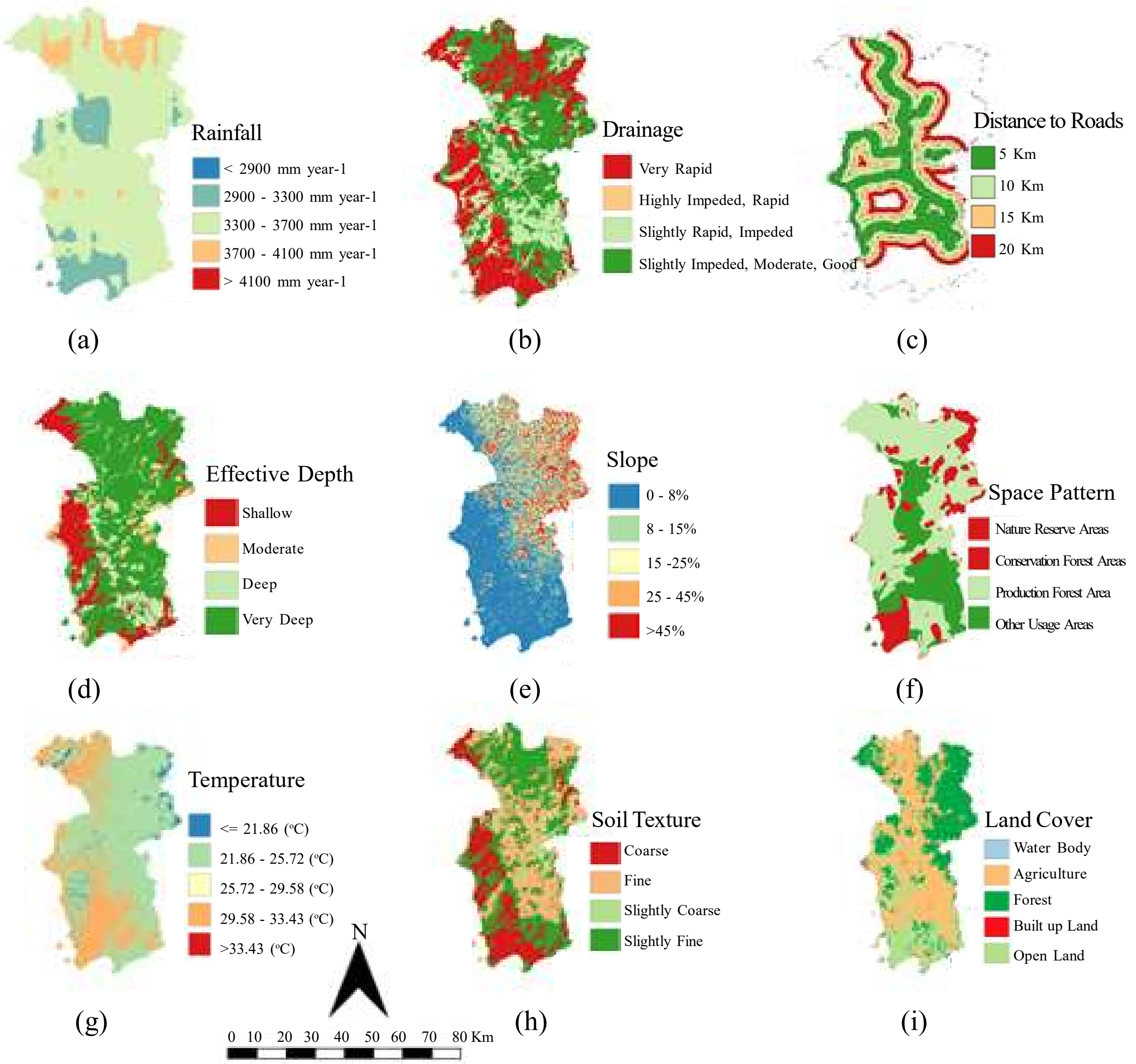

Figure 2. Spatial data of criteria (a) Rainfall; (b) Drainage; (c) Distance from the road; (d) Effective Depth; (e) slope; (f) space pattern; (g) Temperature; (h) Soil texture; (i) Land cover.

(USGS), land map unit maps from the Agricultural Land Resources Instrument Standards Testing Center (BBPSI SDLP) scale 1:50.000, map of actual land use of oil palm plantations in 2022 from the West Kalimantan Provincial Plantation and Livestock Departement. Slope maps from DEM Imageoportal, land surface temperature maps interpretation from Landsat imagery 8 (USGS), and rainfall maps from Climate Hazards Group InfraRed Precipitation with Station data (CHRIPS).

Analysis

The initial stage involved determining the research criteria through a comprehensive literature review. The criteria were selected based on previous studies and subsequently adjusted to the study area's geographical and environmental characteristics. In addition, the selection of criteria considered Indonesia's geographical position, ensuring comparability with other countries located within the same latitude. According to Tapia et al. (2021), Indonesia's biophysical characteristics are highly suitable for oil palm plantation development, particularly in Sumatra and Kalimantan, due to the region's favorable climate. Most areas with suitable biophysical and environmental conditions for oil palm plantations are located between 0° and 10° latitude. The island of Kalimantan, in particular, has soil characteristics and topographical conditions highly favorable for oil palm cultivation (Mantel et al., 2007; Tapia et al., 2021). Based on existing studies, the criteria applied in this research include slope, land cover, spatial pattern, soil texture, adequate depth, drainage, temperature, rainfall, and distance from roads (Gurmessa et al., 2023; Hardjowigeno &

Table 1. Land suitability criteria for oil palm plantations in the study area (Ketapang Regency).

Criteria	Sub criteria	Score Rank*	Citeria	Sub criteria	Score Rank*
Slope (%)	<8	10	Soil Texture	Slightly Fine	8
	8-15	8		Slightly Coarse	7
	>15-25	7		Fine	4
	>25	3		Coarse	3
Land Cover	Open Land	9	Effective Depth	Very Deep	9
	Forest	6		Deep	7
	Agriculture	3		Moderate	3
	Built-up Land	0		Shallow	1
Space Pattern	Other Usage Areas	10	Drainage	Slightly Impeded, Moderate, Good	9
	Production Forest Area	2		Slightly Rapid, Impeded	5
	Conservation Forest Areas	0		Highly Impeded, Rapid	2
	Nature Reserve Areas	0		Very Rapid	1
Temperature (°C)	22-32	10	Distance from the road (km)	0-5	9
	22-32, 32-35	7		5-10	9
	18-20, 35-37	5		10-15	4
	<18, > 37	0		>15	3
Rainfall/year (mm)	1700-2500	9			
	>2500-3500	8			
	>3500-4000	3			
	>4000	0			

Note: * Based on the score rank of the sub-criteria from the expert (2024).

Widiatmaka, 2011; Jaroenkietkajorn & Gheewala, 2021; Pirker et al., 2015; Rhebergen et al., 2016). Figure 2 presents the spatial data used, and Table 1 provides a detailed classification of the criteria and sub-criteria.

To ensure the validity of the selected criteria, expert consultations were conducted with four field specialists in agronomy, soil science, plantation management, and spatial planning. Each expert provided pairwise comparisons of the criteria using Saaty's nine-point scale (1–9), in which 1 indicated equal importance and 9 indicated extreme importance of one criterion over another. The AHP, a multi-criteria decision-making approach introduced by Saaty (2002), was then employed to synthesize these comparisons. The geometric mean method was used to aggregate the four experts' judgments into a single comparison matrix. Each criterion was subsequently weighted and scored, and sub-criteria were assigned rating values on a scale of 1 to 10 to

Table 2. Rating for pairwise comparison based on Saaty (2002).

1/9	1/7	1/5	1/3	1	3	5	6	9
Extreme Strongly	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extreme Strongly
Less Important					More Important			

assess their influence on land suitability (Table 2). To verify consistency, the Consistency Index (CI) and Random Index (RI) were calculated using the number of criteria (n) as per Saaty's (2002) formulation. The Consistency Ratio (CR) was derived using the following equations (Hassan et al., 2025; Kang et al., 2024; Rame et al., 2022):

$$CI = \frac{\lambda_{\max - n}}{n - 1}$$

$$CR = \frac{C1}{R1}$$

CR value of less than 10% (CR < 0.1) was considered acceptable, thereby ensuring the consistency and reliability of the weighting process. In this study, the calculated CR was 0.078 (< 0.1), confirming that the weighting process was valid and internally consistent. The final weights of each criterion are presented in Table 3, with soil texture (0.180), adequate depth (0.131), temperature (0.153), and drainage (0.097) identified as the most influential factors, while slope (0.040) and land cover (0.050) were found to be less significant.

The third stage involved conducting the land suitability analysis by applying the calculated weights and scores to the spatial data layers in QGIS. The overlay technique was employed to integrate all weighted criteria and generate a composite land suitability map. Land suitability was classified into four categories: S1 (Highly Suitable), S2 (Suitable), S3 (Moderately Suitable), and N (Not Suitable). Classification was conducted using the equal interval method, and the suitability score for each land unit was computed as follows (Kang et al., 2024; Qiu et al., 2017; Singh et al., 2021):

$$S = \sum_{i=1}^{n} Wi\, Xi$$

Where:

· S is the suitability of the land

· Wi is the weight of the land suitability criteria

· Xi is the score of sub-criterion I

Table 3. The results of the Analytical Hierarchy Process (geometric mean of four experts).

	Normalization									Weight*
	SL	LC	SP	ST	ED	Dr	Temp	Rf	DFR	
SL	0.040	0.017	0.022	0.060	0.044	0.080	0.051	0.045	0.040	0.040
LC	0.121	0.050	0.020	0.060	0.044	0.032	0.051	0.045	0.052	0.050
SP	0.109	0.149	0.059	0.053	0.044	0.029	0.045	0.045	0.045	0.059
ST	0.121	0.149	0.202	0.180	0.078	0.097	0.284	0.308	0.353	0.180
ED	0.121	0.149	0.178	0.303	0.131	0.097	0.067	0.191	0.068	0.131
Dr	0.049	0.149	0.202	0.180	0.131	0.097	0.067	0.046	0.068	0.097
Temp	0.121	0.149	0.202	0.097	0.299	0.222	0.153	0.135	0.155	0.153
Rf	0.121	0.149	0.178	0.079	0.093	0.287	0.153	0.135	0.155	0.135
DFR	0.156	0.149	0.202	0.079	0.299	0.222	0.153	0.135	0.155	0.155
Total Weight										1.000

SL: Slope; LC: Land Cover; ST: Soil Texture; ED: Effective Depth; Dr: Drainage; Temp: Temperature; Rf: Rainfall; DFR: Distance From The Road; Note:*ë max = 9,906; n = 9; Consistenssy Index (CI) = 0,113 Random Index (RI) = 1,45 Consistensi Rasio (CR) = 0,078; The CR score is below 10% (CR<0,1), making it acceptable.

· n refers to the total number of criteria applied in the land suitability analysis

The final stage involved validating the land suitability analysis results by comparing them with existing land use data. Validation was conducted through an overlay of the generated land suitability map with three reference datasets: (1) land use data from the Ministry of Environment and Forestry (KLHK, 2022), (2) the spatial pattern from the Regional Spatial Plan (SPR) of Ketapang Regency (2015–2035), and (3) the distribution of existing oil palm plantations in Ketapang Regency (Figure 3). The degree of agreement between the suitability classes and existing land use was evaluated to assess the model's accuracy and practical relevance. Areas where highly suitable classes (S1 and S2) overlapped with current oil palm plantations were considered to validate the model, while discrepancies (e.g., suitable areas that remain unused, or unsuitable areas currently cultivated) were identified and discussed as part of the spatial planning implications.

RESULTS AND DISCUSSION

Based on the analysis using the MCDM method (Table 3), soil characteristics, climate, and accessibility were found to have the most decisive influence on land suitability for oil palm plantation development. Slope, spatial pattern, and land cover also contributed to the overall suitability level. These findings emphasize that land suitability is determined not only by biophysical conditions but also by environmental and accessibility factors. This result is consistent with previous studies indicating that tropical regions such as Indonesia, particularly Kalimantan (0°–10° latitude), provide favorable biophysical and climatic conditions for oil palm growth (Mantel et al., 2007; Tapia et al., 2021; Teh et al., 2024). Accessibility is crucial since proximity to major roads improves logistical efficiency and reduces transportation costs (Gurmessa et al., 2023). The integration of MCDM and GIS in this study thus provided a comprehensive framework for assessing oil palm suitability (Phochanikorn & Tan, 2019).

The results of the land suitability analysis (Figure 4; Table 4) indicate that 79.56% (2,385,030.62 ha) of Ketapang Regency is classified as suitable (S1 and S2). Within this proportion, only 3.17% (95,018.16 ha) is categorized as highly suitable (S1), while the majority, 67.11% (2,009,554.44 ha), is suitable (S2). In addition, 7.62% (228,056.28 ha) is classified as moderately suitable (S3), while 20.44% (612,760.92 ha) is not suitable (N). These findings show that although a large proportion of land is technically suitable for oil palm development, the availability of highly suitable land (S1) is minimal. At the same time, the predominance of S2 and S3 categories indicates moderate to significant limitations in soil, slope, and drainage conditions. Therefore, Ketapang Regency has considerable potential for oil palm plantation expansion, but land use must align with regional spatial plans and regulations to ensure sustainability and prevent environmental degradation (Rustiadi et al., 2023; Widiatmaka et al., 2016).

The overlay results (Figure 5; Table 5) further show that land categorized as highly suitable (S1) covers only 3.17% (95,018.16 ha) of the total area, while suitable (S2) land constitutes 23.29%

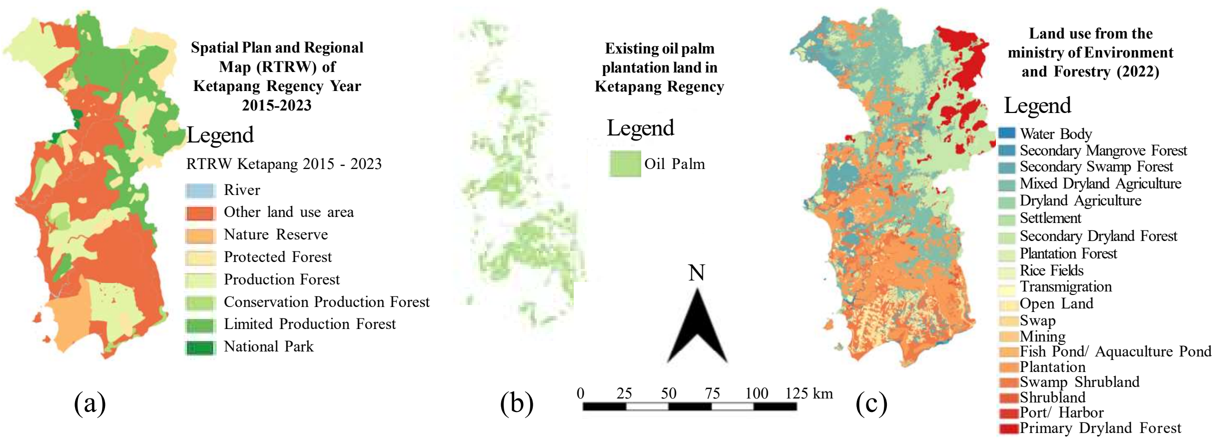

Figure 3. (a) Map of Spatial Plan and Regional (SPR) of Ketapang Regency (2015-2025); (b) Existing oil palm plantation land in Ketapang Regency, and (c) land use from the Ministry of Environment and Forestry (2022).

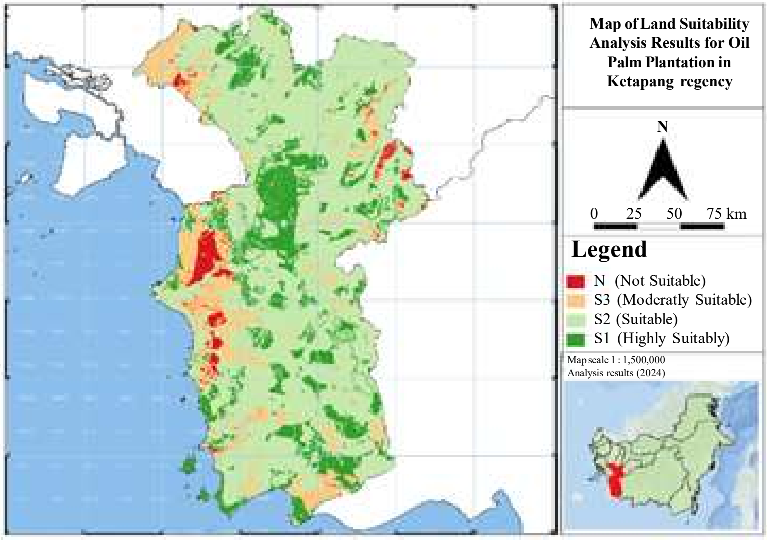

Figure 4. Map of land suitability analysis results for oil palm plantations in Ketapang Regency.

Table 4. Total area of suitability of the oil palm plantation.

Land suitability classification for oil palm	Equal interval of Suitability Value	ha	%
S1 (Highly Suitable)	7.180 – 8.937	372.947.62	12.45
S2 (Suitable)	5.423 – 7.180	2.009.554.44	67.11
S3 (Moderately Suitable)	3.665 – 5.423	530.679.02	17.72
N (Not Suitable)	1.908 – 3.665	81.346.94	2.72
Total		2.994.528.02	100.00

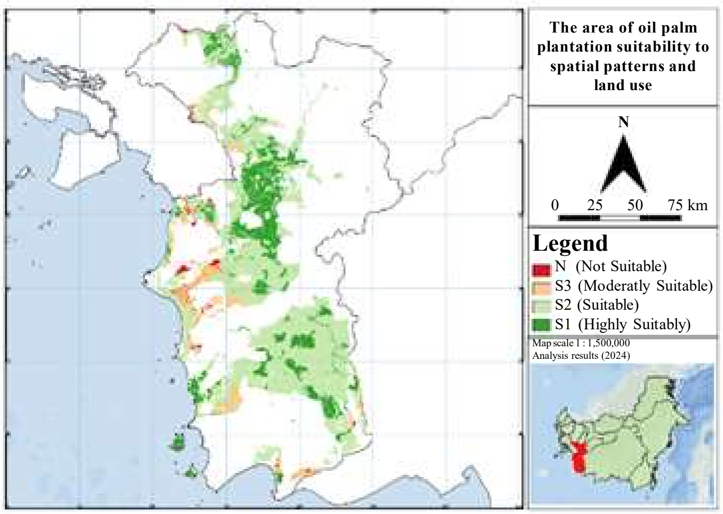

Figure 5. Map of oil palm plantation suitability to spatial patterns and land use in Ketapang Regency.

(697,421.19 ha). In addition, 7.62% (228,056.28 ha) of the area falls into the moderately suitable (S3) category, whereas not suitable (N) areas are mainly associated with steep slopes and poor drainage conditions. When compared to the Regional Spatial Plan (SPR), most suitable lands overlap with Other

Table 5. The area of oil palm plantation suitability to spatial patterns and land use.

Land suitability classification for oil palm	ha	%*
S1 (Highly Suitable)	95.018,16	3.17
S2 (Suitable)	697.421,19	23.29
S3 (Moderately Suitable)	228.056,28	7.62
N (Not Suitable)	15.899,24	0.53
Total	1.036.394,87	34.61

Note: * Percentage of total land from oil palm plantation suitability.

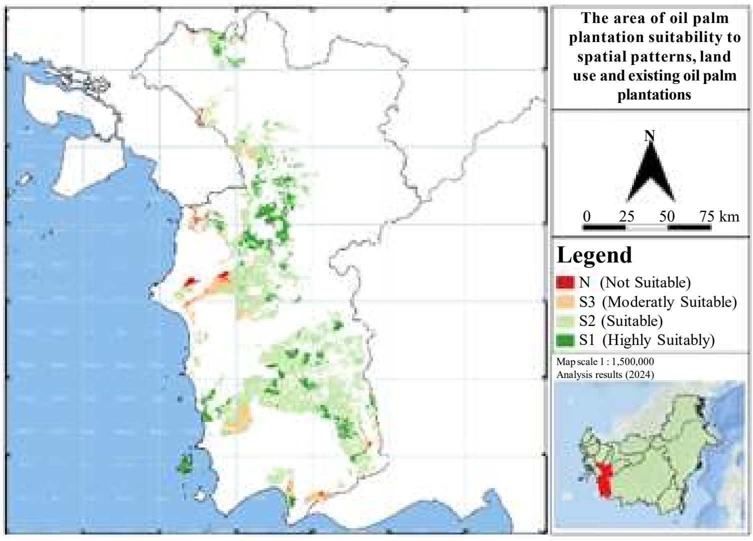

Figure 6. Map of oil palm plantation suitability to spatial patterns, land use, and existing oil palm plantations in Ketapang Regency.

Table 6. The area of oil palm plantation suitability to spatial patterns, land use, and existing oil palm plantations

Land suitability classification for oil palm	ha	%*
S1 (Highly Suitable)	58.854,26	1.97
S2 (Suitable)	380.722,03	12.71
S3 (Moderately Suitable)	110.623,91	3.69
N (Not Suitable)	9.269,06	0.31
Total	559.469,26	18.68

Note: * Percentage of total land from oil palm plantation suitability.

Use Areas (APL) and Conversion Production Forests (HPT). Meanwhile, based on land-use data, suitable areas are currently used for mixed dryland agriculture, plantations, open land, mining, and shrubs. It suggests that although technically suitable, regulatory constraints and competing land uses must be carefully considered to ensure sustainable plantation development (Goenadi et al., 2021).

A comparison between existing oil palm plantations and the suitability analysis (Figure 6; Table 6) shows that 98.34% (550,200.20 ha) of plantations are located in areas classified as highly suitable (S1) or suitable (S2). This high degree of overlap supports the model's robustness, although a small proportion (1.66%) of plantations are located in moderately suitable (S3) or unsuitable (N) areas. The presence of plantations in less suitable zones

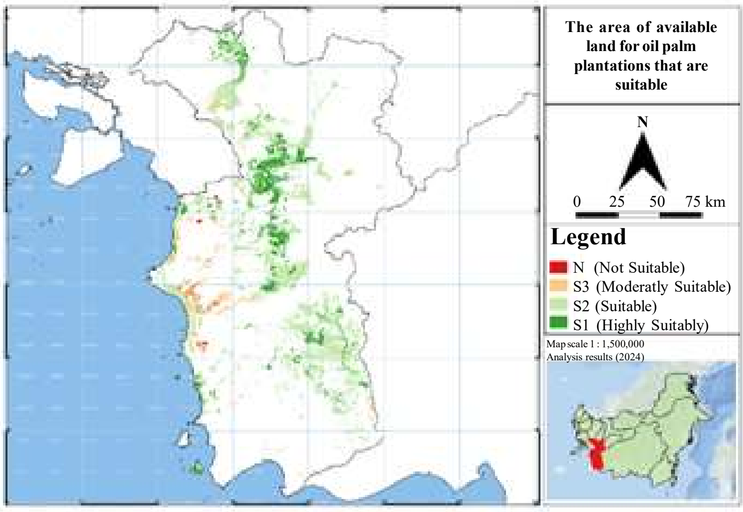

Figure 7. Map of available land for oil palm plantation that is suitable in Ketapang Regency.

Table 7. The area of available land for oil palm plantations that are suitable.

Land suitability classification for oil palm	ha	%*
S1 (Highly Suitable)	36.163,89	1.21
S2 (Suitable)	316.699,16	10.58
S3 (Moderately Suitable)	117.432,37	3.92
N (Not Suitable)	6.630,18	0.22
Total	476.925,60	15.93

Note: * Percentage of total land from oil palm plantation suitability.

indicates potential risks for long-term productivity and environmental sustainability, suggesting the need for improved land-use control and monitoring. To strengthen the robustness of the findings, the suitability results were validated by overlaying them with land-use data from the Ministry of Environment and Forestry (KLHK, 2022), the spatial pattern of the SPR for Ketapang Regency (2015–2035), and the distribution of existing oil palm plantations. The strong agreement between the suitability analysis and observed land use patterns indicates that the model provides reliable guidance. However, the discrepancies highlight areas where regulatory enforcement and planning adjustments are required.

Further analysis (Figure 7; Table 7) identifies potential expansion land, with 1.21% (36,163.89 ha) classified as highly suitable (S1), 10.58% (316,669.16 ha) as suitable (S2), and 3.92% (117,432.37 ha) as moderately suitable (S3). In contrast, 0.22% (6,630.18 ha) of the area was categorized as not suitable (N). These results confirm that the majority of potential land falls within the S2 category, while the proportion of highly suitable land (S1) remains very limited and spatially fragmented. It emphasizes the need for cautious interpretation of expansion opportunities: although large areas are technically suitable, their limitations require careful planning and prioritization. Therefore, the sustainable development of oil palm plantations in Ketapang Regency must involve coordinated efforts among the government, the private sector, and local communities to minimize land-use conflicts and ensure equitable and environmentally responsible expansion.

This study provides a comprehensive spatial assessment of land suitability for oil palm in Ketapang Regency, but it also reveals significant limitations. Future studies should integrate socio-economic variables, such as land tenure, access to inputs and markets, and smallholder participation, into the MCDM framework to generate a more realistic suitability map. Moreover, higher-resolution spatial data (e.g., Sentinel-2 or LiDAR) would improve site-level accuracy, and climate change projections should be included to evaluate potential future shifts in rainfall, temperature, and extreme events. A holistic approach that integrates biophysical, socioeconomic, and climatic dimensions will enable the development of land management strategies that are not only productive but also ecologically sustainable and socially equitable.

CONCLUSIONS

The spatial assessment confirms that while Ketapang Regency possesses vast potential for oil palm development, the scarcity of highly suitable land (S1) necessitates a strategic shift from extensive land clearing to the intensification of the predominant suitable areas (S2) which require specific agronomic interventions to overcome biophysical limitations. Given the high accuracy of the model validated againts existing plantations, this study implies that sustainable expansion is feasible only if strictly aligned with the Region Spatial Plan (SPR) to resolve overlaps with conversion production forest and other land uses. Ultimately, future policy must focus on optimizing productivity within these biophysical and regulatory constraints rather than relying on the availability of prime land, while integrating socioeconomic dimensions to ensure resilience.

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REFERENCES

Adrian, Widiatmaka, Munibah, K., & Firmansyah, I. (2022). Evaluate land suitability analysis for rice cultivation using a GIS-based AHP multi-criteria decision-making approach: Majalengka Regency, West Java Province. *IOP Conference Series: Earth and Environmental Science*, *1109*(1). https://doi.org/10.1088/1755-1315/1109/1/012062

Ambarwulan, W., Nahib, I., Widiatmaka, W., Suryanta, J., Munajati, S. L., Suwarno, Y., Turmudi, T., Darmawan, M., & Sutrisno, D. (2021). Using Geographic Information Systems and the Analytical Hierarchy Process for Delineating Erosion-Induced Land Degradation in the Middle Citarum Sub-Watershed, Indonesia. *Frontiers in Environmental Science*, *9*, 1–10. https://doi.org/10.3389/fenvs.2021.710570

Badan Pusat Statistik Indonesia. (2023). *Statistik Kelapa Sawit Indonesia. 16.*

BPS Kabupaten Ketapang. (2024). *Ketapang dalam angka 2024. 17.*

Danylo, O., Pirker, J., Lemoine, G., Ceccherini, G., See, L., McCallum, I., Hadi, Kraxner, F., Achard, F., & Fritz, S. (2021). A map of the extent and year of detection of oil palm plantations in Indonesia, Malaysia and Thailand. *Scientific Data*, *8*(1), 4–11. https://doi.org/10.1038/s41597-021-00867-1

Goenadi, D. H., Setyobudi, R. H., Yandri, E., Siregar, K., Winaya, A., Damat, D., Widodo, W., Wahyudi, A., Adinurani, P. G., Mel, M., Zekker, I., Mazwan, M. Z., Siskawardani, D. D., Purbajanti, E. D., & Ekawati, I. (2021). Land Suitability Assessment and Soil Organic Carbon Stocks as Two Keys for Achieving Sustainability of Oil Palm (Elaeis guineensis Jacq.). *Sarhad Journal of Agriculture*, *37*(Special Issue 1), 184–196. https://doi.org/10.17582/journal.sja/2022.37.s1.184.196

Gurmessa, M. M., Moisa, M. B., Boru, L. H., Deribew, K. T., Roba, Z. R., Negasa, G. G., Tiye, F. S., & Gemeda, D. O. (2023). Geospatial assessment of potential land suitability for oil palm (Elaeis guineensis Jacq) cultivation in the western parts of Ethiopia. *OCL - Oilseeds and Fats, Crops and Lipids*, *30*. https://doi.org/10.1051/ocl/2023024

Hamdani, Septiarini, A., & Khairina, D. M. (2017). Model assessment of land suitability decision making for oil palm plantation. *Proceeding - 2016 2nd International Conference on Science in Information Technology, ICSITech 2016: Information Science for Green Society and Environment*, 109–113. https://doi.org/10.1109/ICSITech.2016.7852617

Hardjowigeno, S., & Widiatmaka. (2011). *Evaluasi Kesesuaian Lahan dan Perencanaan Tata Guna Lahan*. Gadjah Mada Univerity Press.

Hassan, W. H., Mahdi, K., & Kadhim, Z. K. (2025). Optimal rainwater harvesting locations for arid and semi-arid regions by using MCDM-based GIS techniques. *Heliyon*, *11*(3), e42090. https://doi.org/10.1016/j.heliyon.2025.e42090

Jaroenkietkajorn, U., & Gheewala, S. H. (2021). Land suitability assessment for oil palm plantations in Thailand. *Sustainable Production and Consumption*, *28*, 1104–1113. https://doi.org/10.1016/j.spc.2021.07.031

Kang, Y. O., Yabar, H., Mizunoya, T., & Higano, Y. (2024). Optimal landfill site selection using ArcGIS Multi-Criteria Decision-Making (MCDM) and Analytic Hierarchy Process (AHP) for Kinshasa City. *Environmental Challenges*, *14*. https://doi.org/10.1016/j.envc.2023.100826

Mantel, S., Wösten, H., & Verhagen, J. (2007). *Biophysical Land Suitability for Oil Palm in Kalimantan, Indonesia.*

Nursanti, I. (2023). *Characteristics of Peat with Different Depths in Supporting Growth and Productivity of Oil Palm*. *28*(1), 17–22. https://doi.org/10.5400/jts.2023.v28i1.17-22

Phochanikorn, P., & Tan, C. (2019). An integrated multi-criteria decision-making model based on prospect theory for green supplier selection under uncertain environment: A case study of the Thailand palm oil products industry. *Sustainability (Switzerland)*, *11*(7). https://doi.org/10.3390/su11071872

Pirker, J., Mosnier, A., & Obersteiner, M. (2015). *Interim Report IR-15-006 Global oil palm suitability assessment*. 33. www.iiasa.ac.at

Qiu, L., Zhu, J., Pan, Y., Hu, W., & Amable, G. S. (2017). Multi-criteria land use suitability analysis for livestock development planning in Hangzhou metropolitan area, China. *Journal of Cleaner Production*, *161*, 1011–1019. https://doi.org/10.1016/j.jclepro.2017.07.053

Rame, L. S., Widiatmaka, Hartono, A., & Firmansyah, I. (2022). Multi-criteria decision making for determining landfill location in Malaka Regency, East Nusa Tenggara Province of Indonesia. *Journal of Degraded and Mining Lands Management*, *9*(2), 3405–3413. https://doi.org/10.15243/jdmlm.2022.092.3405

Rendana, M., Rahim, S. A., Idris, W. M. R., Rahman, Z. A., & Lihan, T. (2022). Agricultural Land Evaluation Using GIS-Based Matching Method in Highland Areas for Oil Palm Cultivation. *Caraka Tani: Journal of Sustainable Agriculture*, *37*(1), 100–110. https://doi.org/10.20961/carakatani.v37i1.57441

Rhebergen, T., Fairhurst, T., Zingore, S., Fisher, M., Oberthür, T., & Whitbread, A. (2016). Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana. *European Journal of Agronomy*, *81*, 1–14. https://doi.org/10.1016/j.eja.2016.08.004

Romelah, S., & Niswati, A. (2017). *Improvement of Physical and Chemical Soil Quality of Oil Palm Plantation through Integrated Farming System of Cattle and Oil Palm to Achieve Sustainable Agriculture*. *22*(2), 113–123. https://doi.org/10.5400/jts.2017.22.2.113

Rustiadi, E., Pribadi, D. O., Pravitasari, A. E., Nurdin, M., Iman, L. S., Supijatno, Panuju, D. R., Saad, A., Rosandi, V. B., & Anthony, D. (2023). Developing a precision spatial information system of smallholder oil palm plantations for sustainable rural development. *IOP Conference Series: Earth and Environmental Science*, *1133*(1). https://doi.org/10.1088/1755-1315/1133/1/012072

Saaty, T. L. (2002). Decision making with the Analytic Hierarchy Process. *Scientia Iranica*, *9*(3), 215–229. https://doi.org/10.1504/ijssci.2008.017590

Sharma, S. K., Baral, H., Laumonier, Y., Okarda, B., Purnomo, H., & Pacheco, P. (2019). Ecosystem services under future oil palm expansion scenarios in West Kalimantan, Indonesia. *Ecosystem Services*, *39*(August), 100978. https://doi.org/10.1016/j.ecoser.2019.100978

Singh, K., Fuentes, I., Fidelis, C., Yinil, D., Sanderson, T., Snoeck, D., Minasny, B., & Field, D. J. (2021). Cocoa suitability mapping using multi-criteria decision making: An agile step towards soil security. *Soil Security*, *5*, 100019. https://doi.org/10.1016/j.soisec.2021.100019

Tan, X. J., Cheor, W. L., Yeo, K. S., & Leow, W. Z. (2022). Expert systems in oil palm precision agriculture: A decade systematic review. *Journal of King Saud University - Computer and Information Sciences*, *34*(4), 1569–1594. https://doi.org/10.1016/j.jksuci.2022.02.006

Tapia, J. F. D., Doliente, S. S., & Samsatli, S. (2021). How much land is available for sustainable palm oil? *Land Use Policy*, *102*(November 2020), 105187. https://doi.org/10.1016/j.landusepol.2020.105187

Teh, C. B. S., Cheah, S. S., & Kulaveerasingam, H. (2024). Development and validation of an oil palm model for a wide range of planting densities and soil textures in Malaysian growing conditions. *Heliyon*, *10*(14), e32561. https://doi.org/10.1016/j.heliyon.2024.e32561

Widiatmaka, Ambarwulan, W., & Sudarsono. (2016). Spatial multi-criteria decision making for delineating agricultural land in Jakarta metropolitan area's hinterland: Case study of Bogor regency, West Java. *Agrivita*, *38*(2), 105–115. https://doi.org/10.17503/agrivita.v38i2.746

Yuniarti, W., Sumardjo, Widiatmaka, & Wibawa, W. D. (2022). Development of Highland Vegetable Commodity Areas Through Multi-Criteria Decision Making (MCDM) Analysis and Geographic Information Systems. *IOP Conference Series: Earth and Environmental Science*, *950*(1). https://doi.org/10.1088/1755-1315/950/1/012074

Zhao, Q., Yu, L., Li, X., Xu, Y., Du, Z., Kanniah, K., Li, C., Cai, W., Lin, H., Peng, D., Zhang, Y., & Gong, P. (2024). The expansion and remaining suitable areas of global oil palm plantations. *Global Sustainability*, *7*. https://doi.org/10.1017/sus.2024.8