

RESEARCH ARTICLE



Land Capability Analysis for Sustainable Land Use Planning: A Case Study of Bogor Regency, Indonesia

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ABSTRACT

Uncontrolled land use changes can lead to mismatches with designated spatial patterns, resulting in critical land issues such as erosion and flooding. Bogor Regency has undergone rapid land use transformations, particularly in agriculture, with significant shifts occurring between 1995 and 2001. This study evaluates land capability using a matching and scoring approach to determine its suitability concerning existing spatial patterns. Key factors such as slope, erosion hazards, and soil depth were analyzed to classify land into capability categories. The findings reveal six classes of land capability, ranging from Class II to VII, with Classes IV and VI being the most dominant. Spatial analysis indicates that a large portion of Bogor Regency's land cover aligns well with its land capability. Compatibility with designated spatial patterns is predominantly conditional, suggesting that some areas may require mitigation measures or adjustments for sustainable development. The conditional suitability of land capability with spatial patterns highlights the need for careful planning interventions. Decision-makers must consider land constraints and adopt adaptive land-use policies to mitigate risks such as erosion and flooding. Integrating land capability assessments into planning frameworks can enhance sustainable land management and minimize environmental degradation.

Introduction

Development, population growth, and rising human needs are intertwined phenomena. As development advances to meet diverse needs, it demands more land, resulting in notable shifts in land use patterns. The advancement of development within a region corresponds to the concurrent expansion of the population, accompanied by an increase in both the quality and quantity of essential living standards [1]. This has an impact on uncontrollable changes in land use [2]. Consequently, changes in land use are no longer in line with the agreed-upon spatial patterns. This situation occurs in almost every region, especially at the district level [3]. If this continues unchecked, it can be ensured that the critical land area will increase, erosion and floods will occur frequently, resulting in a decrease in land carrying capacity [4].

Land use in Bogor Regency has undergone rapid changes from 1999 to 2013, particularly in agricultural land, where there was a significant shift between 1995 and 2001 [5]. Bogor Regency has a very high potential for critical land covering 123,923 ha [6]. The regency exhibits a wide variety of land use, ranging from tourism, industry, to residential sectors. The shifting patterns of land use in Bogor Regency have been very high in the last two decades, especially the conversion of agricultural land into built-up areas. There has been a land use change from both wet and dry agricultural land to built-up areas covering 47,953 ha or 16.03% of the total area of Bogor Regency [5].

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Every change in land use must consider its carrying capacity because the balance of land carrying capacity serves as the measure of suitability for any land use. Conversely, if land usage exceeds its carrying capacity, land use becomes ineffective. Therefore, land carrying capacity evaluation is needed to assess how effectively land is being utilized in an area [7]. One of the methods that can be used to conduct a carrying capacity evaluation is land capability analysis [8]. Land capability assessment is a method aimed at optimizing land use by matching it with its inherent potential. Assessing land potential is crucial, especially for policy development, land utilization, and sustainable land management. One of the activities carried out by humans is to optimally utilize available land by adapting its use to the soil's capability and providing treatment according to the necessary conditions, so that the land can function without depleting its fertility, in order to meet their livelihood needs [9]. It requires consideration of land capability when giving guidance on land use.

The classification system categorizes land into eight classes based on its suitability and limitations for various purposes, particularly agriculture [10]. Class I denotes land ideal for agriculture, boasting minimal limitations such as flat topography, good drainage, and fertility. Class II exhibits moderate limitations, necessitating conservation efforts, and is suitable for seasonal crops, grasslands, and commercial forests. In Class III, significant obstacles require specific conservation measures, making it suitable for limited crop options and nature reserves. Class IV presents greater soil obstacles, offering limited crop options and typically used for seasonal crops and commercial forestry. While Class V is not vulnerable to erosion, it faces persistent challenges like flooding or rocky terrain, thus limiting its applications. Class VI features severe limitations, often found on steep slopes, requiring careful management for activities like grazing and forestry. Class VII encounters enduring threats that cannot be mitigated, necessitating a conservation-focused approach for activities like grasslands or forestry. Class VIII has extremely severe limitations, best left in its natural state for purposes like protected forests and nature reserves.

In light of rapid urbanization and increasing land development pressures in Bogor Regency, this research seeks to assess the alignment between the region's land carrying capacity and its existing spatial planning strategies. By analyzing factors such as population growth, land use patterns, environmental considerations, and infrastructure development, the study aims to provide valuable insights into the effectiveness of current spatial planning policies. The outcomes of this research can not only aid local authorities in identifying potential areas for improvement in land management but also contribute to the formulation of more sustainable and resilient spatial planning frameworks. Ultimately, by enhancing our understanding of the interplay between land capacity and spatial planning, this study endeavors to support informed decision-making processes and promote balanced development in Bogor Regency for the benefit of its residents and the environment alike.

Materials and Methods

Study Area

The study was conducted in Bogor Regency, a region located in West Java Province, Indonesia. As shown in Figure 1, Bogor Regency is characterized by diverse topographical conditions, ranging from lowland areas to hilly and mountainous regions. Over the past two decades, this area has experienced significant land cover changes, largely influenced by urban expansion, agricultural activities, and infrastructure development. These rapid changes have raised concerns regarding environmental sustainability, land degradation, and natural resource management. The research was conducted over a nine-month period, from January to September 2023, involving extensive field observations, data collection, and spatial analysis to assess land use dynamics in the region.

Data Collection

The dataset utilized in this study was gathered from multiple reputable agencies, as detailed in Table 1. The collected data underwent rigorous processing through spatial analysis techniques employing a matching method. This methodological approach enabled the integration of diverse datasets to elucidate spatial relationships and patterns pertinent to the research inquiry.

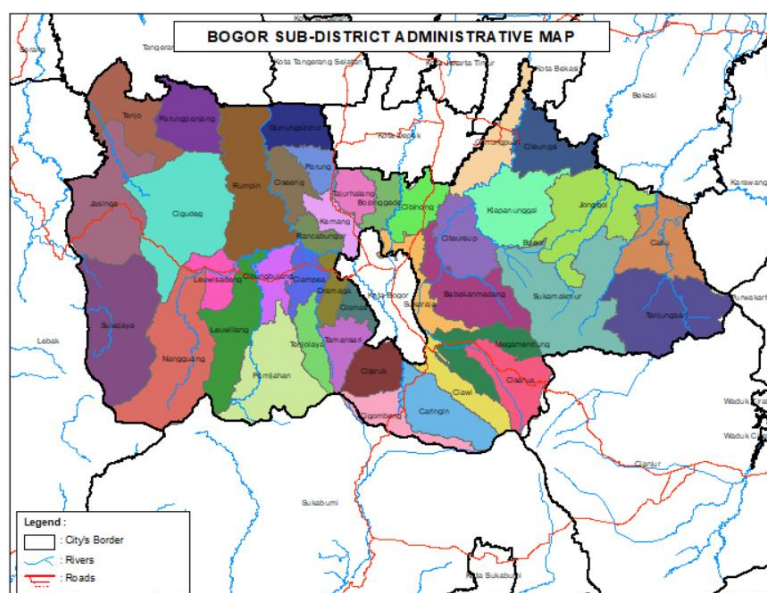


Figure 1. Study area.

Table 1. Dataset.

Parameters	Data sources	Description
Land use	Satellite image SPOT6 (3M)	LAPAN, classified into Fields/Garden, Forest, Settlements, Paddy fields; Rivers/Water, Clouds, Empty Field
Precipitation	Precipitation distribution map, Scale 1 : 250,000	Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG)
Slope	Slope Map, Scale 1 : 250,000	Indonesian Center for Agricultural Land Resources Research and Development (BBSLDP)
Soil type	Soil map, Scale 1 : 250,000	Watershed Management Center (BPDAS Citarum – Ciliwung)
Spatial pattern	Spatial pattern map, 1 : 100,000	Regional Development Planning Agency (BAPPEDA)

Methodology

The method to be used in determining land capability criteria is matching [11]. The matching method is carried out by comparing and matching the criteria of land capability classes with the characteristics of land units, thus obtaining the land potential of each land unit through tabular analysis techniques [12]. Land which is allowed to be used for each land capability class, according to Widiatmaka et al. [13] (Table 2).

Table 2. Criteria for land use based on land capability.

No.	Land capability	Land use
1	I	All types of land use
2	II	All types of land use except Psi
3	III	All types of land use except Psi and Pi
4	IV	Pt, all types of grazing, all types of forests
5	V	All types of grazing (Pgi, Pgds, Pgt), all types of forests
6	VI	Pgds, Pgt, all types of forests
7	VII	Pgt, all types of forests
8	VIII	Nature reserves and protected forests

Source: Widiatmaka et al. [13]; Psi (Highest intensive agriculture); Pi (Intensive agriculture); Psd (Moderately intensive agriculture); Pt (Limited agriculture); Pgi (Intensive grazing); Pgds (Moderate grazing); Pgt (Limited grazing).

Data Analysis

The analysis is conducted by dividing the land into Land Mapping Units (LMU) with similar biophysical characteristics. The analysis is based on the methods used by Kusumandari and Nugroho [14] and Widiatmaka et al. [13]. The characteristics used are limiting factors with seven permanent attributes that are difficult to change, such as soil texture, slope, drainage, effective depth, erosion level, rock percentage, and flood hazard [15–17]. Land capability analysis is performed using the matching method according to Table 3.

Table 3. Land capability criteria.

No.	Limiting factor	Land capability classes							
		I	II	III	IV	V	VI	VII	VIII
1	Soil texture (t) ¹⁾								
	Upper layer (40 cm)	t2/ t3	t1/ t4	t1/ t4	(*)	(*)	(*)	(*)	t5
	Bottom layer	t2/ t4	t1/ t4	t1/ t4	(*)	(*)	(*)	(*)	t5
2	Slope (%) ²⁾	I0	I1	I2	I3	(*)	I4	I5	I6
3	Drainage ³⁾	d0/ d1	d2	d3	d4	(**)	(*)	(*)	(*)
4	Effective soil depth ⁴⁾	k0	k0	k1	k2	(*)	k3	(*)	(*)
5	Erosion ⁵⁾	e0	e1	e1	e2	(*)	e3	e4	(*)
6	Gravel/rocks ⁶⁾	b0	b0	b0	b1	b2	(*)	(*)	b3
7	Flood risk ⁷⁾	o0	o1	o2	o3	o4	(*)	(*)	(*)

Source: Widiatmaka et al. [13]; (*): May possess limiting factor attributes observed in lower classes; (**): The soil surface remains consistently saturated with water; ¹⁾Texture: t₁ (Subtle), t₂ (A bit subtle), t₃ (Moderate), t₄ (Robust), t₅ (Rough); ²⁾Slope: I₀ (0–3%), I₁ (3–8%), I₂ (8–15%), I₃ (15–30%), I₄ (30–45%), I₅ (45–65%), I₆ (>65%); ³⁾Drainage: d₀ (Good), d₁ (Good enough), d₂ (Fairly poor), d₃ (Poor), d₄ (Extremely poor); ⁴⁾Effective soil depth: k₀ (Deep), k₁ (Moderate), k₂ (Limited), k₃ (Extremely limited); ⁵⁾Erosion: e₀ (No erosion), e₁ (Slight), e₂ (Moderate), e₃ (Huge), e₄ (Extremely huge); ⁶⁾Gravel/rocks: b₀ (None or few), b₁ (Moderate), b₂ (Excessively), b₃ (Huge); ⁷⁾Flood risk: o₀ (Not once), o₁ (Infrequently), o₂ (At times), o₃ (Frequently), o₄ (Commonly).

Results

Table 4 shows the land capability of Bogor Regency. There is no Class I land capability in Bogor Regency. Figure 2 shows the distribution of land capability in Bogor Regency. Land capability has limiting factors in each class, consisting of upper layer texture, lower layer texture, slope, drainage, effective soil depth, gravel/rock content, and flood vulnerability level. It indicates that a piece of land requires management and maintenance to elevate its land capability class. Table 5 shows the distribution of limiting factors of land capability.

Table 4. Land capabilities areas.

Land capability classes	Areas (ha)	Percentage (%)
II	26,838.6	9.00
III	52,143.7	17.48
IV	90,947.2	30.49
V	18,968.2	6.36
VI	76,669.3	25.70
VII	32,750.9	10.98

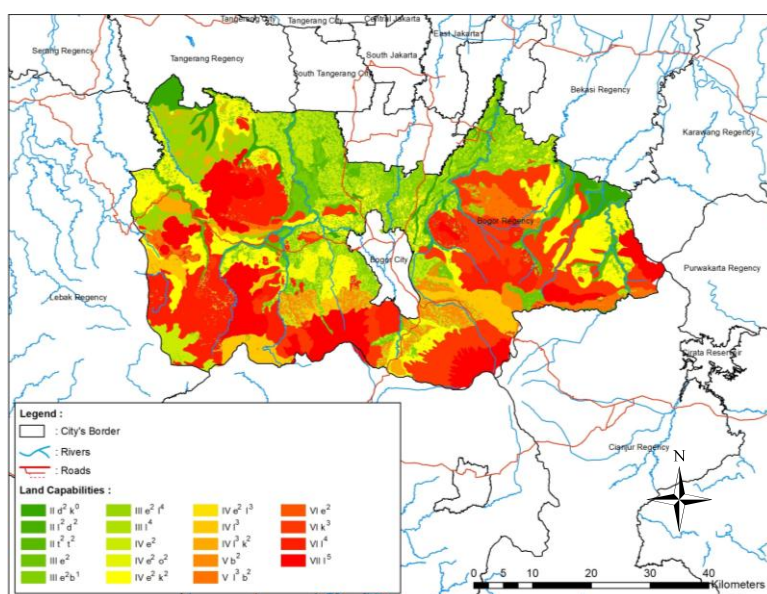


Figure 2. Bogor Regency land capabilities map.

The best land capability class found in Bogor Regency is land capability Class II covering an area of 26,838 ha (9.00%), and land capability Class III covering an area of 52,143 ha or 17.48% of the total area. The land capability in Bogor Regency is predominantly represented by land capability Class IV covering an area of 90,947 ha (30.49%), and land capability Class VI covering an area of 76,669 ha or 25.70% of the total area. Land with land capability Class IV has constraints that limit the types of land use that can be carried out. Class VII land can not be used for any purpose due to extremely limiting factors, as any land utilization may pose risks of massive erosion and flooding in a region. Therefore, land in Class VII should be left in its natural state. The most prevalent limiting factor in Bogor Regency is slope, covering 85,878 ha (28.79%), followed by limiting factors like erosion hazards and effective soil depth, covering 43,692 ha or 14.65% of the total area (Table 5). This is influenced by the hilly topography surrounding it.

Table 5. The area of limiting factors in the land capability classes in Bogor Regency.

Land capability		Areas	
Class	Sub class	Ha	%
II	DRA, ESD	10,319.2	3.46
	DRA, SLO	30.3	0.01
	USL, LSL	16,489.1	5.53
III	ERO	8,133.1	2.73
	ERO, BJR	30,840.2	10.34
	ERO, SLO	12,468.1	4.18
	SLO	702.3	0.24
IV	ERO	26,530.4	8.89
	ERO, BJR	1,165.5	0.39
	ERO, ESD	43,692.4	14.65
	ERO, SLO	99.1	0.03
	SLO	13,833.2	4.64
	SLO, ESD	5,626.3	1.89
V	GR	10,038.5	3.37
	SLO, GR	8,929.7	2.99
VI	ERO	405.1	0.14
	ESD	37,672.6	12.63
	SLO	38,591.6	12.94
VII	SLO	32,750.9	10.98
Total		298,318.1	100.00

ERO: Erosion hazard; BJR: Flood hazard; SLO: Slope; USL: Upper soil layer; LSL: Lower soil layer; DRA: Drainage; ESD: Effective soil depth; GR: Gravel/rocks.

Figure 3 and 4 shows that there is a significant amount of Regional Spatial Planning (RTRW) allocation that exceeds the carrying capacity of the land capability, totaling 45,759 ha of Bogor Regency's total area, where there is alignment between spatial patterns and land capability.

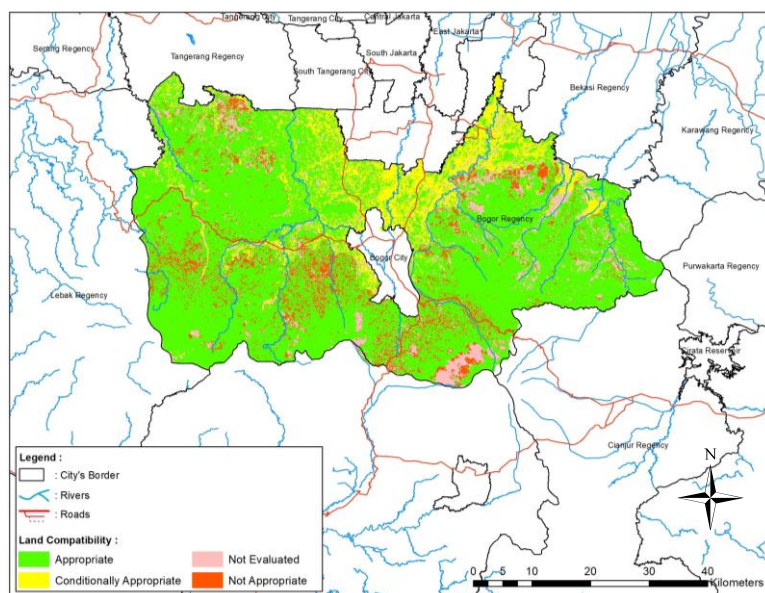


Figure 3. Compatibility of land capability with actual land cover map.

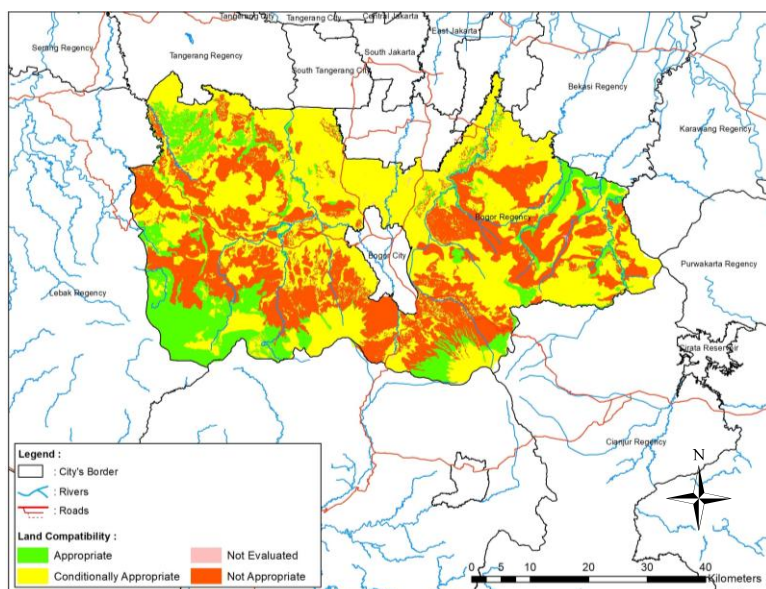


Figure 4. Compatibility of land capability with spatial pattern map.

Table 6 and 7 shows that the analysis results for the entire area of Bogor Regency indicate spatial patterns that are reasonably consistent with land capability. Still, they also suggest the need for specific preliminary treatments in accordance with limiting factors from each class.

Table 6. Summary of limiting factors area for land capability in Bogor Regency.

Limiting factor	Areas	
	Ha	%
DRA, ESD	10,319.2	3.46
ERO	35,068.5	11.76
ERO, BJR	32,005.8	10.73
ERO, ESD	43,692.4	14.65
ERO, SLO	12,567.1	4.21
GR	10,038.5	3.37
ESD	37,672.6	12.63
SLO	85,878.1	28.79
SLO, DRA	30.3	0.01
SLO, GR	8,929.7	2.99
SLO, ESD	5,626.3	1.89
USL, LSL	16,489.1	5.53
Total	298,318.1	100.00

Table 7. The correspondence between land capability and the current land cover, along with spatial arrangements in Bogor Regency.

LCC ¹⁾	Areas (Ha)	PLA ²⁾	KL-PL ³⁾	Areas		PR ⁵⁾	KL-PR ⁶⁾	Areas	
				Ha	% ⁴⁾			Ha	% ⁴⁾
II	26,838.61	LT, FOR	S	12,327.8	45.93	EF, CF, PFR, LPF, PRF, SDA, IZA, WZA, LK, PZA	S	12,875.1	47.97
		STL, PF	CS	8,366.6	31.17	RZA, LUS, MUS, HUS	CS	13,904.6	51.81
		RW, CLO	NA	6,144.1	22.89	Lake	NA	58.7	0.22
III	52,143.72	LT, FOR	S	19,863.8	38.09	EF, CF, PFR, LPF, PRF	S	6,868.6	13.17
		STL, PF	CS	23,844.9	45.73	SDA, IZA, WZA, DZA, PB, RZA, LUS, MUS, HUS	CS	45,169.8	86.63
		RW, CLO	NA	8,434.8	16.18	RP, Lake	NA	105.2	0.20
IV	90,947.22	FOR	S	68,941.5	75.80	CF, PFR	S	7,396.9	8.13
		LT	CS	1,099.3	1.21	EF, LPF, PRF, PD, LUS, MUS, HUS	CS	46,740.1	51.39

LCC ¹⁾	Areas (Ha)	PLA ²⁾	KL-PL ³⁾	Areas		PR ⁵⁾	KL-PR ⁶⁾	Areas			
				Ha	% ⁴⁾			Ha	% ⁴⁾		
V	18,968.26	STL, PF, EF	NS	15,569.6	17.12	SDA, IZA, WZA, DZA, PZA	NS	36,488.5	40.12		
		SP, CLO	NA	5,336.6	5.87	RP, Lake	NA	321.5	0.35		
		FOR	S	18,937.7	99.84	CF	S	864.2	4.56		
		LK	NS	13.4	0.07	EF, LPF, PRF	CS	6,843.9	36.08		
		CLO	NA	17.1	0.09	IZA, WZA, DZA, PZA, RZA, LUS, MUS, HUS	NS	11,241.1	59.26		
						RP, Lake	NA	19.1	0.10		
		VI	76,669.34	FOR	S	64,166.7	83.69	CF, PFR	S	15,447.1	20.15
		LT, STL, PF, EF		NS	6,981.5	9.11	EF, LPF, PRF	CS	15,630.3	20.39	
		RW, CLO		NA	5,521.1	7.20	SDA, IZA, WZA, DZA, PZA, RZA, LUS, MUS, HUS	NS	45,521.1	59.37	
							RP, Lake	NA	70.7	0.09	
VII	32,750.91	FOR	S	27,160.1	82.93	PFR	S	2,307.4	7.05		
		LT, STL, PF, EF	NS	2,149.1	6.56	EF, CF, LPF, PRF	CS	23,746.1	72.51		
		RW, CLO	NA	3,441.6	10.51	SDA, WZA, LK, PZA, RZA, LUS Lake	NS	6,694.3	20.44		
							NA	2.9	0.01		
Total				298,318.06		Total		298,318.06			

¹⁾LLC: Land capability class; ²⁾LUC: Land use cover, LT: Fields/Garden, FOR: Forest, STL: Settlements, PF: Paddy fields, RW: Rivers/water, CLO: Clouds, EF: Empty field; ³⁾LLC-LUC: Compatibility between land capability and actual land cover, S: Suitable, CS: Conditionally suitable, NS: Not suitable, NA: Not assessed; ⁴⁾ Percentage for each land capability class; ⁵⁾SP: Spatial pattern, EF: Enclave forest area, CF: Conservation forest, PFR: Protected forest, LPF: Limited production forest, PRF: Production forest, SDA: Special defense area, IZA: Industrial zoning area, WZA: Wetland zoning area, DZA: Dryland zoning area, PZA: Plantation zoning area, RZA: Rural settlement zoning area, LUS: Low-density urban settlements, MUS: Medium-density urban settlements, HUS: High-density urban settlements, RP: Reservoir planning; ⁶⁾LLC-SP: Compatibility between land capability and spatial patterns in the Regional Spatial Plan, S: Suitable, CS: Conditionally suitable, NS: Not suitable, NA: Not assessed.

Discussion

Class I land capability is land suitable for all types of land use without the need for specific soil maintenance [17,18]. The best land capability class found in Bogor Regency is land capability Class II covering an area of 26,838 ha or 9.00%, and land capability Class III covering an area of 52,143 ha or 17.48% of the total area of Bogor Regency. Based on the analysis of land capability, the land capability in Bogor Regency is predominantly represented by land capability Class IV covering an area of 90,947 ha or 30.49%, and land capability Class VI covering an area of 76.669 ha or 25.70% of the total area of Bogor Regency. Land with land capability Class IV has constraints that limit the types of land use that can be carried out. These constraints require intensive management and maintenance [19]. The use of land in Class IV is very limited due to a combination of limiting factors such as slope, erosion hazards, effective soil depth, and susceptibility to flooding [20–22].

The worst land capability class found in Bogor Regency is land capability Class VII. Land capability Class VII has severe limiting factors, making it unsuitable for human activities. Class VII land can only be left in its natural state without human intervention [23,24]. Land with land capability Class VII covers an area of 32,750 ha or 10.98% of the total area of Bogor Regency.

Land capability is influenced by limiting factors in each class, including upper and lower soil texture, slope, drainage, effective soil depth, gravel/rocks, and flood vulnerability. It is indicate that land requires management and maintenance to improve its capability class [17,22]. Based on the land capability analysis, the limiting factors in the best land capability class are predominantly upper and lower soil texture, covering an area of 16,489 ha, requiring conservation practices like soil loosening to enhance its class. In land capability Class VII, the limiting factor identified is a very high slope class, ranging from 45 to 65% [25–27]. Class VII land cannot be used for any purpose due to extremely limiting factors, as any land utilization may pose risks of massive erosion and flooding in a region. Therefore, land in Class VII should be left in its natural state.

The distribution of land carrying capacity in Bogor Regency can be seen in Figures 3 and 4. The compatibility of land capability with actual land cover and spatial patterns shows significant differences. Through spatial analysis, it's evident that the alignment between land capability and the current land cover is primarily influenced by land capability classes that correspond closely to the actual land cover, covering an area of 211,397.87 ha or 70.86% out of the entire land area of Bogor Regency. Meanwhile, the compatibility of land capability and spatial patterns are primarily characterized by conditionally suitable land capability classes, encompassing a total area of 152,035.08 ha or 50.96%.

The land capability Class II, which is the best class found in Bogor Regency, is allocated quite well, with a compatibility of 45.93% with actual land cover and 47.97% with spatial patterns. Land Class III is predominantly characterized by conditionally suitable compatibility, where soil conservation measures are needed to reduce erosion and flooding [28–30]. Conservation measures for Class III land can include the construction of terraces to minimize the slope level on Class III land [31].

Conclusions

According to the findings of the research analysis, Land capability in Bogor Regency spans from land capability Classes II to VII, with the area primarily marked by land capability Class IV, encompassing 90,947 ha or 30.49%, and land capability Class VI, covering 76,669 ha or 25.70% of Bogor Regency's total area. As for limiting factors in land capability, the dominant factors include slope, covering an area of 85,878 ha or 28.79%, followed by limiting factors such as erosion hazards and effective soil depth, covering an area of 43,692 ha or 14.65% of the Bogor Regency area. Spatial analysis indicates that Bogor Regency demonstrates a notable alignment between land capability and actual land cover, encompassing 211,397.87 ha or 70.86% of its total area. Additionally, the correspondence between land capability and spatial patterns is primarily marked by conditionally suitable regions, spanning 152,035,08 ha or 50.96% of Bogor Regency's total area.

Author Contributions

IA: Conceptualization, Methodology, Software, Writing – Review & Editing; **W:** Writing – Review & Editing; **S:** Writing – Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

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