Assessment of Land Suitability and Spatial Development Direction for *Hevea Brasiliensis* Cultivation in West Bandung Regency, Indonesia

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Abstract
This study assesses land suitability and spatial development direction for rubber (Hevea brasiliensis) cultivation in West Bandung Regency, Indonesia, using a Geographic Information System (GIS)-based approach. A descriptive survey method was employed, integrating primary field data from 40 sample points and secondary data from maps, documents, and literature. Land suitability was evaluated based on physical factors including climate, soil type, slope, and water availability, using the matching technique with the maximum limitation method. The analysis identified 36,478.8 ha (29.50%) of land as suitable for rubber cultivation, with 26,950.6 ha classified as highly suitable (S1) and 9,528.2 ha as moderately suitable (S2). However, after considering land use designation and spatial planning (RTRW) regulations, the potential development area was refined to 21,234.728 ha (16.26% of the regency's total area). This refined area is not intended for exclusive rubber cultivation but serves as spatial guidance for farmers and policymakers interested in expanding rubber farming. The findings provide a biophysical and spatial basis for land use planning and rubber cultivation expansion in West Bandung Regency.

Keywords: GIS Analysis, Land Suitability, Rubber Cultivation, Spatial Planning, West Bandung Regency

1. Introduction

Indonesia, as a developing nation with diverse geographical conditions, is endowed with abundant land resources that play a critical role in agricultural, plantation, and forestry sectors [1]. Land serves as a fundamental asset underpinning livelihood, cultural practices, and the identities of Indonesia's diverse populations. However, the rising demand for land driven by population growth, alongside socio-economic pressures, has intensified competition for limited land resources, often leading to deforestation, land degradation, and conversion of agricultural land [2]. Studies indicate that agricultural expansion can lead to substantial forest loss globally, with estimates of deforestation ranging from 104 to 345 million hectares, while in Indonesia, more than 462,500 hectares of land have experienced degradation and deforestation due to unsustainable land use practices [3]. The conversion of agricultural land to residential and industrial areas also threatens food supply sustainability [4]. In Java, much rice paddy land is being converted for non-agricultural purposes, reducing the land's capacity to produce food and contribute to national food security [5]. Between 2011 and 2022, nearly 91% of converted land in Java was rice paddies [6]. While government initiatives such as Indonesia's Social Forestry program attempt to balance land management interests by promoting community involvement and formalizing traditional land-use practices [7], the fundamental challenge remains: optimizing land utilization to meet current needs while protecting resources for future generations [8].

West Bandung Regency, located in West Java Province, exemplifies this challenge [9]. The regency covers an area of 130,577.40 hectares, with elevations ranging from 200 to 2,000 meters above sea level. Land use is dominated by agricultural cultivation, covering 78,446.16 ha (59.96%) of the total area, followed by protected areas (19,171.04 ha or 14.65%), non-agricultural cultivation areas

(25,812.82 ha or 19.73%), and other uses (7,147.9 ha or 5.65%) [10]. Population growth in the region averaged 2.58% per year between 2013 and 2023, creating increasing pressure on existing land resources and driving the conversion of agricultural land to other uses [11]. This condition is critical because it can threaten the region's food security and agricultural productivity, including rubber an important plantation commodity in Indonesia [12].

Rubber (*Hevea brasiliensis*) is a vital commodity with significant economic and ecological roles [13]. Beyond its use in vehicle tires, conveyor belts, and various other products, rubber can function as a CO_2 sink and its wood has the potential to replace some types of wood exploited from forests [14]. Based on Table 1 regarding the area and production of rubber plantations in West Bandung Regency in 2025, rubber plantations in West Bandung Regency covered 2,807.81 hectares, with production reaching 3,699.78 tons and productivity of 1,764.95 kg/ha/year. Private Large Plantations (PBS) contributed the largest area (1,550.24 ha) with productivity of 1,984 kg/ha/year, followed by State-Owned Large Plantations (PBN) (904.37 ha; 1,700 kg/ha/year) and Smallholder Plantations (PR) (353.20 ha; 1,000 kg/ha/year). The sector involves 12 farmer groups and supports 1,700 households, demonstrating its socio-economic importance. The projected increase in global demand for rubber reaching 31.3 million tons by 2035 indicates that production growth, particularly in Indonesia at 3% per year, can be achieved through crop rejuvenation and new plantings [15].

Despite its great potential, rubber plantation development faces challenges, particularly in optimizing land utilization for cultivation expansion [16]. While existing studies provide valuable insights into rubber cultivation in Indonesia [17], there is a gap in research specifically focusing on West Bandung Regency. Existing literature largely ignores the integration of GIS-based land suitability analysis with local physical factors including climate, soil type, slope, and water availability in the context of West Bandung Regency's unique geomorphological conditions [18]. Furthermore, these studies have not yet explored how spatial planning (RTRW) regulations and current land use designations intersect with biophysical suitability to determine viable areas for rubber expansion. This study addresses these gaps by integrating biophysical land suitability assessment with spatial planning constraints to provide comprehensive development direction guidance.

This study aims to: (1) analyze the conditions of physical geographic factors that support the suitability of rubber (*Hevea brasiliensis*) cultivation land in West Bandung Regency; and (2) identify and determine the direction of potential development for rubber cultivation in West Bandung Regency. By using GIS to assess land suitability, this research offers valuable insights for policymakers and agricultural planners seeking to optimize land use for rubber cultivation based on biophysical and spatial considerations.

2. Study Area

The research location (Figure 1) is in West Bandung Regency, one of the regencies in West Java Province. The geographical location of West Bandung Regency is between 107° 22′ East Longitude and 108° 05′ East Longitude, and between 6° 41′ South Latitude and 7° 19′ South Latitude. West Bandung Regency has an area of 1,305.77 km^2. The territorial coverage of West Bandung Regency includes 13 sub-districts, namely: Padalarang, Cikalongwetan, Cililin, Parongpong, Cipatat, Cisarua, Batujajar, Ngamprah, Gununghalu, Cipongkor, Cipeundeuy, Lembang, and Sindangkerta.

Table 1: Area and production of rubber plantations in West Bandung Regency in 2025

Commodity	Type of Plantation	Total Area (ha)	Harvested Area (ha)	Production (Tons)	Productivity (kg ha^{-1} yr^{-1})
Rubber	Smallholder Plantations (PR)	353.20	214.20	214.20	1,000.00
Rubber	State-Owned Large Plantations (PBN)	904.37	874.37	1486.43	1,700.00
Rubber	Privately-Owned Large Plantations (PBS)	1,550.24	1,007.58	1,999.15	1,984.00
Rubber	Total	2,807.81	2,096.25	3,699.78	1,764.95

Note: Rubber is produced in the form of dry rubber. PR = Smallholder Plantations; PBN = State-Owned Large Plantations; PBS = Privately-Owned Large Plantations. Productivity is calculated as total production divided by harvested area. The total productivity value (1,764.95 kg ha^{-1} yr^{-1}) is the weighted average across all plantation types.

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Figure 1: Study area location map of West Bandung Regency

3. Methods and Data

This research employed a descriptive survey method with a spatial approach based on Geographic Information Systems (GIS). This approach was selected because the study aims to identify, classify, and describe the actual and potential land suitability classes for rubber (*Hevea brasiliensis*) in West Bandung Regency, and to formulate development directions.

3.1 Population

The population of this study comprised all land units within West Bandung Regency, covering a total area of 130,577.40 ha. The population included all land use categories: agricultural cultivation areas (rice fields, dry fields, mixed gardens, plantations), non-agricultural cultivation areas (settlements, industry, infrastructure), protected areas, and other uses (scrubland, grasslands, vacant land). The population was defined as all land units rather than only existing rubber plantations because the primary objective was to identify potential areas for rubber cultivation expansion, requiring the evaluation of all biophysically suitable lands regardless of their current use.

3.2 Sample

The sampling technique employed was stratified random sampling, with strata defined by land units (Figure 2). Land units were generated through the overlay of five physical parameter maps: slope, land use, soil type, rainfall, and elevation. The number of sample points was allocated proportionally to the area of each land unit; larger land units received more sample points. From the total land units identified, 40 sample points were selected to represent the dominant land units covering the majority of the regency's area. Land units with very small areas (< 50 ha) or located in protected areas with restricted access were not sampled in the field but remained in the GIS analysis using secondary data. The sampling intensity (approximately one sample per 3,264 ha) was determined based on landscape heterogeneity and the availability of resources for field survey and laboratory analysis. Based on Table 2, there are 40 sample points which are a systematic classification of land units in West Bandung Regency based on three main physical parameters: rainfall, soil type, and elevation. This classification is a fundamental step in land suitability analysis for agricultural or plantation purposes, where each unique combination will be assessed for its suitability to the growing requirements of a specific crop (such as rubber).

Table 2: Research area sample of West Bandung Regency

No	Land Unit	Rainfall (mm/year)	Soil Type	Elevation (m asl)	Area (ha)	Percentage (%)
1	AALV1	1500 - 2000	Alluvial	0 - 1000	6,747.00	5.17
2	AALV2	1500 - 2000	Alluvial	1000 - 2000	64.56	0.05
3	ALAT1	1500 - 2000	Latosol	0 - 1000	5,401.00	4.14
4	ALAT2	1500 - 2000	Latosol	1000 - 2000	2,330.00	1.78
5	APOD1	1500 - 2000	Red-Yellow Podsol	0 - 1000	505.50	0.39
6	BALV1	2000 - 2500	Alluvial	0 - 1000	2,629.00	2.01
7	BALV2	2000 - 2500	Alluvial	1000 - 2000	693.60	0.53
8	BAND2	2000 - 2500	Andosol	1000 - 2000	5,097.00	3.90
9	BLAT1	2000 - 2500	Latosol	0 - 1000	6,779.00	5.19
10	BLAT2	2000 - 2500	Latosol	1000 - 2000	2,879.00	2.20
11	BPOD1	2000 - 2500	Red-Yellow Podsol	0 - 1000	5,133.00	3.93
12	BPOD2	2000 - 2500	Red-Yellow Podsol	1000 - 2000	1,309.00	1.00
13	CALV1	2500 - 3000	Alluvial	0 - 1000	632.60	0.48
14	CALV2	2500 - 3000	Alluvial	1000 - 2000	740.50	0.57
15	CAND1	2500 - 3000	Andosol	0 - 1000	22.92	0.02
16	CAND2	2500 - 3000	Andosol	1000 - 2000	10,080.00	7.72
17	CAND3	2500 - 3000	Andosol	> 2000	24.52	0.02
18	CLAT1	2500 - 3000	Latosol	0 - 1000	24,550.00	18.8
19	CLAT2	2500 - 3000	Latosol	1000 - 2000	2,029.00	1.55
20	CPOD1	2500 - 3000	Red-Yellow Podsol	0 - 1000	14,150.00	10.80
21	CPOD2	2500 - 3000	Red-Yellow Podsol	1000 - 2000	7,444.00	5.70
22	CREG2	2500 - 3000	Regosol	1000 - 2000	254.10	0.19
23	CREG3	2500 - 3000	Regosol	> 2000	47.50	0.04
24	DALV2	3000 - 3500	Alluvial	1000 - 2000	88.41	0.07
25	DAND1	3000 - 3500	Andosol	0 - 1000	243.00	0.19
26	DAND2	3000 - 3500	Andosol	1000 - 2000	5,287.00	4.05
27	DAND3	3000 - 3500	Andosol	> 2000	13.14	0.01
28	DLAT1	3000 - 3500	Latosol	0 - 1000	10,600.00	8.12
29	DLAT2	3000 - 3500	Latosol	1000 - 2000	15.14	0.01
30	DPOD1	3000 - 3500	Red-Yellow Podsol	0 - 1000	1,784.00	1.37
31	DPOD2	3000 - 3500	Red-Yellow Podsol	1000 - 2000	1,235.00	0.95
32	DREG2	3000 - 3500	Regosol	1000 - 2000	607.40	0.47
33	DREG3	3000 - 3500	Regosol	> 2000	57.19	0.04
34	EAND1	3500 - 4000	Andosol	0 - 1000	419.60	0.32
35	EAND2	3500 - 4000	Andosol	1000 - 2000	326.80	0.25
36	ELAT1	3500 - 4000	Latosol	0 - 1000	395.30	0.30
37	ELAT2	3500 - 4000	Latosol	1000 - 2000	0.34	0.00
38	EREG2	3500 - 4000	Regosol	0 - 1000	588.80	0.45
39	FREG2	4000 - 4500	Regosol	1000 - 2000	41.22	0.03
40	Reservoir / Water Body				9,332.26	7.15
				Total	130,577.40	100.00

3.3 Data Collection

Data collection was conducted through four techniques: field survey, literature study, documentation study, and laboratory analysis.

3.3.1 Field survey

Field surveys were conducted to directly measure and observe land parameters at each sample point. The parameters measured/observed included: slope inclination (%), surface rock fragments, rock outcrops, root depth (cm), soil pH (measured directly using a soil pH meter), and soil drainage class. For each sample point, geographic coordinates were recorded using a handheld GPS receiver (Garmin eTrex 30x) with an accuracy of ±3 meters, in the WGS 1984 UTM Zone 48S projection system, and stored in both decimal degrees and UTM formats. These coordinate data were subsequently imported into the GIS database for spatial integration. For each land unit, one composite soil sample was collected from the surface layer (0–30 cm depth). The composite sample consisted of five subsamples taken from the four corners and the center of a 10 m × 10 m plot, thoroughly mixed to form a single representative sample. For land units exceeding 5,000 ha, two composite samples were collected from different locations within the same land unit to accommodate internal variability, and the results were averaged.

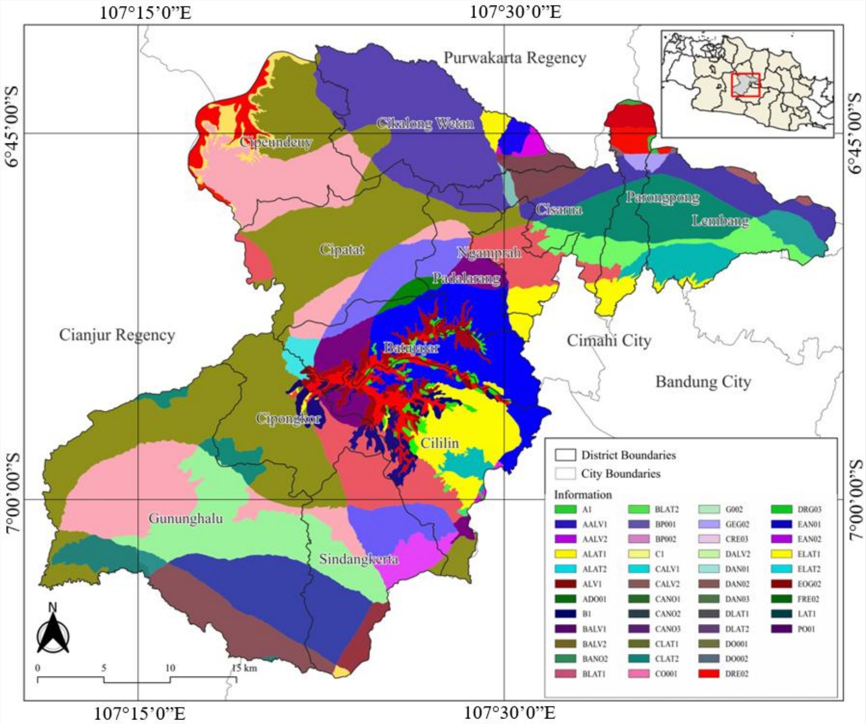

Figure 2: Land unit and sample area map

3.3.2 Literature and documentation study

The literature study was conducted to gather theoretical foundations and previous research findings relevant to land resource evaluation and rubber cultivation. The documentation study was conducted to collect secondary data, including: soil maps, rock type maps, land use maps, topographic maps, rainfall data from nearby stations, monographs of West Bandung Regency, the West Bandung Regency Spatial Plan (RTRW) documents, and relevant Government Regulations and Minister of Forestry Regulations.

3.3.3 Laboratory analysis

Laboratory analysis was conducted to obtain soil parameters that cannot be measured in the field. The collected soil samples were analyzed to determine: salinity (mmhos/cm), total N, available P_2O_5, available K_2O, CEC (me/100g soil) in the subsoil layer, and soil texture (surface layer). The laboratory analysis produced primary data on land potential, which were then identified and classified according to the land suitability criteria for rubber cultivation.

3.4 Data Processing and Analysis

3.4.1 GIS overlay and spatial analysis

All GIS analyses were performed using ArcGIS 10.8 (ESRI, Redlands, CA, USA). Statistical analysis of laboratory data was conducted using IBM SPSS Statistics 26, and the calculation of suitability matrices and development priorities was performed using Microsoft Excel 2019.

Data Input and Preparation

Five thematic maps were prepared as input layers:

1. Slope Map: Derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with 30 m spatial resolution, using the Surface → Slope tool in ArcGIS 10.8, producing percentage slope classes.
2. Soil Type Map: Digitized from the 1:250,000 scale soil map of West Java (provided by the Indonesian Soil Research Institute). Soil types were classified according to the Indonesian soil classification system.
3. Rainfall Map: Generated from 10-year average rainfall data (2014–2023) obtained from 12 meteorological stations in and around West Bandung Regency. Interpolation was performed using the Inverse Distance Weighting (IDW) method with a power parameter of 2, at 30 m cell resolution.
4. Elevation Map: Derived from the same SRTM DEM (30 m resolution), classified into three elevation zones: 0–1000 m, 1000–2000 m, and >2000 m above sea level.
5. Land Use Map: Digitized from the West Bandung Regency Spatial Plan (RTRW) documents at 1:200,000 scale.

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Coordinate System and Projection: All layers were projected to the WGS 1984 UTM Zone 48S coordinate system and resampled to a uniform 30 m × 30 m grid cell resolution using the Resample tool to ensure spatial consistency across all datasets.

Overlay Procedure for Vector and Raster Data Integration: Since vector and raster data cannot be directly overlaid in a single operation, the integration was performed through a two-stage overlay procedure**:**

Stage 1: Raster Data Integration (Raster Calculator)
The three raster datasets (slope, rainfall, and elevation) were first combined using the Raster Calculator t**o**ol. Each raster was classified into discrete classes:

- Slope: classified into <8%, 8–15%, 15–30%, >30%
- Rainfall: classified into <1500, 1500–2000, 2000–2500, 2500–3000, 3000–3500, 3500–4000, >4000 mm/year
- Elevation: classified into 0–1000 m, 1000–2000 m, >2000 m

The Raster Calculator combined these three classified rasters into a single integrated raster layer where each cell represented a unique combination of slope, rainfall, and elevation classes. This integrated raster was then converted to vector format using the Raster to Polygon tool, producing a polygon layer where each polygon represented a unique combination of the three raster-derived parameters.

Stage 2: Vector Data Integration (Intersect Tool)
The integrated polygon layer (from Stage 1) was then overlaid with the two vector datasets (soil type map and land use map) using the Intersect tool. The Intersect tool combines multiple vector layers, preserving the attributes of all input layers and creating new polygons where boundaries intersect.

Final Output: Land Units
The result was a single integrated vector layer where each polygon represented a unique combination of all five physical parameters (slope, rainfall, elevation, soil type, and land use). These polygons were defined as land units and assigned a unique Land Unit ID following a systematic naming convention. The final land unit layer was then intersected with the administrative boundary of West Bandung Regency to produce the study area land unit map at 1:200,000 scale**.**

Validation and Quality Control
The overlay results were validated through:

1. Visual inspection of the overlay output against input maps to ensure spatial alignment
2. Attribute consistency checks to ensure no data loss during conversion
3. Field verification at 40 sample points to confirm the accuracy of land unit classification

The overlay procedure is illustrated in the workflow diagram presented in Figure 3.

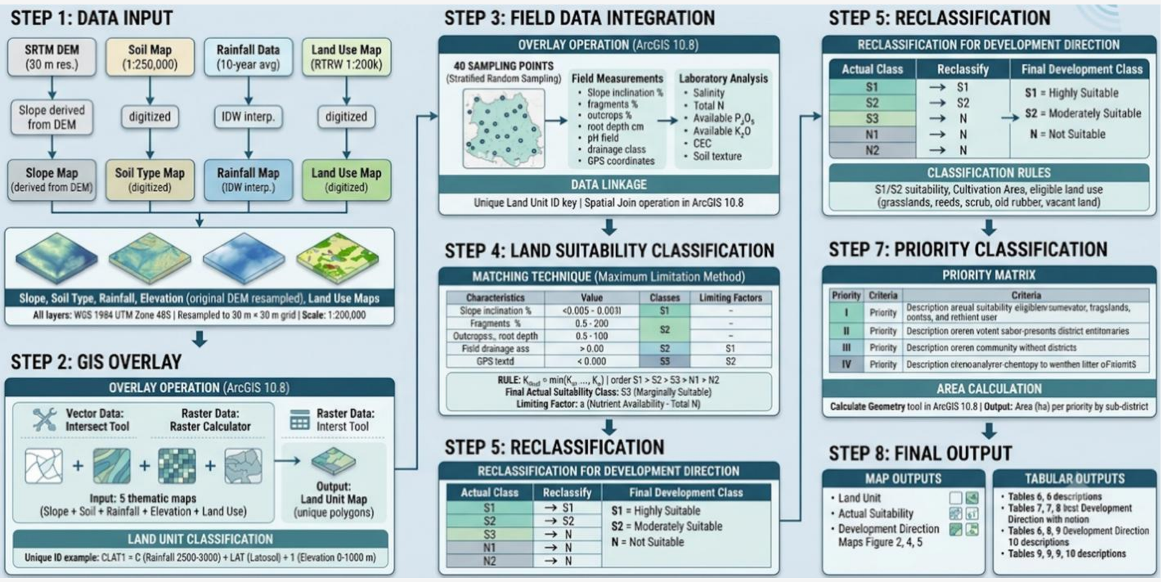

Figure 3: GIS workflow land suitability analysis

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3.4.2 Determining the location for land suitability for rubber cultivation

Actual land suitability was determined using the matching technique (maximum limitation method), following the framework established by the Soil Research Institute (1993) as illustrates in Figure 4. For each land unit, the measured land characteristics (temperature, rainfall, dry month duration, soil drainage, texture, effective depth, CEC, base saturation, pH, salinity, slope, erosion hazard, and flooding) were compared against the standard growth requirements for rubber (*Hevea brasiliensis*) presented in Table 3.

Table 3: Standard criteria for land suitability for rubber trees (*Hevea brasiliensis*)

Land Quality	Land Characteristics	Unit	S1 (Highly Suitable)	S2 (Moderately Suitable)	S3 (Marginally Suitable)	N (Not Suitable)
Climate						
Temperature	Mean annual temperature	°C	26 – 30	24 – < 26 or > 30 – 34	22 – < 24 or > 34 – 36	< 22 or > 36
Water availability	Mean annual rainfall	mm yr^{-1}	2,500 – 3,000	2,000 – < 2,500 or > 3,000 – 3,500	1,500 – < 2,000 or > 3,500 – 4,000	< 1,500 or > 4,000
Water availability	Dry months (< 75 mm $month^{-1}$)	months yr^{-1}	1 – 2	2 – 3	3 – 4	> 4
Rooting media						
Drainage	Soil drainage class	-	Well drained	Moderately well drained	Somewhat poorly drained	Poorly / very poorly drained
Texture	Soil texture	-	Silty clay, silty clay loam, clay loam, silt, silt loam, loam	Sandy clay loam, sandy loam, loamy sand, clay	Sandy clay, sandy loam	Sand, heavy clay
Effective depth	Soil depth	cm	> 100	75 – 100	50 – < 75	< 50
Coarse fragments	Gravel/rock fragments	%	< 15	15 – 35	35 – 60	> 60
Nutrient retention						
CEC	Cation exchange capacity	cmol(+) kg^{-1}	> 24 (high)	16 – 24 (medium)	5 – < 16 (low)	< 5 (very low)
Base saturation	Base saturation	%	35 – 50	20 – < 35 or > 50 – 70	< 20 or > 70	-
Soil pH	pH (H_2O)	-	4.5 – 5.5	5.5 – 6.5	6.5 – 7.5	> 7.5 or < 4.0
Organic C	Organic carbon	%	> 2.0 (high)	1.0 – 2.0 (medium)	0.5 – < 1.0 (low)	< 0.5 (very low)
Nutrient availability						
Total N	Total nitrogen	%	> 0.50 (high)	0.25 – 0.50 (medium)	0.10 – < 0.25 (low)	< 0.10 (very low)
Available P	P_2O_5 (Bray/Olsen)	ppm	> 20 (high)	10 – 20 (medium)	5 – < 10 (low)	< 5 (very low)
Available K	K_2O (exchangeable)	me $100g^{-1}$	> 0.40 (high)	0.20 – 0.40 (medium)	0.10 – < 0.20 (low)	< 0.10 (very low)
Toxicity						
Salinity	Electrical conductivity (ECe)	dS m^{-1}	< 2	2 – < 4	4 – < 8	≥ 8
Al saturation	Al saturation	%	< 20	20 – 40	40 – 60	> 60
Exchangeable Na	Exchangeable sodium percentage (ESP)	%	< 6	6 – < 15	15 – < 30	≥ 30
Terrain						
Slope	Slope gradient	%	< 8	8 – 15	15 – 30	> 30
Surface rocks	Surface rock fragments	%	< 3	3 – < 15	15 – < 40	≥ 40
Erosion hazard						
Erosion	Erosion hazard level	-	Very low (I)	Low (II)	Moderate (III)	High – Very high (IV–V)
Flooding						
Flooding	Flooding frequency	-	None	Rare (> 1 in 10 yrs)	Occasional (1 in 5–10 yrs)	Frequent (≥ 1 in 5 yrs)

Note: S1 = Highly Suitable; S2 = Moderately Suitable; S3 = Marginally Suitable; N = Not Suitable. Suitability class is determined by the most limiting characteristic (minimum law). Adapted and updated from Soil Research Institute (1993), with additional references from TNAU (2023) [19] and FAO guidelines [20].

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Each land characteristic was assigned a suitability class: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (currently not suitable), or N2 (permanently not suitable), based on the criteria in Table 3. The final land suitability class for each land unit was determined by the lowest class among all evaluated characteristics i.e., the characteristic with the lowest suitability class determines the final class. The suitability class is defined in Equation 1:

$$K\_final = min(K_1, K_2, K_3, \ldots, K_n) \quad \text{Equation 1}$$

Where K represents the suitability class for each characteristic ($K \in \{S1, S2, S3, N1, N2\}$), with priority order S1 > S2 > S3 > N1 > N2.

This approach follows the principle of the "weakest link" in land evaluation a single severely limiting factor can render the entire land unit unsuitable, regardless of other favourable conditions. Limiting factors for each land unit were identified as the land characteristics whose suitability class was lower than the overall potential class of the unit. Specifically:

- For land units classified as S2, the limiting factor(s) were the characteristic(s) scoring S3 or lower, while all other characteristics scored S1 or S2.
- For land units classified as *N*, the limiting factor(s) were the characteristic(s) scoring N1 or N2.

Each limiting factor was denoted by a subscript code following the suitability class as follows:

t = temperature
w = water availability (rainfall/dry months)
r = root condition (drainage, texture, depth)
n = nutrient retention (CEC, base saturation, pH)
a = nutrient availability (N, P, K)
x = toxicity (salinity, alkalinity)
eh = erosion hazard
l = slope/terrain gradient

Example: S2eh indicates moderately suitable land with erosion hazard as the limiting factor; N1l indicates not suitable land limited by slope.

- For the purpose of rubber cultivation development planning, the actual land suitability classes (S1, S2, S3, N1, N2) were reclassified into three simplified classes (S1, S2, and N) according to the following rules:

S1 (Highly Suitable) → remains S1
S2 (Moderately Suitable) → remains S2
S3 (Marginally Suitable) → reclassified as N
N1 (Currently Not Suitable) → reclassified as N
N2 (Permanently Not Suitable) → reclassified as N

The rationale for reclassifying S3 to N is that marginally suitable lands are economically unviable for commercial rubber cultivation, as they require prohibitively high investment to overcome existing limiting factors, likely resulting in financial losses for farmers. This approach aligns with the principle that efforts to improve limiting factors must consider economic feasibility [21].

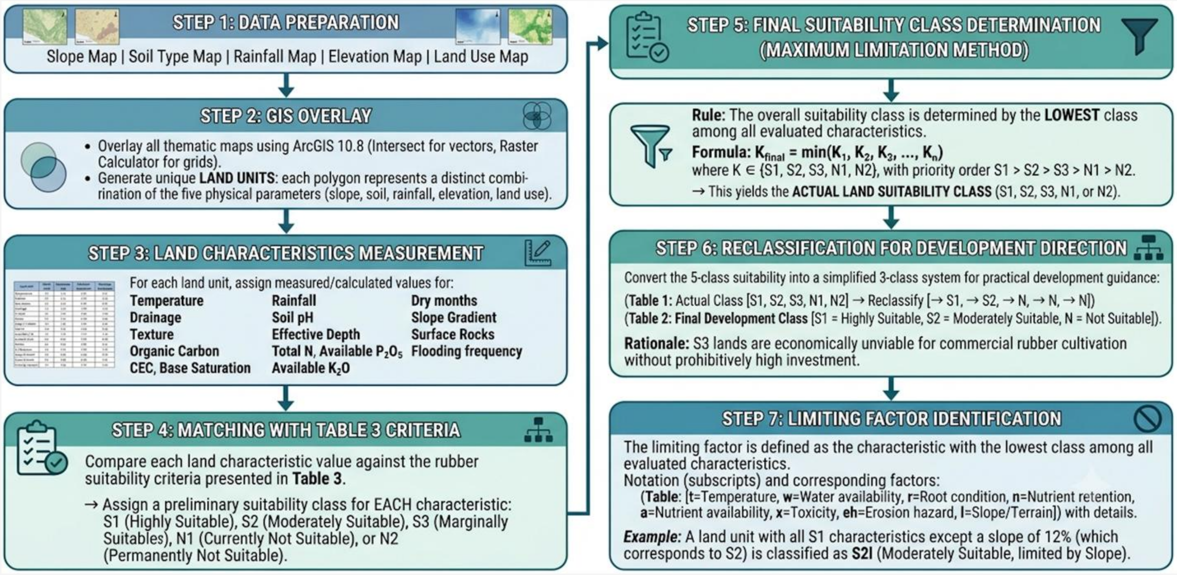

Figure 4: Land Suitability Analysis Process Flowchart

3.4.3 Calculation of development direction priorities

The development guidelines for rubber plantations in West Bandung Regency were prepared spatially using Geographic Information Systems and descriptively. The map of directions for smallholder rubber development was created using a map overlay system of land suitability for rubber crops with land use maps, forest area maps of West Bandung Regency adjusted to the West Bandung Regency Regional Spatial Plan, and considering Government Regulation Number 6 of 2007 jo Government Regulation Number 3 of 2008 concerning Forest Management and Forest Utilization Planning [22], as well as Ministry of Forestry Regulation Number P.37/Menhut-II/2007 concerning Community Forests [23] and Ministry of Forestry Regulation Number p.49/Menhut-II/2008 jo number P.14/Menhut-II/2010 concerning Village Forests [24], and Law Number 41 of 2009 concerning the Protection of Sustainable Food Agricultural Land [25]. All overlaid maps are at a scale of 1:200,000. The criteria for determining the direction of rubber plantation development in West Bandung Regency, based on actual land suitability class and land use, can be seen in Table 4. Based on Table 4, this provides clear guidance on zones that can or cannot be used for rubber plantation development, and defines directions or limitations based on existing land conditions. This categorization is useful in sustainable spatial planning and land use in West Bandung Regency. The prioritization of rubber development directions was calculated using a multi-criteria decision matrix integrating three main factors:

Step 1 – Suitability Class Filtering: Only land units with actual suitability classes S1, S2, or S3 were considered. Land units with N1 or N2 classes were excluded from development directions.

Step 2 – RTRW Zoning: Land units were classified based on their RTRW designation:

- Cultivation Area: Eligible for development direction;
- Protected Area: Excluded from development direction regardless of suitability class.

Step 3 – Land Use Type: Within eligible areas, land use types were ranked by priority as Table 5.

Table 4: Determining the development directions for rubber plantations in West Bandung Regency

Regional Spatial Planning Plan (RTRW)	Land Use	Land Suitability Class	Category
Cultivation Area	Old and unproductive rubber plantations, grasslands, reeds, shrubs, community gardens (fields, mixed gardens)	S1, S2, S3	Development direction
Cultivation Area	Rice fields, built-up areas (settlements, buildings), large plantations	S1, S2, S3, N1, N2	Not Recommended
Protected Area	Regardless of the type of land use	S1, S2, S3, N1, N2	Not Recommended

Table 5: Prioritization of rubber development directions in West Bandung Regency

Priority Direction Location	Suitability Class	Land Use (Availability)	Forest Status
Priority I	S2	Unutilized land (grasslands, reeds, scrubland)	Outside forest area
Priority II	S1	Old/unproductive rubber plantations	Outside forest area
Priority III	S2	Vacant land and community gardens	Designated as Community Forest (HTR)
Priority IV	S1, S2	Grasslands, reeds, scrub, old rubber	Production forest / APL

4. Result

4.1 Agricultural Area

West Bandung Regency can be said to be an agricultural area. Based on land use in West Bandung Regency, the land use group for agricultural cultivation is the largest, covering 78,446.16 ha (59.96%) of West Bandung Regency's total area, as shown in Table 6. Based on Table 6, land use in West Bandung Regency, the land use group for agricultural cultivation is the largest, covering

78,446.16 ha (59.96%) of West Bandung Regency's area. Protected areas cover 19,171.04 ha (14.65%), non-agricultural cultivation covers 25,812.82 ha (19.73%), and other uses cover 7,147.9 ha (5.65%), which is the smallest area in West Bandung Regency. Supported by vast land resources, it's no wonder the most dominant occupation of its residents is farming. Agricultural land, especially rice fields, is the main source of income for families.

Agricultural land in West Bandung Regency is highly influenced by weather and climate factors, especially rainfall. During the rainy season, farmers plant rice in paddy fields. However, during the dry season, farmers diversify their crops, planting various types of plants other than rice. Most farmers plant palawija (secondary crops), while others grow different types of commodities. Three out of 13 sub-districts in West Bandung Regency cultivate rubber trees. In these three sub-districts, the land used for rubber cultivation is fields/dryland. The utilization of land planted with rubber is the focus of this research. To evaluate land resources, information on land characteristics and quality is needed. This information is obtained from a number of samples from each land unit. The area and land quality samples taken based on land units can be seen in Table 7.

Table 6: Land use composition in West Bandung Regency

No	Land Use Type	Total Area (ha)	Percentage (%)
A	Protected Area		
	1 Protected Area	19,171.04	14.65
	Quantity of A	19,171.04	14.65
B	Cultivation Area		
	1 Cultivation Area Agriculture		
	a. Mixed Garden	8,758.76	6.70
	b. Plantation/garden	9,562.95	7.31
	c. Rice field	16,309.44	12.47
	d. Rainfed Rice Fields	19,342.69	14.79
	e. Field	24,472.31	18.71
	Quantity of B1	78,446.16	59.96
	2 Non-Agricultural Cultivation		
	a. Industry	2,270.73	1.74
	b. Institution	251094	0.19
	c. Road	2,0000.00	1.53
	d. Railroad track	52.76	0.04
	e. Market / shops	776.79	0.59
	f. Settlement	20,260.16	15.49
	g. Field	50.02	0.04
	h. Park	35.11	0.03
	i. Mine	114.31	0.09
	Quantity of B2	25,812.82	19.73
	Quantity of B	104,256.98	79.69
C	Other		
	1 Empty Land	3,580.13	2.83
	2 Rumput	3,567.78	2.82
	Quantity of C	7,147.90	5.65
	Total Sum of A, B, C	130,577.40	100.00

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Table 7: Suitability level of actual land for rubber plants in West Bandung Regency

Land Units	t	w		r			re	eh	l	11	Total Area (ha)	Percentage (%)
1	2	3	4	5	6	7	8	9	10			
AALV1	S1	S2	N1	N1	S1	S1	S1	S1	S1	N1w	6,747.00	5.17
AALV2	S1	S2	N1	N1	S1	S1	S1	S1	S1	N1w	64.56	0.05
ALAT1	S1	S2	S2	S2	S1	S1	S1	S2	S2	S2eh	5,401.00	4.14
ALAT2	S2	S3	S2	S2	S1	S1	S1	N1	S3	N1l	2,330.00	1.78
APOD1	S1	S2	N1	N1	S1	S1	S1	S1	S1	N1w	505.50	0.39
BALV1	S1	S2	S2	S2	S1	S1	S1	N1	S3	N1l	2,629.00	2.01
BALV2	S3	S2	S2	S2	S1	S1	S1	N1	S3	N1l	693.60	0.53
BAND2	S3	S2	S2	S2	S3	S3	S3	N1	S3	N1l	5,097.00	3.90
BLAT1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	6,779.00	5.19
BLAT2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S2t	2,879.00	2.20
BPOD1	S1	S2	S2	S2	S1	S1	S1	N1	S3	N1l	5,133.00	3.93
BPOD2	S3	S2	S2	S2	S1	S1	S1	N1	S3	N1l	1,309.00	1.00
CALV1	S1	S1	S1	S1	S1	S1	S1	S2	S2	S2eh	632.60	0.48
CALV2	S3	S2	S2	S2	S1	S1	S1	N1	S3	N1l	740.50	0.57
CAND1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	22.92	0.02
CAND2	S3	S2	S2	S2	S3	S3	S3	N1	S3	N1l	10,080.00	7.72
CAND3	S3	S2	S2	S2	S3	S3	S3	N1	S3	N1l	24.52	0.02
CLAT1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	24,550.00	18.80
CLAT2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S2t	2,029.00	1.55
CPOD1	S1	S2	S2	S2	S1	S1	S1	N1	S3	N1l	14,150.00	10.80
CPOD2	S1	S2	S2	S2	S1	S1	S1	N1	S3	N1l	7,444.00	5.70
CREG2	S2	S2	S1	S1	S1	S1	S1	N1	S3	N1l	254.10	0.19
CREG3	S2	S2	S1	S1	S1	S1	S1	N1	S3	N1l	47.50	00.04
DALV2	S3	S1	S1	S1	S1	S1	S1	N1	S3	N1l	88.41	0.07
DAND1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	243.00	0.19
DAND2	S3	S1	S1	S1	S1	S1	S1	N1	S3	N1l	5,287.00	4.05
DAND3	S3	S2	S2	S2	S3	S3	S3	N1	S3	N1l	13.14	0.01
DLAT1	S3	S1	S1	S2	S1	S1	S1	N1	S3	N1l	10,600.00	8.12
DLAT2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	15.14	0.01
DPOD1	S1	S1	S1	S2	S1	S1	S1	N1	S3	N1l	1,784.00	1.37
DPOD2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	1,235.00	0.95
DREG2	S2	S1	S1	S1	S1	S1	S1	N1	S3	N1l	607.40	0.47
DREG3	S2	S1	S1	S1	S1	S1	S1	N1	S3	N1l	57.19	0.04
EAND1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	419.60	0.32
EAND2	S1	S1	S1	S1	S1	S1	S1	N1	S3	N1l	326.80	0.25
ELAT1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	395.30	0.30
ELAT2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	0.342	0.00
EREG2	S2	S3	S1	S1	S1	S1	S1	N1	S3	N1l	588.80	0.45
FREG2	S2	N1	S1	S1	S1	S1	S1	N1	S3	N1wl	41.22	0.03
Reservoir/Water Body											9.332.26	7.15
Total											130,577.40	100.00

*Note:

1. Land Units
2. t = temperature
3. w = water availability (rainfall/dry months)
4. w = water availability (length of dry season months)
5. r = root condition (drainage)
6. r = root condition (texture)
7. r = root condition (depth)
8. re = Coarse Fragments (%)
9. l = slope/terrain gradient
10. eh = erosion hazard
11. Land Suitability Level

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4.2 Determination of Land Suitability for Rubber Cultivation Development

Based on Table 7, it can be seen that land suitability class S1 in land unit CLAT1 has an area of 24,550 ha (18.8%) of the total area of West Bandung Regency, and the smallest land unit area is land suitability class S1 in land unit ELAT2 with an area of 0.342 ha (0.01%) of the total area of West Bandung Regency. Meanwhile, for land suitability class N1, the largest area is in land unit CPOD1 with an area of 14,150 ha (10.8%) with the limiting factor being slope steepness, and for land suitability class S2, the largest area is in land unit ALAT1 with an area of 5,401 ha (4.14%) with the limiting factors being erosion hazard level and slope. The purpose of conducting a land suitability analysis for rubber crops in West Bandung Regency is to identify the potential for developing rubber cultivation from the perspective of its physical geography. Land suitability analysis for rubber plantations in West Bandung Regency has been conducted based on information regarding slope steepness, elevation, and climate conditions, namely rainfall. For mapping actual land suitability for rubber plants, an administrative map of West Bandung Regency at a scale of 1:200,000 is required, along with information on soil conditions assuming equal fertility levels. This resulted in land suitability information down to the class and subclass level. Data on the distribution of land suitability analysis for rubber plantations in the West Bandung Regency area can be seen in Table 8.

Based on Table 8 and Figure 5, the land suitability map for rubber crops shows that 36,478.8 ha (29.50%) of land in West Bandung Regency is suitable for rubber cultivation. The unsuitable land area is 87,187.3 ha (70.50%). In reality, most of the land falls into the Very Suitable (S1) class, covering an area of 26,950.6 ha (21.79%), and the land classified as Moderately Suitable (S2) for rubber crops in West Bandung Regency covers an area of 9,528.2 ha (7.70%). The spatial location of the land with actual land suitability classes is presented on the Land Suitability Map for Rubber Commodities in West Bandung Regency. Land with suitability classes S1, S2, and N in each sub-district of West Bandung Regency, with varying areas, the sub-district with the largest area of S1 suitability class is Cipatat sub-district, which is 6,053 ha. The land with S2 suitability class is Cipatat sub-district, which is 1925 a. The sub-district with N rubber land suitability class is in all sub-districts, and the largest is Gunung Halu sub-district, which is 24,560 ha. Classes S2 and N have limiting factors. The limiting factors for S2 suitability class are drainage, slope, and soil texture. For N (unsuitable) land suitability class, it is limited by slope. Some of the limiting factors can be overcome, while the limiting factors for class N are quite difficult to overcome. The limiting factors of slope and soil texture are relatively difficult to overcome, although they can be overcome, it requires very high costs, while the drainage limiting factor can be overcome with fertilization and the construction of drainage channels. When repair efforts are undertaken, they will increase the cost of the farmer's operations and will result in small profits for the farmer, or even losses.

Table 8: Area of land suitability classes for rubber plants in each land suitability class for rubber plants in West Bandung Regency

No	Subdistrict	Suitability Class (ha)		
		S1	S2	N
1	Cikalongwetan	7,536.0	0.0	4,079.0
2	Cipeundeuy	5,591.0	0.0	2,867.0
3	Parongpong	159.6	1,440.0	2,638.0
4	Cisarua	855.3	1,196.0	3,418.0
5	Lembang	0.0	332.0	9,257.0
6	Cipatat	6,053.0	1,925.0	4,093.0
7	Padalarang	1,811.0	758.3	2,469.0
8	Ngamprah	562.7	1,701.0	905.3
9	Batujajar	0.0	203.2	6,783.0
10	Cipongkor	0.0	1,113.0	6,670.0
11	Cililin	0.0	0.0	9,939.0
12	Gununghalu	3,033.0	859.70	24,560.0
13	Sindangkerta	1,349.0	0.0	9,509.0
West Bandung Regency (Total)		26,950.6	9,528.2	87,187.3

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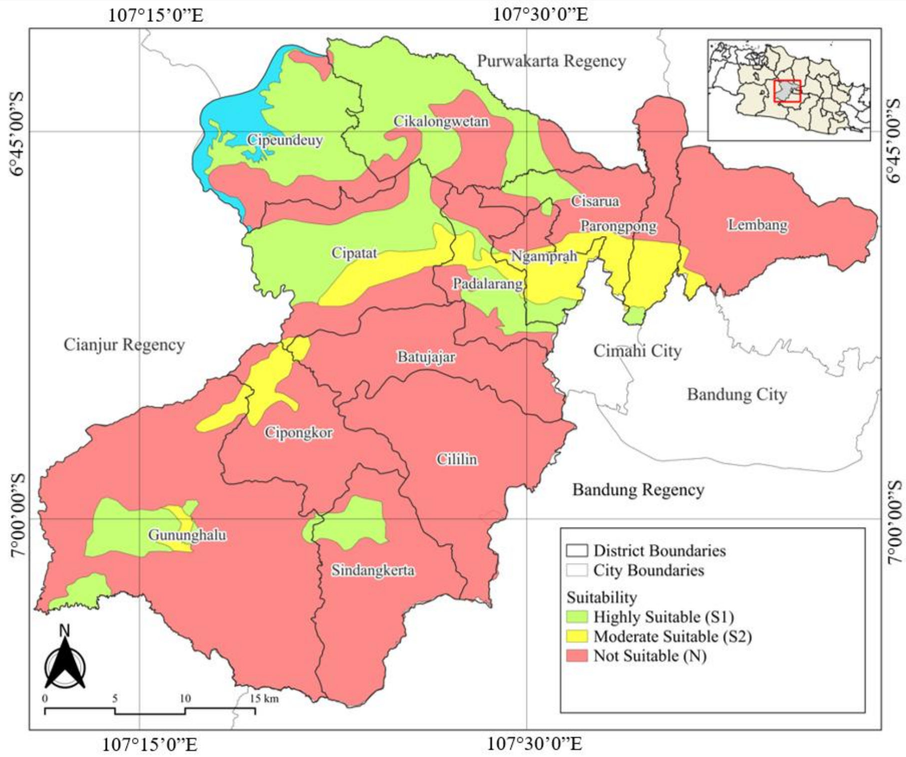

Figure 5: Land Suitability Map for Rubber Commodities in West Bandung

Table 9: Area of land suitability classes for rubber plants in each land suitability class for rubber plants in West Bandung Regency

No	Subdistrict	Suitability Class (ha)				
		S1	S2l	S2r (drainage)	S2t	Nl
1	Cikalongwetan	7,536.0	0.0	0.0	0.0	4,079.0
2	Cipeundeuy	5,591.0	0.0	0.0	0.0	2,867.0
3	Parongpong	159.6	979.9	156.6	303.5	2,638.0
4	Cisarua	855.3	1,128.5	15.3	52.2	3,418.0
5	Lembang	0.0	235.7	12.2	84.1	9,257.0
6	Cipatat	6,053.0	1,878.7	46.3	0.0	4,093.0
7	Padalarang	1,811.0	758.3	0.0	0.0	2,469.0
8	Ngamprah	562.7	1,131.7	123.1	446.2	905.3
9	Batujajar	0.0	203.2	0.0	0.0	6,783.0
10	Cipongkor	0.0	1,065.5	47.5	0.0	6,670.0
11	Cililin	0.0	0.0	0.0	0.0	9,939.0
12	Gununghalu	3,033.0	571.7	288.0	0.0	24,560.0
13	Sindangkerta	1,349.0	0.0	0.0	0.0	9,509.0
West Bandung Regency (Total)		26,950.6	7,953.3	688.9	886.0	87,187.3

Considerations regarding efforts to improve limiting factors must consider economic aspects. When the limiting factors or constraints of the land are overcome, it must be calculated whether the rubber cultivation business will be economically profitable [21]. The area of actual land suitability classes with limiting factors can be seen in Table 9. Based on Table 9 and Figure 6, the actual land suitability map for rubber plants reveals that land in West Bandung Regency is suitable for rubber cultivation on 36,478.8 ha (29.50%). Unsuitable land covers 87,187.3 ha (70.50%). In reality, most of the land falls into the Very Suitable (S1) class, covering 26,950.6 ha (21.79%), and land in the Moderately Suitable (S2) class covers 9,528.2 ha (7.70%) for rubber plants in West Bandung Regency.

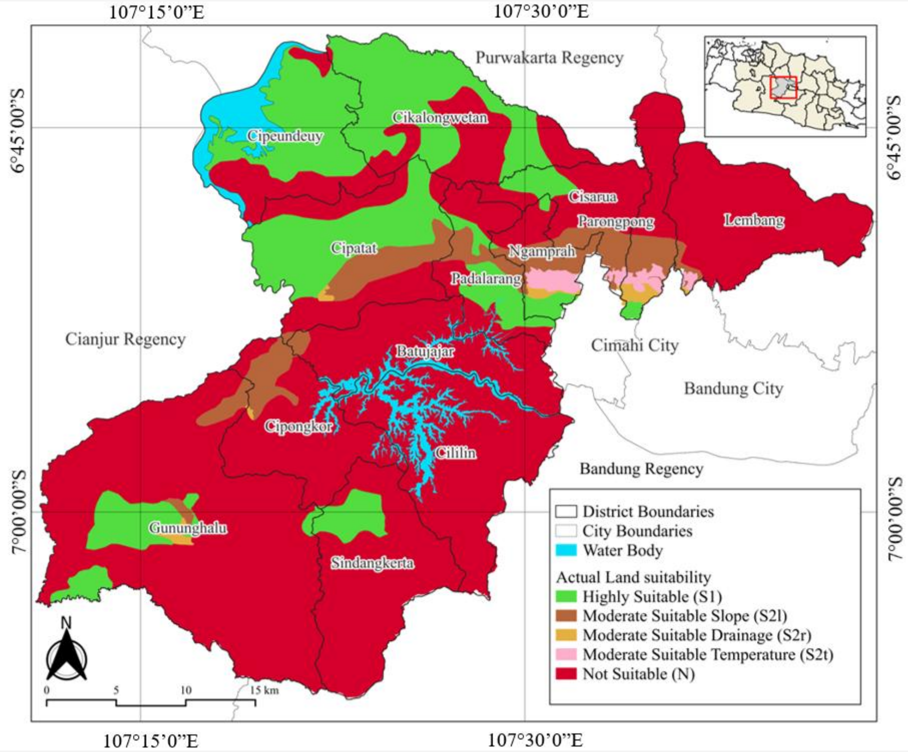

Figure 6: Actual land suitability map for rubber commodities in West Bandung

Land with suitability classes S1, S2, and N in each sub-district in West Bandung Regency with varying areas). The sub-district with the largest area of S1 suitability class land is Cipatat Sub-district, which is 6053 ha. The sub-district with S2 suitability class land is Cipatat Sub-district, with an area of 1878.73 ha. Land with N rubber suitability class is found in all sub-districts, with the largest area being Gunung halu Sub-district, which is 24560 ha. Spatially, the location of land with actual land suitability classes is presented on the Land Suitability Map for Rubber Commodities in West Bandung Regency.

4.3 Potential Development directions for Rubber Cultivation (Hevea Brasiliensis) in West Bandung Regency

To map the locations that will serve as guidelines for rubber crop development in the West Bandung Regency area, a development direction map is needed. This development direction map contains information about the spatial distribution patterns of spatial and biophysical aspects suitable for rubber cultivation. The spatial aspect in this study refers to the land that will be directed in accordance with the Regional Spatial Plan (RTRW) in West Bandung Regency. The biophysical aspect in this study is that the land to be directed is suitable based on the results of land suitability evaluation for rubber crops in West Bandung Regency.

In this study, rubber crop commodities were chosen as the research object because rubber is a crop with good market prospects, is quite popular with the community, has been cultivated for generations, and is one of the main plantation commodities in West Bandung Regency. Land use types in wetlands such as irrigated rice fields and rainfed rice fields are not directed toward rubber cultivation because wetlands are a very important land use type and a major asset for regional food security. Most of the wetlands in West Bandung Regency are planted with rice and other food crops such as corn, etc. The location of the rubber plant development instruction is divided into several priorities, considering the provisions of the rubber plantation development instruction in the West Bandung Regency area. (Table 4), the status of forest area, suitability class, and current land use. The prioritization of development directions can be seen in Table 10. The prioritization of rubber development directions presented in Table 10 was determined not solely by biophysical suitability class, but by integrating ease of implementation and socio-economic feasibility as key decision criteria. This approach recognizes that land suitability alone does not guarantee successful rubber cultivation expansion; social, economic, and institutional factors are equally critical.

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Table 10: Rationale for prioritization of rubber development directions in West Bandung Regency

Priority Direction Location	Suitability Class	Land Use (Availability)	Rationale for Priority
Priority I	S2	Grasslands, reeds, and scrubland outside forest areas	*Highest ease of implementation*: Land is unutilized, no ownership conflicts, no conversion costs, ready for planting
Priority II	S1	Old/unproductive rubber plantations outside forest areas	*High biophysical suitability but moderate implementation difficulty:* Requires negotiation with farmers, compensation for lost income during replanting
Priority III	S2	Vacant land and community gardens outside forest areas designated as Community Forest (HTR)	*Moderate implementation difficulty:* Involves community agreement and formal HTR designation process
Priority IV	S1, S2	Grasslands, reeds, shrubs, old rubber within production forests and Other Use Areas (APL)	*Lowest priority*: Located within forest areas, requires additional permits and compliance with forestry regulations

Priority I (S2 lands with grasslands, reeds, and scrubland outside forest areas) was ranked highest because these lands are unutilized and readily available for planting. They involve no ownership conflicts, require no compensation payments, and entail minimal conversion costs. Although these lands are only moderately suitable (S2), their immediate availability makes them the most feasible option for rapid rubber expansion. Priority II (S1 lands with old/unproductive rubber plantations outside forest areas) was ranked second despite having higher biophysical suitability. The lower priority is due to implementation constraints: these lands are already cultivated by farmers, requiring negotiation, compensation for lost income during the replanting period (typically 5–7 years), and potentially facing resistance from farmers who rely on existing rubber income. The higher transaction costs and social complexity reduce their practical feasibility despite superior agronomic conditions.

Priority III (vacant land and community gardens in HTR-designated areas) involves additional administrative processes related to community forest designation, which slows implementation.

Priority IV (lands within production forests and APL) was ranked lowest due to regulatory requirements and permitting processes associated with forest area utilization, as stipulated by Government Regulation No. 6 of 2007 [22] and Ministry of Forestry Regulation No. P.37/Menhut-II/2007 [23].

This prioritization framework aligns with the principles of sustainable land use planning advocated by [22], which emphasizes that successful agricultural development must consider not only biophysical suitability but also social acceptability, economic viability, and institutional feasibility. By prioritizing lands with the lowest implementation barriers, the development direction provides practical guidance that can be readily adopted by farmers and local government, thereby accelerating the realization of benefits for community welfare. The area of land directed for rubber plant development in each sub-district, along with its prioritization, is presented in Table 11. Based on Figure 7 and Table 11, land suitable for rubber cultivation in West Bandung Regency is found in 13 sub-districts, totalling 21,234.728 ha or 16.26% of the West Bandung Regency area. The sub-district with the largest potential land area is Cipatat sub-district, with an area of 5,455.1 ha (4.1%), followed by Cikalongwetan and Cipeundeuy sub-districts, each with an area of 48,2697 ha (3.69%) and 2801.71 ha (2.14%) of the West Bandung Regency area, respectively. Spatially, the location of rubber crop development guidelines in West Bandung Regency can be seen on the West Bandung Regency Rubber Development Guidelines Map.

Table 11: Area of rubber plantation development guidance locations and their prioritization in West Bandung Regency

No	Subdistrict	Priority of rubber development direction (ha)				
		Not Recommended	Priority I	Priority II	Priority III	Priority IV
1	Cikalongwetan	6,788.03	2,020.0	2,781.0	12.9	13,.0
2	Cipeundeuy	5,647.67	514.1	2,279.0	8.6	0.0
3	Parongpong	3,254.75	600.8	295.6	86.5	0.0
4	Cisarua	4,036.75	883.8	528.4	0.0	20.4
5	Lembang	9,367.11	144.0	73.2	4.7	0.0
6	Cipatat	6,615.90	3,194.0	2,028.0	98.6	134.5
7	Padalarang	4,101.00	503.1	269.6	164.6	0.0
8	Ngamprah	1,994.93	654.9	457.6	61.6	0.0
9	Batujajar	6,921.32	12.4	0.0	0	64.9
10	Cipongkor	7,168.10	318.5	296.4	0	0.0
11	Cililin	9,939.00	0.0	0.0	0	0.0
12	Gununghalu	26170.10	797.6	1,485.0	0	0.0
13	Sindangkerta	10,430.50	129.3	298.2	0	0.0
West Bandung Regency (Total)		102,435.16	9,772.5	10,792.0	437.4	232.8

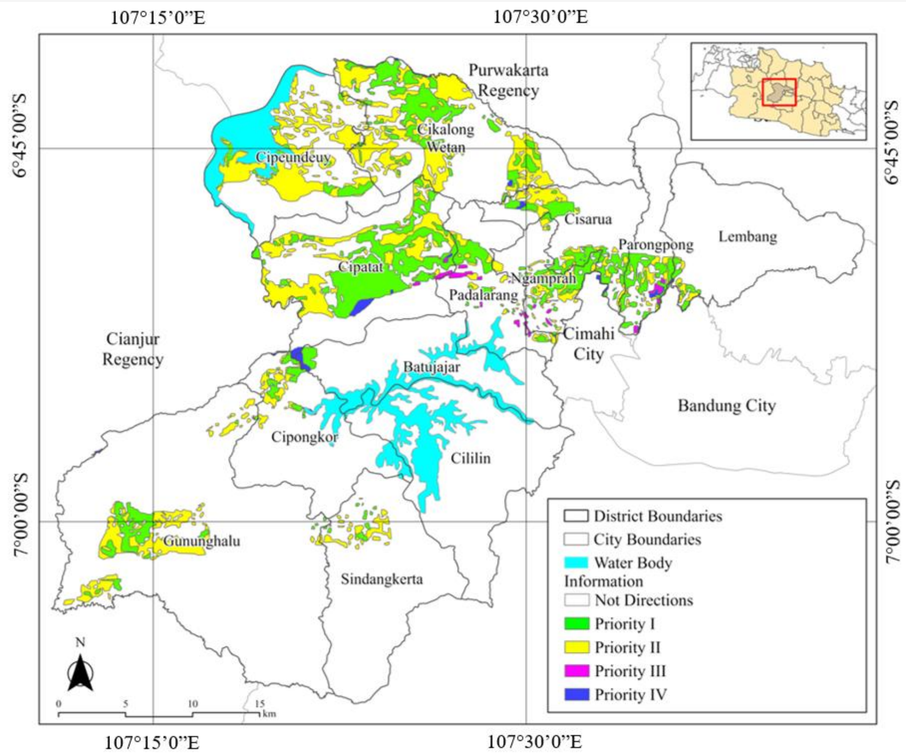

Figure 7: Map of rubber plantation development directions in West Bandung Regency

5. Discussion

5.1 Physical Characteristics of the Region and their Influence on Rubber Potential

The analysis reveals that the physical factors most supportive of rubber cultivation in West Bandung Regency are rainfall (2,500–3,000 mm/year) and temperature (average 26–30°C), which align with the optimal growth requirements for rubber plants. Rubber (*Hevea Brasiliensis*) grows optimally in tropical climates with temperatures ranging from 25°C to 35°C, averaging approximately 28°C, and requires well-drained soils with pH ranging from 4.5 to 6.0 [26]. Studies in Peninsular Malaysia have confirmed that tropical rainforest climates with regular rainfall of approximately 2,000–2,500 mm per year and average temperatures of 26–28°C provide suitable conditions for commercial rubber cultivation [27]. The climatic conditions in West Bandung Regency, particularly in sub-districts with elevations below 1,000 m above sea level such as Cipatat, Cikalongwetan, and Cipeundeuy, fulfill these requirements.

However, slope gradient emerged as the primary limiting factor, rendering 70.5% of the land in West Bandung Regency unsuitable (N) for rubber cultivation. The predominance of slopes exceeding 30% in the northern and eastern areas of West Bandung Regency particularly in Lembang, Parongpong, Cisarua, and Gununghalu sub-districts constitutes a major obstacle to rubber development in these areas. While some studies suggest that slope class does not significantly influence rubber growth and productivity when planting management is well executed [28], from a land suitability evaluation perspective, slope remains a critical limiting factor particularly when considering that management intensity among smallholder farmers is often suboptimal. Furthermore, elevation has been shown to significantly affect rubber production, with lower elevations (approximately 84.5 m above sea level) identified as optimal [29]. Steep slopes not only complicate harvesting operations but also increase the risk of soil erosion, which subsequently reduces land productivity [30].

The distribution of S1 (highly suitable) land, covering 26,950.6 ha (21.79%), is concentrated in Cipatat (6,053 ha), Cikalongwetan (7,536 ha), and Cipeundeuy (5,591 ha). These three sub-districts are characterized by flat to gently sloping terrain (<8%), suitable rainfall patterns, and Latosol soils with good drainage and effective depth exceeding 100 cm. Research on Latosol soils in Indonesia has demonstrated that this soil type, when properly managed, supports optimal rubber growth [31]. These conditions establish these sub-districts as primary priority areas for rubber development from a biophysical perspective. Notably, despite being highly suitable agronomically, the existing rubber plantation area in these sub-districts remains limited Privately-Owned Large Plantations (PBS) cover only 1,550 ha and State-Owned Large Plantations (PBN) cover 904 ha (Table 1). This indicates substantial potential for expansion on underutilized S1 lands. Conversely, Lembang (9,257 ha of N land) and Gununghalu (24,560 ha of N land) sub-districts are dominated by unsuitable land. In Lembang, the primary limiting factor is elevation exceeding 1,000 m above sea level, resulting in average annual temperatures below 24°C, which falls below the optimal threshold for rubber growth. In Gununghalu, slope gradient exceeding 30% constitutes the dominant limiting factor. These findings confirm that rubber is a lowland to mid-elevation crop that is intolerant of low temperatures and requires humid tropical conditions [32] [33] and [34].

5.2 Interpretation of Suitability Classes and Limiting Factors

The analysis reveals that of the 36,478.8 ha of suitable land (S1 and S2), only 21,234.728 ha are directed for rubber development (Table 11). This significant reduction is attributed to existing land use and spatial planning (RTRW) designations. The reduction from 36,478.8 ha (suitable land) to 21,234.728 ha (development direction) occurs through several mechanisms. First, S1 and S2 lands located within protected areas (19,171.04 ha) cannot be allocated for rubber cultivation (Table 6) due to their ecological functions as water recharge zones and biodiversity conservation areas. Second, lands currently used for irrigated rice fields (16,309.44 ha) and rainfed rice fields (19,342.69 ha) are not allocated for rubber, as they constitute sustainable agricultural land protected by Law No. 41 of 2009 concerning the Protection of Sustainable Food Agricultural Land. Third, settlement areas (20,260.16 ha) and industrial areas (2,270.73 ha) cannot be converted as they have been designated for other purposes.

These findings demonstrate that conversion of rice fields to rubber plantations is not recommended from a food security perspective. In Indonesia, agricultural land conversion has become a serious threat to national food security, with rice field conversion occurring at an alarming rate [35]. Approximately three million hectares of rice fields in Indonesia are not yet formally protected, making them vulnerable to conversion [36]. Under current regulations, rice fields designated as Sustainable Food Agricultural Land (LP2B) must be protected and never converted to other uses, constituting at least 87% of all raw paddy land [37]. The agricultural sector is often sacrificed for economic growth, resulting in significant land cover transformation into built-up areas and plantations [38]. This study reinforces that food agricultural land protection policies must remain a priority in spatial planning [39].

The most dominant limiting factor within the S2 class is slope gradient (S2l), covering 7,953.25 ha (Table 9), particularly in Parongpong, Cisarua, and Ngamprah sub-districts. This limiting factor is difficult to overcome, as it requires terracing and soil conservation measures that entail high costs [40]. Efforts to improve limiting factors must consider economic aspects; if improvement costs exceed potential returns, the land should not be developed [21]. The second most significant limiting factor is drainage (S2r), covering 688.91 ha, concentrated in Gununghalu and Ngamprah. This factor is relatively manageable through the construction of drainage channels and raised beds, consistent with recommendations from the Soil Research Institute (1993). The soil texture limiting factor (S2t), covering 886.04 ha, is primarily found in Parongpong, Ngamprah, and Lembang, where sandy textures (sandy loam) dominate, resulting in low water and nutrient retention capacity [41].

5.3 Development Priority: Policy Logic

The designation of Priority I for underutilized S2 lands (grasslands, reeds, scrubland) above Priority II for S1 lands with old rubber is based on the logic of ease of implementation, rather than solely on agronomic suitability class. This logic is explained as follows.

Priority I lands (grasslands/reeds/scrubland), covering 9,772.5 ha, are lands without ownership conflicts and ready for planting without requiring negotiation or compensation. Although classified as only S2, these lands offer the lowest transaction costs and can immediately provide economic benefits. This approach aligns with the concept of "low-hanging fruit" in agricultural development planning, where priority is given to interventions that are easiest and quickest to implement [20].

Priority II lands (S1 old rubber), covering 10,792.02 ha, despite being agronomically superior, face significant socio-economic constraints. First, these lands are already owned and cultivated by farmers, requiring complex negotiations. Second, replanting programs require compensation for income loss during the waiting period (5–7 years) before new trees begin producing. Third, there is potential resistance from farmers whose livelihoods depend on existing rubber income. Research indicates that most rubber trees managed by smallholder farmers in Indonesia are over 25 years old and require replanting [42]; approximately 400,000 hectares of rubber are old or damaged and need to be replanted [43]. However, low rubber prices and low labor productivity have driven conversion of rubber plantations to more profitable crops [44]. These high transaction costs make Priority II lands less practically feasible despite their agronomic superiority.

Priority III lands (HTR-designated areas) and Priority IV lands (forest areas) face more complex administrative and regulatory barriers, placing them at the lowest priority. Utilization of forest areas for rubber cultivation requires special permits and compliance with forestry regulations as stipulated in Government Regulation No. 6 of 2007 [22] and Minister of Forestry Regulation No. P.37/Menhut-II/2007 [23].

This prioritization logic differs from conventional approaches that rely solely on agronomic suitability classes. This study demonstrates that institutional and socio-economic factors are equally important as biophysical factors in determining the success of plantation development. Participatory approaches involving stakeholders have proven effective in designing sustainable and resilient rubber cultivation systems, as well as enhancing the inclusion, relevance, and impact of development programs [16].

5.4 Implications for Spatial Planning

The findings of this study have significant implications for spatial planning in West Bandung Regency. First, the identification of substantial available S1 land (26,950.6 ha) that remains underutilized for rubber indicates a misalignment between land potential and current designation. Local government should consider allocating these lands (particularly grasslands and scrublands) for rubber plantation development, especially in Cipatat, Cikalongwetan, and Cipeundeuy sub-districts. The alignment between land use and RTRW has been identified as a key factor in spatial planning in West Bandung Regency [45], and a similar approach should be applied to rubber plantation development.

Second, the limited area of smallholder rubber plantations (PR) only 353.20 ha with productivity of 1,000 kg/ha/year, far below PBS (1,984 kg/ha/year) and PBN (1,700 kg/ha/year) indicates that replanting and intensification programs are urgently needed. In Indonesia, rubber plantations are dominated by smallholders (85% of the total 3.34 million hectares), providing income for 12.5 million farmers and their families [43]. However, productivity at the smallholder level remains a major challenge, with yields only 40–50% of the productivity of government and private large plantations. The fact that 71% of Indonesia's rubber is produced by smallholders with low productivity demonstrates that increasing yields at the smallholder level could have significant positive effects on both the Indonesian economy and smallholder welfare [46].

The government could adopt programs similar to the Smallholder Rubber Replanting Project (PPKR) that has been successfully implemented in several regions of Indonesia. The Ministry of Agriculture has committed to helping rubber farmers improve productivity and income through replanting programs and adoption of modern cultivation techniques [47]. Replanting programs also aim to improve latex quality and add value through smallholder-based industrialization processes. Farming support systems for smallholders, including disease control assistance, fertilization technology training, and participatory replanting programs, have been implemented in various regions such as Jambi to improve rubber production [48].

Third, given that Priority I lands (ready-to-plant lands) cover 9,772.5 ha, the government should provide incentives in the form of superior clones, fertilizers, and technical assistance to encourage farmers to utilize these lands. Without policy support, this potential may remain untapped due to farmers' limited capital. Research shows that superior rubber clones have high productivity potential (>2,500 kg/ha) and can shorten the immature period, allowing tapping activities to begin on trees younger than 4 years [49] and [50]. However, due to limited capital and information access, only a small proportion of smallholders have accessed highly productive clonal planting material [50]. The Indonesian Rubber Research Institute has released recommended superior rubber clones named IRR (Indonesian Rubber Research) series, with IRR 309 and IRR 310 showing latex yield potentials of 2,221 kg/ha/year and 2,059 kg/ha/year, respectively [51] and [49]. These clones are responsive to ethephon stimulant application, with average production increases over 5 years reaching 130% for IRR 309 and 87% for IRR 310 [49]. Rubber agroforestry using selected clonal planting material can achieve yields comparable to monoculture plantations with lower investment costs and higher labor returns [52]. Rubber-based agroforestry systems have been shown to demonstrate higher net returns in the long term compared to rubber monoculture [53]. Rubber agroforests can provide diversified income, offering resilience against volatile rubber markets [54].

5.5 Comparison with other Studies

The findings of this study are consistent with research conducted in other regions of Indonesia and neighboring countries. In South Sumatra, studies have shown that smallholder rubber plantation productivity remains low due to poor quality planting material and limited adoption of improved cultivation practices [55] and [56]. Smallholders continue to experience low rubber productivity. These findings are consistent with PR productivity in West Bandung Regency at only 1,000 kg/ha/year. In Jambi, research demonstrated that the adoption of superior clones can increase productivity to 2,000 kg/ha/year, indicating significant potential for improvement if replanting programs are implemented in West Bandung [48] and [50]. Superior clones such as IRR 309 and IRR 310 have been shown to produce average yields of 53.2 and 52.7 grams per tree per tapping with ethephon stimulation [50]. Farming support systems for smallholders in Jambi have included disease control assistance, fertilization technology, and replanting program training [48]. In Malaysia, Latosol and Andosol soils with good drainage are the best soil types for rubber [57], consistent with the finding that Latosol soils dominate highly suitable areas in West Bandung. Studies in Peninsular Malaysia have confirmed that tropical rainforest climates with regular rainfall of approximately 2,000–2,500 mm per year and average temperatures of 26–28°C provide suitable conditions for commercial rubber planting [27]. The key difference from previous studies is the integration of land suitability analysis with spatial planning (RTRW) and prioritization based on ease of implementation. This approach provides a novel contribution to the literature on rubber plantation planning in Indonesia, as most previous studies have focused solely on biophysical aspects without considering institutional and spatial constraints. This study also demonstrates that rubber-based agroforestry systems integrated with food crops can offer a solution for sustainable rubber and food production.

5.6 Study Limitations and Future Research

This study has several limitations that should be acknowledged. First, the analysis is based on secondary data from maps at 1:200,000 scale, which may not capture micro-topographic and micro-climatic variations at the site level. Second, the study does not consider economic analysis (production costs, market prices, financial feasibility), which is crucial for farmer decision-making. Third, the study does not provide in-depth analysis of institutional aspects (presence of cooperatives, market access, partnerships with processing factories). Future research is recommended to: (1) conduct economic feasibility analysis (Net Present Value, Internal Rate of Return) for each suitability class to provide more comprehensive recommendations for policymakers; (2) utilize high-resolution imagery data (Sentinel-2 or Landsat) for more accurate land use mapping; (3) conduct participatory analysis involving farmers and stakeholders to validate the resulting development directions; and (4) assess the potential of rubber-based agroforestry systems as a more sustainable alternative, as these systems offer income diversification and greater ecosystem service provision compared to monoculture plantations.

6. Conclusion

This study assessed the biophysical land suitability and spatial development direction for rubber (Hevea brasiliensis) cultivation in West Bandung Regency using a GIS-based approach that integrates physical land characteristics with spatial planning (RTRW) regulations. The analysis revealed that while a substantial portion of land is biophysically suitable for rubber cultivation, slope gradient emerged as the most dominant limiting factor, rendering the majority of the total land area unsuitable, predominantly in the northern and eastern sub-districts where steep slopes and high elevations result in temperatures below the optimal threshold for rubber growth. After integrating land use designation and spatial planning regulations, the potential development area was refined to a more modest proportion of the total area, concentrated in three sub-districts characterized by flat to gently sloping terrain, suitable rainfall, and Latosol soils with good drainage. Within the moderately suitable class, the primary limiting factors were slope gradient, soil texture, and drainage, each requiring different levels of intervention. Development priorities were classified into four categories based on ease of implementation: underutilized lands outside forest areas, old rubber plantations requiring replanting, vacant lands and community gardens in designated areas, and lands within production forests, with prioritization emphasizing that institutional and socio-economic factors particularly land availability, ownership status, and transaction costs are equally important as biophysical suitability in determining practical development feasibility. The practical significance of these findings lies in their applicability to regional planning: the identification of clear priority zones provides guidance for targeted interventions, while the classification of limiting factors informs the type and cost of improvements required. The study has several limitations, including reliance on medium-scale maps that may not capture micro-topographic and micro-climatic variations, the absence of economic feasibility analysis, and limited examination of institutional aspects. For practitioners, the findings suggest that local government should prioritize reallocating underutilized lands for rubber development while protecting rice fields from conversion in accordance with national law, implement urgent replanting programs to address low smallholder productivity through access to superior clones and modern cultivation techniques, and provide incentives to encourage utilization of ready-to-plant lands.

Environmental safeguards must include protection of protected areas, rice fields, and steep slopes from conversion, with appropriate drainage and soil management practices where needed. Future research should conduct economic feasibility analysis for each suitability class, utilize high-resolution imagery for more accurate mapping, adopt participatory approaches with farmers and stakeholders, and assess rubber-based agroforestry systems as sustainable alternatives offering income diversification and greater ecosystem services than monoculture. The development directions identified serve as spatial guidance, not mandatory designations, providing a biophysical and spatial basis for informed land use planning and rubber cultivation expansion in West Bandung Regency.

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