Sriwijaya Journal of Environment
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Carrying Capacity Analysis for Measuring Land Capability in Arid Area

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Article history

Received	Received in revised form	Accepted	Available online
17 September 2024	15 December 2024	30 December 2024	31 December 2024

Abstract: The study of sustainable development in an area must include environmental carrying capacity (ECC). Measurement of environmental carrying capacity is needed to determine the limits of an area's ability to support individual behavior, such as consumption of natural resources and disposal of waste into nature. This study aims to evaluate the ECC analysis based on land capability in dry areas in East Nusa Tenggara as a contribution to spatial planning strategies. The results of this study show that Timor Tengah Selatan Regency, which is dominated by dry areas, has a land capability classification ranging from class I to III, or as much as 42% of the total area that can be exploited for agricultural and plantation activities. This research can be used as input for the 5-year revision cycle of the Timor Tengah Selatan Regency spatial plan so that land allocation in the RTRW is more in line with the land's carrying capacity.
Keywords: environmental carrying capacity, land capability, arid area, Timor Tengah Selatan Regency

1. Introduction

Optimal environmental carrying capacity is a must to be able to achieve sustainable development goals concerning the carrying capacity of space for economic activities carried out by the community [1]. The carrying capacity analysis ensures that human activities do not exceed the ecosystem's capacity and create environmental damage. The limits of an area's ability to tolerate individual behavior in terms of consuming natural resource products and waste disposal are expressed in terms of environmental carrying capacity. A land capability unit is one of the approaches in environmental carrying capacity analysis based on the type of activity and research environment in an ecological space [2].

The land capability analysis could be carried out by considering factors such as rainfall, soil texture, land slope, and potential for erosion. The concept of land capability is founded on the assumption that each land component has a unique capacity to offer ecosystem services. It further claims that a substantial percentage of this capacity is required to maintain soil and land health, with the remainder potentially accessible for various human enterprises [3]. Even though recent studies have shown that the land capability classification criteria are not limited to previous but consider parent material as one of the land capability classifications [4].

As the Minister of Environment and Forestry's Regulation pointed out, there are eight categories of land capability and land categorization, as shown below.

Table 1. Categorization of Land Capability

Land Category	Capability
I - II	Agricultural
III - VI	Various uses but still can be used for agriculture
VII - VIII	Conservation

Source: Regulation of the Minister of the Environment & Forestry No. 17/ 2009

The calculation of land capacity based on carrying capacity must be performed in relatively arid areas. The arid areas are classified as those dominated by dust storms or desert landforms, with scant vegetation and limited water resources[5]. Knowing the condition of the area allows us to analyze to determine whether the land in the area can still be used for the local population, such as agricultural land, given that extreme weather conditions are currently occurring in every region of Indonesia and the arid area it is feared that it will have a significant influence on land capacity [6].

According to a report from BPS-Statistics of Nusa Tenggara Province [7]. Most of the East Nusa Tenggara region is arid due to minimal rainfall and is classified into two types: (i) The climate in dry places is tropical. The arid tropical climate of East Nusa Tenggara is found in the province's western and central regions. This area records rainfall data of 500-1000 mm annually. This region also has a prolonged dry season, lasting 6-8 months; (ii) The arid subtropical climate. The arid area with a subtropical climate in East Nusa Tenggara is in the province's east. This area receives less rainfall than drier places with tropical climates, averaging 250-500 mm

annually. This region also has a lengthened dry season, lasting 8-10 months.

The main objective of this research is to estimate the carrying capacity of the environment in terms of land capability in dry areas in East Nusa Tenggara province as an effort to contribute to developing regional spatial planning strategies. The research questions we want to try to answer by collecting samples from arid areas on Timor Island, Nusa Tenggara Province, are:

a. Regarding land capability, can arid areas in Timor Tengah Selatan Regency still be used for agricultural areas, or can they no longer be used for agricultural areas?
b. If the land cannot be used for agriculture, what type can be used in the arid area of Timor Tengah Selatan Regency?

2. Material and Methods

2.1. Data Collection and Analysis

There are numerous approaches or methodologies to calculate environmental carrying capacity. Wang et al. [8] their studies entitled "Review of Evaluation on Ecological Carrying Capacity: The Progress and Trend of Methodology" described that there are six sub-categories of ECC methodology: Evaluation Index System (EIS), Ecological Footprint (EF), System Dynamics (SD) method, Decision-Making Optimization (DMO) model, Safety Coefficient (SC) method, and Artificial Intelligence (AI) method. Meanwhile, Subekti & Suroso [2], divided the ECC model into nine sub-categories, which are based on (i) Land Capability; (ii) Land Supply and Demand Ratio; (iii) Water Supply and Demand Ratio; (iv) Graphical Model (Logistic Growth; (v) Uni Constraint Model; (vi) IPAT Equation; (vii) Pressure, State, Response (PSR) Model; (viii) Ecological Footprint; and (ix) Ecosystem Service.

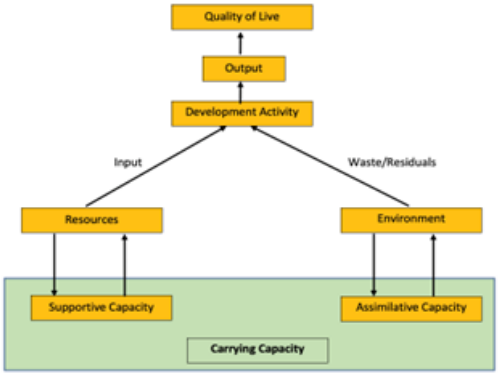

Figure 1. Carrying Capacity
Source: Regulation of the Minister of the Environment Indonesia No.17/2009

In the previous literature discussion, we have identified various models of ECC. This study will adopt land capability analysis to identify ECC in arid areas based on land capability classification. Land capability analysis (LCA) is a tool for determining an area's ECC. LCA is based on the premise that different types of land have varying capacities to support various sorts of human activity. We can establish the greatest degree of human activity that a place may support without producing unacceptable environmental damage by measuring its land capability [9].

According to the Regulation of the Minister of the Environment No.17/2009 about The Environmental Carrying Capacity Determination Guidelines in Spatial Planning, many factors influence a certain area's land capabilities, including soil type, slope, climate, and vegetation. Land capability classification can be grouped into eight (8) classes. The USDA categorization was utilized in this study to classify land capabilities. In order of limitation degree, the categorization system has eight class ranks. Lands classified as Class I-Class IV are suitable for cultivation and other uses, whereas property classified as Class V-Class VIII is generally unsuitable for cultivation. Capability analysis yields three primary categories: capability unit, capability class, and capability subclass. A capability unit is a set of land units with the same land management categories. The capability class divides all land into eight classes based on the risk of soil damage or limiting factors, which increases from Class I to Class VIII. Capability subclasses provide extra information about the capability class's limitations and hazards [3].

The first two classes (class I and class II) are ideal land for agricultural use, and the last two classes (class VII and class VIII) are land that must be protected or used for conservation purposes. Class III to VI can be considered for a variety of additional applications. However, agricultural property in classes III and IV is still accessible to agriculture [10]. Land capability analysis has been widely employed for a variety of reasons around the world, including in Indonesia. In general, land capacity analysis is utilized for preliminary land analysis. Land capability analysis has been used in regional planning, agriculture surveys, plantation surveys, forestry surveys, land usage determination, and land degradation assessment [11]. Land use planners can determine the best use for a certain region and avoid overuse of the land by considering these aspects.

Land Capability Classification is a systematic assessment of land components and grouping them into several categories based on properties potentially constrained in their sustainable use. Land Capability is seen as the capacity of the land itself for a particular type or level of general use [12].

Table 2. Land Capability Class

Land Capability Class	Development Classifications
A	Very Low
B	Low
C	Moderate
D	High
E	Very High

Source: Minister of Public Works Regulation No. 20/PRT/M/2007

Based on the Regulation of the Minister of Public Works No. 20/PRT/M/2007 [13], there are at least 9 indicators of land capability units.

Table 3. Land Capability Unit

No	Land Capability Unit	Indicators									
		Slope	Morphology	Elevation	Soil Type	Altitude	Watershed	Precipitation	Land Use	Land Movement	Earthquake-prone
1	Morphology	■	■								
2	Ease Of Work	■		■	■						
3	Slope Stability	■	■			■					
4	Foundation Stability	■	■		■	■					
5	Water Availability						■	■	■		
6	Drainage	■		■				■			
7	Erosion	■	■		■			■			
8	Waste Disposal	■				■		■	■		
9	Natural Disaster									■	■

Source: Adapted from Wirawan, Kumurur and Warouw [12]

The method used in this study is to analyze the carrying capacity using land capability classification in an arid area, East Nusa Tenggara. The data used in this study came from the Strategic Environmental Assessment (SEA) of the Timor Tengah Selatan Regency, the Regional Spatial Plan Documents of the Timor Tengah Selatan Regency, and other secondary sources such as research reports, regulations, and scientific articles. This study was limited to identifying land capability based on class only due to the limited data and indicators available. Land use, land cover, and mapping data were sourced from technical materials of the Regional Spatial Plan Documents of the Timor Tengah Selatan Regency and analyzed using ArcGIS 10.8 (data analysis) & ArcGIS Pro 3 (layout) software.

2.2. Study Area

This study was conducted in Timor Tengah Selatan Regency, East Nusa Tenggara, Indonesia. As a key part of the island of Timor, Timor Tengah Selatan Regency is located between 9°28' to 10°10' South Latitude and 124°4'00" to 124°49'0" East Longitude. Topographical conditions in the Timor Tengah Selatan Regency include mountainous areas, highlands, and lowlands, including coastal areas.

3. Results and Discussion

Land characteristics in dry climates could be categorized into several types: soil characteristics, vegetation, water resources, and landforms. Arid terrain with a dry climate is commonly characterized as an expanse of land that is never inundated or water-logged for most of the year, with rainfall of 2,000 mm/year and dry months of more than seven months (< 100 mm/month) [14]. According to Mulyani, Nursyamsi, & Irsal [15], in East Nusa Tenggara, the soil characteristics with sediment and volcanoes are the parent materials with the greatest spread, reducing the dominating soil of Inceptisols (Haplustepts) connected with Alfisols (Haplustalfs) and Entisols (Ustortherts) to around 2.1 million hectares.

The features and plant kinds can also identify land characteristics in arid areas. For example, Xu et al. [16] described a kind of plant that can live in a dry climate area. "Populus Euphratica" and other plants in dry areas have a significant ability to adapt to drought and salinity. Still, seedlings lack these advantages and require adequate water and salt. Many herbaceous plants seem the same. After decades or even hundreds of years of natural selection in desert environments, perennial herbaceous plants can live longer due to the unique potential of experiencing wet years.

Due to high temperatures and low humidity, evaporation rates in drylands are frequently higher than precipitation rates. This indicates that there is a net loss of water from the ground surface, decreasing the amount of water available for plant development and other processes [17]. Arid areas with dry humidity levels require substantial attention, particularly those linked to water sources and management because water availability is limited. Heavy rains are the key limiting factor. As a result, it stands to reason that those arid, dry temperatures are associated with enclaves of poverty and food insecurity, particularly in East Nusa Tenggara [15].

Based on Law 32/2009, Environmental Support Capacity (DDLH) is defined as the ability of environmental space to support human activities and other living things to create environmental balance. Some of the potential carrying capacity of the environment in Timor Tengah Selatan Regency include:

3.1. Land Capability

Land use is the dominant function that appears or is assigned to an area. Land use in Timor Tengah Selatan Regency is shown below:

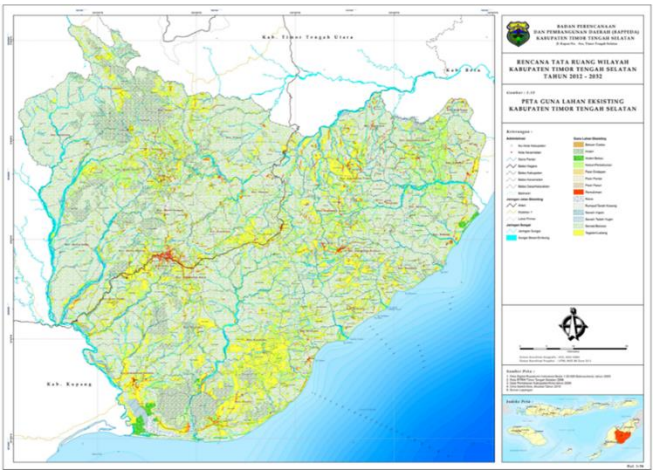

Figure 2. Existing Land Use Timor Tengah Selatan Regency
Source: RTRW Timor Tengah Selatan Regency 2012 – 2032

Land use in Timor Tengah Selatan Regency is dominated by dry forests spread throughout the area. The land use map is the result of an analysis that shows the location of the distribution of various types of land use in the Timor Tengah Selatan Regency area, including settlements, plantations, moorlands, forests, and rice fields. Details, types of land use, area, and percentage of land area can be seen in:

Table 4. Land Use in Timor Tengah Selatan

Land Use Type	Area (Ha)	Percentage of Land Area (%)
Residential Area	7,208.37	1.8
Plantations	18,965.17	4.75
Farm	58,510.07	14.64
Forest	36,174.96	9.05
Mangrove Forest	1,667.77	0.42
Irrigated rice fields	2,548.55	0.64
Rainfed rice fields	918.73	0,23
Swamp	951.79	0,24
River/lake	6,790.61	1,7
Sediment	35.56	0,01
Beach Sand	37.56	0,01
Tidal Sand	0.09	0,00
Schist	192.26	0,05
Grass	14,679.57	3,67
Shrub	250,883.80	62,79
Total	**399,564.30**	**100**

Source: Regional Spatial Planning Plan Timor Tengah Regency, 2018

The data in Table 4 shows that the most significant type of land use is moor/field covering 58,510.07 Ha (14.64%), followed by forest area covering 36,174.96 Ha (9.05%), and plantation covering 18,965.17 Ha (4.75%). After analysis, it is known that the land that has been used only covers 132,784.20 Ha (33.23%) of the land use area, while most of those are still shrubs with an area of 250,883.80 Ha (62.79%) and grass/empty land covering 14,679.57 Ha (3.67%).

In the report on carrying capacity and environmental capacity in different locations [18], it is stated that the potential decline in productivity due to poorly managed land use or excessive intensification needs to be the main focus to avoid land degradation that can be detrimental to long-term food security.

3.2. Food Carrying Capacity

The term "carrying capacity" comes from ecology and refers to the most significant number of species that may survive in any natural environment [19]. The concept of Environmental Carrying Capacity (ECC) is the optimum ability of a country's or region's ecological system to enable economic and social development in a given time [20]. Although it is a complex concept, the environmental carrying capacity is crucial to comprehending how human activity affects the environment.

The potential carrying capacity in Timor Tengah Selatan Regency relies on corn commodities with a land area of 79,033 ha. At the same time, the total rice production (paddy and field rice) of the Timor Tengah Selatan Regency in 2017 reached 20,754 tons from the harvest area. The harvest area for cassava commodities was 7,341 ha, followed by sweet potatoes, peanuts, green beans, and soybean commodities, with a production level of 65 tons/year. The total need for rice equivalent food to meet the needs of the Timor Tengah Selatan population is 57,533.52 tons/year, so the amount of food carrying capacity is 2.30. It can be concluded that Timor Tengah Selatan Regency is statistically capable of food self-sufficiency. Still, on the other hand, it has not been able to realize a decent livelihood for the local community.

This aligns with research from Wijaya et al. [21], which addresses the evaluation of land use sustainability and how it supports the food sector, especially agriculture, given the environmental conditions that are vulnerable to degradation. In addition, on Timor Island, there have been reports of reliance on food imported from outside the region, such as rice and instant noodles, indicating problems with limited local food-carrying capacity [22]This is also a concern for areas that rely on agricultural land to meet their food needs, which is closely linked to sustainable land management and utilization.

3.3. Land Capability Unit Spatial Analysis

Each land capability unit has various levels ranging from high to low based on the calculation of each indicator used. The following is the proportion of area for each class:

Table 5. Land Use in Timor Tengah Selatan Regency

Level	Morphology (%)	Ease Of Work (%)	Slope Stability (%)	Foundation Stability (%)	Water Availability (%)	Erosion (%)	Drainage (%)	Waste Disposal (%)	Natural Disaster (%)
High	12.08	77.74	10.61	22.41	26.74	0.01	51.08	0.001	25.36
Sufficient	40.80	-	33.01	37.38	41.58	46.00	48.92	1.54	-
Moderate	41.60	22.25	37.17	38.65	29.61	-	-	13.48	36.43
Less	5.35	0.01	17.68	1.57	2.07	53.99	0.001	33.52	-
Low	0.17	-	1.53	0.0004	-	-	-	51.46	38.21
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Source: Analysis, 2023

The following unit calculations are based on Table 3 with spatial analysis using ArcGIS 10.8 software.

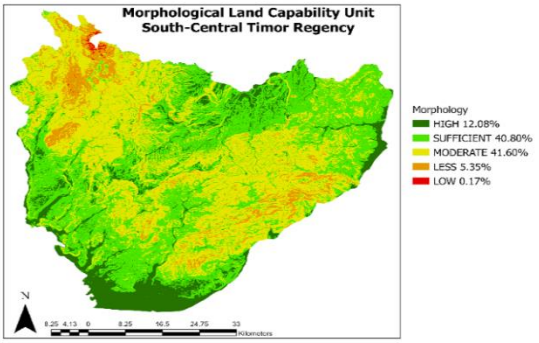

Figure 3. Morphological Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

Morphology refers to the shape of the land surface, such as plains, hills, or mountains. It determines the ability of land to support certain activities, such as agriculture, settlement, or industry. The overlay will integrate morphological layers to identify areas suitable for specific land uses. The indicators used to formulate

this unit are Slope and Morphology. The analysis results in a dominance of land classes with moderate and sufficient values of 41.60% and 40.80%, respectively.

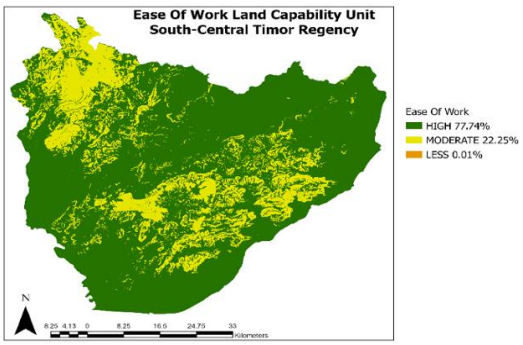

Figure 4. Ease of Work Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

This factor includes the extent to which the land can be worked using existing technology or tools. For example, hard or rocky land may be more challenging to cultivate, while flatter and more fertile land is easier to work on. In an overlay analysis, this becomes important for determining the potential of land for agriculture or development. The indicators for this unit are Slope, Elevation, and Soil Type. This unit has a dominant high-class value, with more than 2/3 coverage.

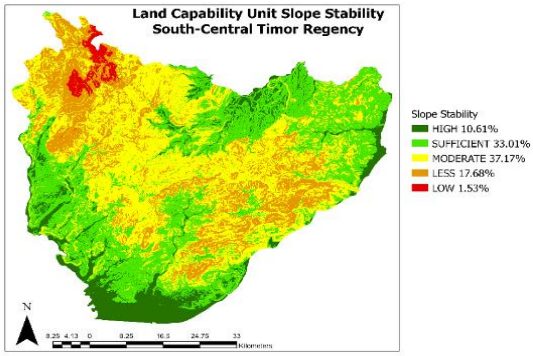

Figure 5. Slope Stability Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

The slope of land affects its stability and susceptibility to erosion. Land with slopes greater than 15% tends to be more susceptible to erosion and unsuitable for some types of agriculture or development. Overlaying slope stability with other factors helps determine whether land use can occur without causing degradation. The indicators for this unit are Slope, Morphology, and Altitude. The map shows that 37.17% of the moderate values are in the central region. Variations in the periphery areas, such as the northern region, are considered low. Meanwhile, the western region, which borders Kupang Regency, is rated high.

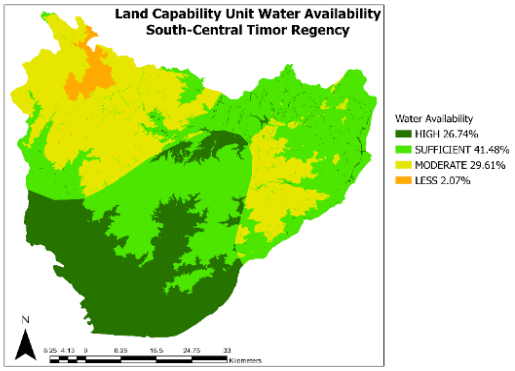

Figure 6. Water Availability Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

Watershed, Precipitation, and Land Use indicate water availability in the land capability unit. Timor Tengah Selatan Regency is predominantly at a sufficient level at 41.48%, with a high level in the western part and a moderate to low level in the northern part. Water availability is an essential factor in agriculture and settlement. In the overlay, the layer depicting water resources will help identify areas that can be used for agricultural activities or urban development.

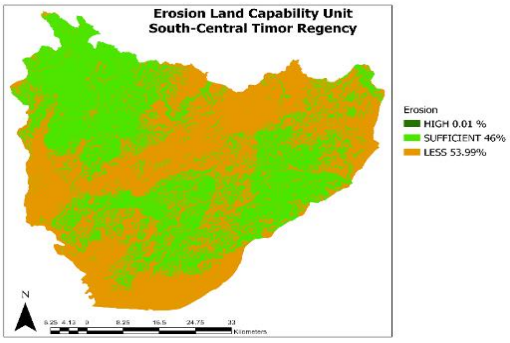

Figure 7. Erosion Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

Erosion indicators are formed by slope, morphology, soil type, and precipitation. Less level covers more than half of the area, meaning that the erosion level in TTS Regency is fairly well managed. Land's erosion potential significantly affects its ability to support agriculture and other land uses. By overlaying erosion data, areas prone to erosion can be seen and need careful protection or management.

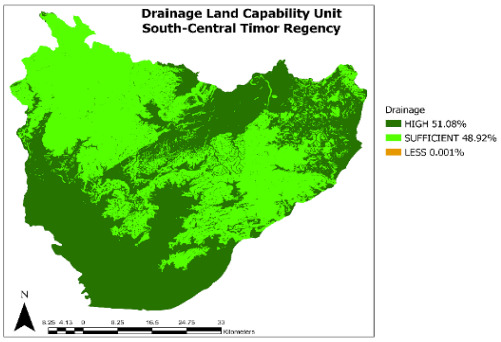

Figure 8. Drainage Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

Drainage-forming factors are assessed using slope, elevation, and precipitation indicators. The area in TTS Regency is quite good, with an almost equal proportion of high and sufficient levels. Land with poor drainage can cause flooding problems and damage to building structures or crops. This drainage overlay is vital for mapping areas requiring special development or agricultural planning attention.

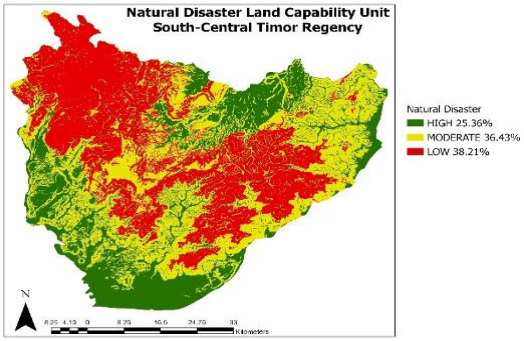

Figure 9. Natural Disaster Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

The land overlay must consider natural disasters such as earthquakes, landslides, and floods. Mapping disaster-prone areas helps in safe land use planning.

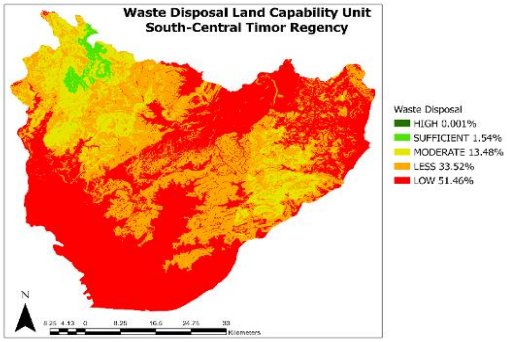

Figure 10. Waste Disposal Land Capability Unit in Timor Tengah Selatan Regency
Source: Analysis, 2023

Waste Disposal indicators are derived from Slope, Altitude, Precipitation, and Land Use. The map shows that low levels cover the majority of areas. This indicates that Timor Tengah Selatan Regency can properly manage waste generated by households and industries. Waste management, both solid and liquid, also affects the carrying capacity of the land. This overlay helps ensure that land used for industrial or residential activities has proper waste disposal systems to maintain environmental quality.

The seven analyzed Land Capability Units will become a mapping that provides a complete picture of land capability in Timor Tengah Selatan Regency and its impact on environmental quality [23], [24]. Permen PU No. 20/PRT/M/2007 examines land capability classification according to its designation. At the same time, Permen LH No. 17/2009 emphasizes the assessment of the ecological impact of land use based on the seven indicators that have been analyzed spatially.

3.4. Land Capability Analysis

LCA was conducted by overlaying/intersecting the nine (9) LC maps analyzed previously to obtain a total weighted value derived from the score multiplied by the weighted value from Regulation No. 20/PRT/M/2007.

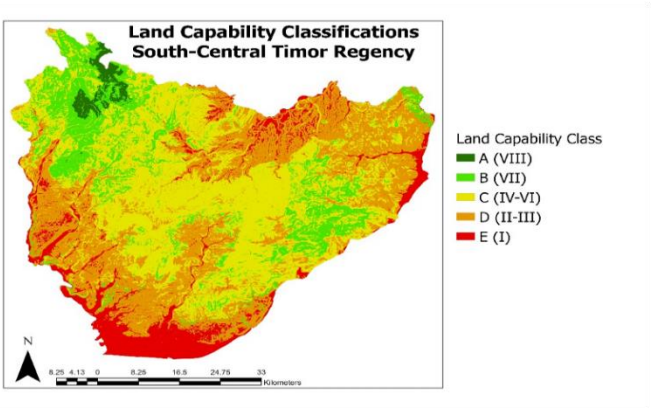

Figure 11. Land Capability Classifications in Timor Tengah Selatan Regency
Source: Analysis, 2023

Below is a description of the final results of the land capability classification in Timor Tengah Selatan Regency.

Table 6. Land Capability Class & Development Classifications in Timor Tengah Selatan Regency

Total Weighted Value	Land Capability Class		Development Classifications	Area (Ha)	%
	Regulation No 20/PRT/M/2007	Regulation No 17/2009			
48 - 70	A	VIII	Very Low	6,079.99	1.54
71 - 92	B	VII	Low	59,310.60	15.00
93 -114	C	IV - VI	Moderate	159,052.10	40.24
115 - 136	D	II-III	High	128,898.52	32.61
137 - 160	E	I	Very High	41,936.17	10.61
	TOTAL			**395,277.38**	**100.00**

Source: Analysis, 2023

The Regulation of the Minister of Public Works No. 20/PRT/M/2007 [13] classified land into five classes, including:

a. Classes A & B are lands included in protected/conservation areas, so they must be preserved. This is why their development classifications are low and very low, with a development intensity of 0%.
b. Class C is land included in the buffer zone, has conditions for its use, and is suitable for agriculture and plantations with a maximum development intensity of 20%.
c. Class D & E is land included in the development area and the cultivation zone with a maximum development intensity between 50-70%.

Meanwhile, in the Regulation of the Minister of Environment No. 17/2009 [10], the land is classified into eight classes, including:

a. Class I & II are lands suitable for agricultural land use (annual and perennial crops)
b. Classes III-VI can be considered for other uses (cultivation zones) or can also be used for agricultural/plantation land use
c. Class VII & VIII are lands that must be protected/have a conservation function (grasslands, trees, and natural vegetation)

After Land Capability analysis, it was found that although Timor Island's characteristics are arid, identified by the limited productivity of rice fields, no rivers flowing throughout the year to irrigate rice fields, minimal rainfall, and water volume in local dams [22], most of the Timor Tengah Selatan Regency area occupies a buffer zone suitable for agriculture and plantation activities at 40.24%.

However, this is not necessarily a positive thing because a report from the Rainforest Journalism Fund [22] confirmed that the condition of Food Carrying Capacity in Timor Tengah Selatan Regency has experienced a crisis due to a shift in staple food consumption from corn & tubers to rice. Dependence on rice has become a dilemma because the natural conditions of NTT do not optimally support rice production to meet local food needs. Access to rice is limited, causing children to no longer recognize local foods such as corn and tubers. They prefer instant noodles, biscuits, and rice [25], [26]

4. Conclusion

Land capability analysis has been widely employed around the world for a variety of reasons. The calculation of land capacity based on carrying capacity must be performed in relatively arid areas to find out if the arid area is still possible for agricultural activities. From this study, it can be concluded that the Timor Tengah Selatan Regency, which is dominated by arid areas, has land capability classifications ranging from class I to class III, or as much as 42% of the total area that may be exploited for agriculture and plantation activities. Water availability and drainage limit land capacity in the Timor Tengah Selatan Regency. The most prevalent land uses are shrubs, farmland, woods, and plantations. Meanwhile, land use for residential areas accounts for only 1.8% of the entire area of Timor Tengah Selatan Regency. This research can be applied as input for the 5-year revision cycle of the Timor Tengah Selatan Regency spatial plan so that land areas in the spatial plan align with the land's carrying capacity.

Therefore, it can be concluded that the land capability in TTS can still be analytically capable of supporting agricultural and plantation activities in fulfilling local food needs. Still, the main factor of climate and weather change in NTT Province causes a high dependence on food supply from outside the region, and the lack of water availability has caused local conflicts related to access to water [27]. The high level of mining activity in TTS also impacts agricultural and plantation productivity through groundwater pollution [28].

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