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Environmental Carrying Capacity for Spatial Planning of Lemo Sub-Watershed, North Barito Regency, Central Kalimantan, Indonesia

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Abstract: Environmental carrying capacity is frequently used to describe environmental resilience against natural resource utilization. The Lemo Sub-watershed (DAS) in North Barito Regency, Indonesia, is highly vulnerable to pressure from businesses and activities using the natural resources in coal mining, forestry, and plantations. The objective of this study was to quantify the environmental carrying capacity of the Lemo sub-watershed based on the land and water capacity. The status of environmental carrying capacity obtained in this study would then be employed to develop regional spatial planning policies to protect and manage the environment in the watershed. The land capability was determined using a spatial method based on geographic information systems. The land carrying capacity was measured using total local commodity production data and decent living needs. Furthermore, water availability was obtained using the coefficient of land use runoff and annual rainfall data. In contrast, the water demand was calculated from the conversion results to the needs for a decent living. The spatial analysis results showed that the Lemo sub-watershed with 54,810 ha has 8 land capability classes. The suitability evaluation showed a mismatch between land use and land capability, where 6.68% of the Lemo sub-watershed area was not suitable for the spatial pattern plan of the regency (SPPR), 45.65% was not in line with the SPPR outline policy. The land carrying capacity status showed a deficit, where the land requirement was 43,484 ha compared to land availability based on the total agricultural commodity production with an area of 6,765 ha. However, the status of the Lemo sub-watershed carrying capacity becomes a surplus when the land availability refers to the North Barito Regency SPPRSP Map with a 53,005 ha for cultivation areas. Results of the study imply it is still possible to utilize natural resources in the Lemo sub-watershed further.

Keywords: spatial planning, land capability, land carrying capacity, water carrying capacity.

印度尼西亚中加里曼丹省北巴里托摄政区莱莫子流域空间规划的环境承载能力

摘要：环境承载能力经常被用来描述环境对自然资源利用的恢复力。印度尼西亚北巴里托摄政区的莱莫子流域极易受到来自利用煤矿、林业和种植园自然资源的企业和活动的压力。本研究的目的是根据土地和水的容量来量化莱莫子流域的环境承载能力。本研究获得的环境承载能力状况将用于制定区域空间规划政策，以保护和管理流域环境。利用基于地理信息系统的空间方法确定土地容量。土地承载能力是使用当地商品生产总量数据和体面生活需求来衡量的。此外，利用土地利用径流系数和年降雨量数据获得了可用水量。相比之下，需水量是从转换结果到体面生活需要的结果中计算出来的。空间分析结果表明，54810 公顷的勒

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莫子流域有 8 个土地能力等级。适宜性评价显示土地利用与土地能力不匹配，其中 6.68%的勒莫子流域面积不适合摄政区空间格局规划，45.65%不符合摄政区规划空间格局规划政策。土地承载能力状况显示不足，土地需求为 43,484 公顷，而以农业商品总产量为基础的土地可用面积为 6,765 公顷。然而，当可用土地参考北巴里托摄政区摄政空间格局规划地图时，莱莫子流域的承载能力状态变为过剩，其中种植面积为 53,005 公顷。研究结果表明，仍有可能进一步利用莱莫子流域的自然资源。

关键词：空间规划、土地承载力、土地承载力、水承载力。

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1. Introduction

The reduced availability of natural resources, biodiversity loss, land degradation, pollution, high population growth, and migration to cities are socio-environmental problems facing humanity. The solution offered to overcome the challenges is using spatial economic concepts through a combination of spatial policies, spatial and land management, and spatial planning with land protection [1, 2]. In Indonesia, North Barito Regency, Central Kalimantan Province, has considerable economic potential in the forest resources sector, mineral, and coal mining. As a result, the Mining and Quarrying Business Sector was the largest contributor to the regency's Gross Regional Domestic Product (GRDP) of the regency in 2020 at 32.52%, followed by the Agriculture, Forestry, and Fisheries Business Sector at 11.84% [3]. Moreover, the Lemo sub-watershed is part of the Barito watershed in the North Barito Regency. Therefore, the area has been widely used for its natural resources, making it highly vulnerable to changes due to pressure from these businesses and activities.

The environmental carrying capacity of an area is an important factor to consider when implementing a sustainable development process [4, 5]. Meanwhile, sustainable development is characterized by a land quality that provides a decent life for the population without reducing the quality of the environment. An increase in land productivity is one of the indicators of successful environmental management, followed by growth in community welfare [6, 7]. Therefore, the preparation of environmental protection and management programs for the Lemo sub-watershed area is needed to sustain its function as a provider of environmental services. That must be in line with the carrying and bearing capacity, divided into land and water [8-10] for humans to benefit from the watershed ecosystem. These protection and management efforts include spatial planning through the determination of detailed spatial plans in the area based on the carrying capacity of the environment [11, 12].

Environmental carrying capacity measures the relationship between human socio-economic activities and the environment to measure and manage sustainable development [13]. Environmental carrying capacity leads to comparison and balance between supply and demand [14, 15]. The environmental carrying capacity is determined by knowing the capacity of the natural environment and resources to support human/population activities [16]. Meanwhile, it is influenced by the condition and characteristics of the resources in the relevant expanse of space. That leads to limiting the determination of the appropriate use of space.

According to the Indonesian Ministry of Environment [17], the guidelines for determining the carrying capacity of the environment are based on (1) land capacity for spatial use allocation, (2) comparison between land availability and demand, as well as (3) comparison between water availability and demand. Previous studies determined the environmental carrying capacity using an analytical approach to land capability and land and water carrying capacities [18-20]. Therefore, this study aims to determine the environmental carrying capacity of the Lemo sub-watershed and evaluate the suitability of land use with capabilities in the North Barito Regency Spatial Planning (SPPRSP) 2019-2039. The results are expected to be used as the basis for preparing plans for using natural resources and space by determining the function of the Lemo sub-watershed area with regional regulations for detailed spatial plans.

2. Methods/Materials

2.1. Study Site

This study was conducted in the Lemo sub-watershed with 54,810 ha, where the Lemo River hydrological system forms the Lemo Watershed (DAS) system. As the main contributor to the watershed hydrological system, Lemo River has 24 tributaries, including 9 rivers, namely Kelampusan, Sekako, Mosak, Nango, Tehey, Usi, Sepayang, and Bondan. The Lemo sub-watershed covers the Central Teweh and South Teweh sub-districts (Fig. 1). Based on the results of the 2020 population census, the population in

Central Teweh Sub-district is 58,308 people, while are 15,269 in the South Teweh Sub-district [21].

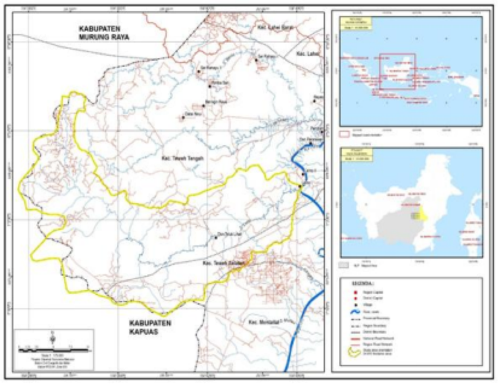

Fig. 1 Study area orientation map

According to the Schmidt–Ferguson climate classification, the study area has a climate type D or a temperate region. On the other hand, based on the Oldeman classification system, it has a wet climate type. The highest rainfall data for 2009-2018 was obtained in December 2009 at 638 mm, while the lowest rainfall was observed in September 2015 at 6 mm. Meanwhile, the highest monthly rainy days for 28 days occurred in December 2011, February 2016, and November 2017, while the lowest was observed in September 2009 and 2015 with 2 rainy days.

The type of soil in the Lemo sub-watershed is dominated by Ultisols, with sandstone and shale deposits as the parent materials. The bulk density of the soil ranged from 1.10–1.63 g cm−3 with a slab to granular soil structure, while the soil consistency ranged from non-sticky to sticky. Generally, the soil is clay textured with an average sand content of 41.49%, 41.00% silt, and 17.51% clay. The study area mostly has a flat topography with a slope of <2%, followed by a sloping/hilly topography with a slope of 16-25%, while <1% has a very steep hilly topography (> 40%). It is located at an altitude of 50-75 meters above sea level (asl).

2.2. Land Capability Classes

Spatial analysis was carried out by overlaying several maps, namely slope, soil, erosion, and drainage/inundation, to determine the land capacity class of the study area. The Indonesian Ministry of Environment [17] classifies land into eight classes. Moreover, classes I and II are land suitable for agricultural use, and classes III to VI are for various other purposes. In contrast, classes VII and VIII are lands that need to be protected or for conservation functions.

Subsequently, the land capability class from the spatial analysis is overlaid with a land-use map in the RTRWK spatial pattern plan to evaluate land-use suitability with land capability. Finally, the evaluation is carried out by considering the actual land use or spatial pattern, limiting factors, and land capability class [22, 23].

Table 1 Land capability class level of Lemo sub-watershed

No.	Class	Function	Areas (ha)
1.	I	Agriculture (annual crops, grass crops, forests, and nature reserves)	2,427.69
2.	II	Agriculture (seasonal crops, grass crops, pastures, production forests, protected forests, and nature reserves)	20,170.22
3.	III	Agriculture (seasonal plants, plants that require tillage, grass plants, grasslands, production forests, protected forests, and nature reserves) and non-agriculture	26,573.75
4.	IV	Agriculture (seasonal crops, grass crops, production forests, pastures, protected forests, and nature reserves) and non-agriculture	2,216.15
5.	V	Agriculture (grass crops, pastures, production forests, protected forests, and nature reserves) and non-agriculture	348.25
6.	VI	Agriculture (grass crops, pastures, production forests, protected forests, and nature reserves) and non-agriculture	2,193.66
7.	VII	Meadow and production forest	91.13
8.	VIII	Meadow, nature recreation, nature reserve	789.14
Total areas			54,810.00

2.3. Analysis of Land Availability and Demand

The determination of the status of the carrying capacity of the land was obtained from a comparison between land availability (SL) and land demand (DL) based on criteria from the Indonesian Ministry of Environment [17], which include:

- $S_L > D_L$, the carrying capacity of the land is declared surplus.
- $S_L < D_L$, the land's carrying capacity is declared in deficit or exceeded.

Land availability was calculated using Equation 1 as stated below:

$$S_L = (\Sigma(P_i \times H_i)/Hb) \times (1/Ptv_b) \quad (1)$$

Where S_L is the availability of land (ha), and P_i is the actual production of each commodity (the units depend on the type of commodity). Commodities considered include agriculture, plantations, forestry, livestock, and fisheries. H_i is the unit price of each type of commodity (IDR unit^{-1}) at the producer level, Hb is the unit price of rice (IDR unit^{-1}) at the producer level, Ptv_b is rice productivity (kg ha^{-1}).

Land demand was calculated using Equation 2 as stated below:

$$D_L = N \times KHL_L \quad (2)$$

where D_L is the total need for land equivalent to rice (ha), *and* N is the total population (people). KHL_L is the area of land required for decent living needs per population divided by local rice productivity, which is assumed to be 1 ton of rice equivalent per capita^{-1} year^{-1}.

2.4. Analysis of Water Availability and Demand

The status of the carrying capacity of water was from the comparison between water availability (S_A) and water demand (D_A), namely:

- $S_A > D_A$, the water carrying capacity is declared surplus.
- $S_A < D_A$, the water carrying capacity is declared in deficit or exceeded.

Water availability was calculated using the Runoff Coefficient Method modified from the rational approach [24, 25]:

$$C = \Sigma(C_i \times A_i)/\Sigma A_i \quad (3)$$

$$R = \Sigma R_i/m \quad (4)$$

$$S_A = 10 \times C \times R \times A \quad (5)$$

where S_A is water availability (m^3 year^{-1}), C is the weighted runoff coefficient; C_i is the runoff coefficient for land use [24]; A_i is the land-use area i (ha). R is the area's average annual rainfall (mm year^{-1}), R_i is the annual rainfall at station i, m is the number of rainfall observation stations, A is the area (ha), and 10 is the conversion factor from mm ha to m^3.

Water demand was calculated using Equation 6 as stated below:

$$D_A = N \times KHL_A \quad (6)$$

where D_A is the total water demand (m^3 year^{-1}), N is the total population (people), KHL_A is the water requirement for a decent life, 1,600 m^3 of water capita^{-1} year^{-1} [17].

3. Results and Discussion

3.1. Land Capability for Space Use Allocation

The overlay results of maps, including slope, soil, erosion, and drainage/inundation maps, showed the land capability class of the study area (Table 1). The spatial analysis indicated that the allocation of space or land use in line with land capability is for agriculture, which must be protected and used for other purposes. The largest land area is in Class III, covering an area of 26,574 ha, while the smallest was observed in Class VII, with 91 ha. The area with a Class II land capacity of 20,170 ha and Class III of 26,574 ha with an agricultural area designation allows the Lemo sub-watershed to become a center for agricultural and food crop production in the spatial pattern policy revision.

Land use with Class III as an agricultural area requires intensive soil management and conservation measures to avoid degradation in quality [26]. Meanwhile, the limiting factors on Class III land to be developed into agricultural areas include high erosion rates, stunted root growth, and relatively steep slopes. Land units with erosion and slope limiting factors, when used for agricultural cultivation, require soil conservation measures such as making terraces [27], planting in strips [28], and using mulch [29]. Barriers to the distribution of rocks on the soil surface that inhibit the development of plant roots can be overcome by developing planting methods with intensive silvicultural patterns [30]. It indicates that relatively great efforts and costs are required to develop Class III land into agricultural areas.

3.2. Land Use of Lemo Sub-Watershed

The regional spatial pattern plan is a source of land use data or land use plans in a regional space. For example, the land-use plan of the Lemo sub-watershed is an overlapping map with Basic Geospatial Information (BGI), Thematic Geospatial Information data on RTRWK Technical Materials, and North Barito Year 2019-2039 [31]. The land use and its area plan for the Lemo sub-watershed are shown in Table 2.

Table 2 Land use and land use plan for Lemo sub-watershed

No.	Designation	Order I	Order II	Areas (ha)	Type of Spatial Designation System
1.	Plantation	Agricultural area	Plantation area	2,463.85	Cultivation designated area
2.	Rural settlement	Residential area	Residential area	5.50	Cultivation designated area
3.	Crops	Agricultural area	Food crops area	265.02	Cultivation designated area
4.	River	Local protected area	Waters	93.21	Protected area
5.	River border	Local protected area	River border	45.54	Protected area
6.	Nature reserve and nature conservation areas	Conservation areas	Nature reserve area/nature reserve	1,665.93	Protected area
7.	Conversion production forest	Production forest area	Convertible production forest Area	1,030.03	Cultivation designated area
8.	Permanent production forest	Production forest area	Permanent production forest area	49,240.92	Cultivation designated area
Total areas				54,810.00	

Based on the spatial pattern and land use plan in the study area, two designations were discovered: the cultivation area of 53,005 ha and a protected area of 1,805 ha (Table 2). Meanwhile, areas designated for cultivation include plantations, settlements/rural areas, food crops, permanent production forests, and conversion production forests. Protected areas include nature and conservation/nature reserves, rivers, and river borders.

3.3. The Suitability of the Lemo Sub-Watershed Space

The suitability of land capability with land use or land use plans of the Lemo sub-watershed with the spatial pattern plan of the North Barito RTRWK was evaluated by overlaying the land capability map of the Lemo sub-watershed with the 2019-2039 North Barito RTRWK map. The results showed a mismatch between land use and land capability in several segments of the Lemo sub-watershed. The land use not in line with the land capacity was 3,661 ha (6.68%), while 51,149 ha (93.32%) was in line with the land capacity. Therefore, land use for cultivation or other activities for biomass production must be adjusted to the capabilities and characteristics of the land. That may result in land degradation [32, 33] and threaten sustainable agriculture [34]. The map of the suitability of land capability to the spatial pattern plan of the North Barito RTRWK is shown in Fig. 2.

3.4. Land Carrying Capacity

The actual production data of 20 local commodities from North Barito Regency agricultural services showed that the total production value ($\sum(P_i \times H_i)$) for Central and South Teweh Districts is IDR 114,528,425,000. It has the unit price of rice at the producer level (Hi) is IDR 10,000 kg^{-1}, and rice productivity (Ptv_b) is 1,693 kg ha^{-1} (Table 3). Based on these data, the land availability (S_L) in the Lemo sub-watershed calculated using Eq. 1 gave 6,765 ha. However, the available land for cultivation is 53,005 ha based on the land use map of the North Barito RTRWK (Table 2).

Table 3 Total production values

No.	Commodity	Production (P_i kg)		Price per unit IDR kg^{-1} (H_i)	Production Values (P_i x H_i IDR)	
		Central Teweh Sub-district	South Teweh Sub-district		Central Teweh Sub-district	South Teweh Sub-district
1.	Paddy	2,132,000	582,000	4,150	8,847,800,000	2,415,300,000
2.	Corn	4,302,000	143,000	3,200	13,766,400,000	457,600,000
3.	Cassava	4,000	11,000	2,500	10,000,000	27,500,000
4.	Rubber	5,117,420	938,070	6,000	30,704,520,000	5,628,420,000
5.	Palm oil	973,390	1,463,710	1,250	1,216,737,500	1,829,637,500
6.	Cocoa	21,130	5,250	30,000	633,900,000	157,500,000
7.	Coconut	10,580	8,050	3,000	31,740,000	24,150,000
8.	Pepper	0	40	80,000	-	3,200,000
9.	Candlenut	0	900	3,000	-	2,700,000
10.	Cow	144,722	14,021	100,000	14,472,200,000	1,402,100,000
11.	Buffalo	1,625	0	90,000	146,250,000	-
12.	Goat	6,869	1,050	150,000	1,030,350,000	157,500,000
13.	Pig	21,142	13,501	90,000	1,902,780,000	1,215,090,000
14.	Laying Chicken	2,057	391	35,000	71,995,000	13,685,000
15.	Broilers	659,969	104,808	30,000	19,799,070,000	3,144,240,000
16.	Free-range Chicken	20,122	13,074	60,000	1,207,320,000	784,440,000
17.	Duck	1,234	793	60,000	74,040,000	47,580,000
18.	Race Eggs	130,819	8,678	20,000	2,616,380,000	173,560,000
19.	Free Eggs	4,136	5,780	40,000	165,440,000	231,200,000
20.	Duck Eggs	1,991	1,879	30,000	59,730,000	56,370,000
Subtotal					96,756,652,500	17,771,772,500
Total production values					114,528,425,000	

Total land demand (D_L) is obtained by multiplying the population (N) with the area of land needed for a decent living requirement per resident (KHL_L) and is calculated using Eq. 2. The total population of Central and South Teweh Sub-districts is 73,577 people. Assuming KHL_L is 1,000 kg person1 year^{-1}: 1,693 kg ha^{-1} year^{-1} = 0.591 ha person^{-1}, the total land requirement (D_L) in the Lemo sub-watershed is 43,484 ha. The status of the carrying capacity of the land is determined from a comparison between land availability (S_L) and land demand (D_L), where S_L (6,764.82 ha) < D_L (43,484 ha), which showed that the carrying capacity of land in the Lemo sub-watershed is declared in deficit or exceeded.

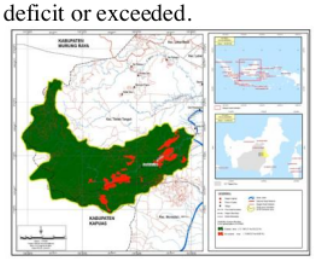

Fig. 2 Suitability of land capability to spatial patterns RTRWK

That is because the food crop agriculture is not the main sector contributing to the gross domestic, regional product (GDRP) for North Barito Regency [3]. It has implications for low agricultural production at the district level, causing land availability to be inconsistent with real conditions in the field and the calculation of the land's carrying capacity to be in deficit. The use of local agricultural production data to calculate land availability for environmental carrying capacity is weak when the agricultural sector is not the main contributor to the GDRP. Several studies have suggested that the calculation of land availability based on actual local production can be replaced with space allocation data. That is carried out according to the RTRWK that the local government determined to calculate land carrying capacity [31, 35]. The results of the analysis showed that the allocation of the availability of the cultivated area on the land use map or land use plan of the North Barito RTRWK is 53,005 ha. When the comparison between land availability and land demand refers to the availability of cultivated area land according to the North Barito

RTRWK, the status of the land carrying capacity of Lemo sub-watershed, namely S_L (53,005) ha > D_L (43,484 ha), is declared surplus.

3.5 Water Carrying Capacity

Water availability is determined by the runoff coefficient method based on land cover or land use information and annual rainfall data. The runoff coefficient from land cover or land use data in the Lemo sub-watershed refers to the runoff coefficient and C_i [24, 25]. The results of the weighted runoff coefficient calculation are shown in Table 4.

Due to a weighted runoff coefficient of 0.08, an average annual rainfall of 3,246.70 mm year^{-1} [21], and an area of 54,810.00 ha, the water availability in the Lemo sub-watershed is 142,361,302 m^3 year^{-1}. Water needs are calculated from the conversion results to decent living needs. Based on the guidelines for determining the carrying capacity of the Environment in Regional Spatial Planning, the regulation of the State Minister for the Environment of Indonesia Number 17 of 2009 stipulates the water requirements for decent living at 1,600 m^3 capita^{-1} year^{-1}. Since the population of Central and South Teweh Sub-districts is 73,577 people, using Equation 6, the water demand is 117,723,200 m^3 year^{-1}. The status of the water carrying capacity was determined from the comparison between water availability (S_A) and water demand (D_A). Water availability (S_A) is 142,361,302 m^3 year^{-1} > (D_A) water demand is 117,723,200 m^3 year^{-1}. Therefore, the carrying capacity of water is declared surplus.

Table 4 Value of weighted runoff coefficient (C) of Lemo sub-watershed

No.	Land Use in Lemo Sub-watershed	Runoff Coefficient (C_i)	Land Areas (A_i)	C_i x A_i
1.	Scrub	0.07	2,126.95	148.89
2.	Swamp scrub	0.2	8.18	1.64
3.	Secondary dryland forest	0.03	36,338.39	1,090.15
4.	Mining	0.9	1,386.89	1,248.20
5.	Mixed dry land farming	0.1	13,451.44	1,345.14
6.	Settlement	0.6	4.99	2.99
7.	Plantation	0.4	842.99	337.20
8.	Plantation forest	0.05	556.96	27.85
9.	Waters	0.05	93.21	4.66
			54,810.00	4,206.72
Weighted runoff coefficient: $C = \Sigma(C_i \times A_i)/\Sigma A_i$				0.08

4. Conclusion

The study results showed that land uses in the study area suitable for land capability were agricultural use, conservation land, and land for other uses. The spatial analysis also showed that a small proportion of land (6.68%) in the study areas was not in line with the spatial pattern plan of the regency spatial plan (SPPRSP). Quantification of land availability using agricultural commodity production data showed that the areas of land availability were smaller than the land required for a decent living (deficit land carrying capacity). However, based on the SPPRSP of the study area, study areas provided cultivated lands whose area of these lands exceeds the land required for a decent life. Therefore, the land carrying capacity becomes a surplus when the land availability refereed to the area of cultivated land based on the SPPRSP. This analysis revealed that the determination of land carrying capacity using agricultural production data has a weakness when the agricultural sector is not the main sector contributing to gross domestic regional product (GDRP). That is also a limitation of this study. The determination of land availability is carried out using cultivation land availability data based on the SPPRSP, not based on calculations using agricultural commodity data as stated in the guideline for determining land carrying capacity. Analysis of water carrying capacity revealed that water availability exceeds the demand for water (surplus water carrying capacity). Based on land and water carrying capacity, the environmental carrying capacity of the Lemo sub-watershed showed surplus status. Therefore, it could be concluded that the current use of natural resources does not decrease environmental quality. This study also demonstrates that spatial planning for further utilization of natural resources in the study area may be achieved by allocating a wider area for the agricultural, plantation, and forestry business sectors.

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