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Forest Land Change Assessment of Karang Mumus Sub-Watershed Area

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Abstract

Karang Mumus watershed is an important area as a port and gateway to the inland of East Kalimantan, causing the trade sector and water transportation services in this city to be very developed. Traders and immigrants from various regions who came in, stopped by, performed business, and stayed have caused the riverbanks to develop into economic and trade centers. One of the issues in the Karang Mumus sub-watershed is the conversion of forest area to agricultural land. With the improper use of agrotechnology and soil conservation, agricultural operations result in erosion and reduced land yield. This study aims to evaluate the Karang Mumus sub-potential watersheds to support land capability by using the overlay method (geoprocessing) of a geographic information system (GIS) based on criteria for classifying land capabilities and a data analysis approach. The findings revealed that the Karang Mumus sub-land watersheds primarily are categorized as land capacity class III, with a moderate erosion limiting factor that covers 15,864 ha (50.45%). The remaining areas are categorized into land capability classes IV and VI, with class IV having a severe slope limiting factor and class VI having a severe slope limiting factor with a fairly strong soil sensitivity to erosion, covering 8,751.14 ha (27.83%) and 6,829.85 ha (21.72%), respectively. Class III land is recommended for agricultural cultivation, application of appropriate agro-technology, and soil and water conservation. This study recommends that class IV and VI lands area are used for community forests or plantation forests managed by government agencies involved in the forest area stabilization center (BPKH) Region IV Samarinda.

Keyword: *agriculture, agro technology, erosion, productivity*

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Introduction

According to the Samarinda City Spatial Plan 2011–2030, the city of Samarinda has developed relatively fast, particularly in the mining and plantation industries. It is vital to restrict land use by using the idea of environmental carrying capacity based on land capability since the majority of the City of Samarinda area has been used as a plantation and mining area, which can boost regional revenue. The regional spatial plan (*rencana tata ruang wilayah*, RTRW) of Samarinda needs to be reviewed and updated as the city expands.

One of the tools that can be used to evaluate land suitability for land use is the geographic information system (GIS). GIS can manage spatial data in the form of maps and tables and understand the relationship between the two. Map and table-based spatial analysis can be done quickly, efficiently, and accurately.

The dynamics of using forest land to become agricultural land causes damage to the sub-watershed ecosystem, including an increase in the value of the average flow coefficient (C average), where the higher average C value causes the resulting in greater flood discharge (Agus & Wulandari, 2012; Endayani et al., 2019; Halim, 2014). Other effects include alteration of the watershed's hydrological state both locally and beyond, drought, erosion, and lower land production (outside the scene) (Halim, 2014; Pertiwi et al., 2011; Ping, 2012). A dynamic ecosystem that connects upstream and downstream is a sub-watershed (Hadi & Shrestha, 2011; Harini et al., 2016; Rawat et al., 2018). Land use depends on the capability and location of the land (Kurowska et al., 2020; Chen et al., 2021; Matos et al., 2021).

Different inhibiting characteristics, such as soil texture, slope, soil surface, water capacity, and erosion rate, define how land is used (Oduro & Agyemang-duah, 2020; Mora et al., 2021; Olsen et al., 2021). There are physical, ecological, economic, and institutional factors that influence land usage (Piccinelli et al., 2020; Weng et al., 2020; Talukdar et al., 2021). Geological features, soil, water, climate, plants, animals, and humans are examples of physical and biological variables (Hadi & Shrestha, 2011; Nezami, 2013; Ping et al., 2012). Profits, market conditions, and transportation are the characteristics of economic forces. Land legal, political, social, and administrative contexts define institutional elements (Halim, 2014; Maryati, 2012; See et al., 2018).

Karang Mumus River is a transportation way used by the community and is one of the sub-watersheds of Samarinda. It is become problematic, due to forest degradation and uncontrolled change in the Karang Mumus Sub-watershed that covers 31,444.99 ha (BPDAS Mahakam Berau, 2017). The forms and patterns of degradation that occur are very diverse, including: 1) a decrease in vegetation density; 2) changes in the type of land cover vegetation, 3) impermeability, namely the change of cultivated land into residential land whose surface is impermeable to water, and 4) conversion of forest land functions to non-forest designations. The conversion of forest function to non-forest land for 7.8 decades reached 7,806.57 ha (28.86%), while the forest area that experienced encroachment was 4,550.45 ha (58.29%) of the total forest area of 7,806.57 ha (BPDAS Mahakam Berau, 2017). The amount of the existing forest distribution is 7,806.57 ha (24.83%), while shrubs dominate the land use on an area of 13,634.21 ha (43.63%) (BPDAS Mahakam Berau, 2017).

The use of forest land for agriculture has implications on the fluctuations in river discharge in the Karang Mumus sub-watershed. This can be seen from the coefficient value of the river regime in 2008 of 78.57 (maximum discharge 110 m second^{-1}, and minimum discharge 1.4 m^3 second^{-1} (Pertiwi et al., 2011; Wasis, 2012; George et al., 2013), resulting in the Karang Mumus Sub-important watershed's land reaching 20,062 ha (63.8%) (BPDAS Mahakam Berau, 2017). The agriculture productivity from this area reached 5.34 tons ha^{-1} of paddy, 3.57 tons ha^{-1} of maize, and 1.38 ton ha^{-1} of soybeans which was less than the national productivity for rice commodities (5.45 tons ha^{-1}), corn (5.14 tons ha^{-1}), and soybeans (5.14 tons ha^{-1}), and it can be concluded that land damage has an impact on reducing the production of several types of superior commodities (1.6 tons ha^{-1}) (BPS Kota Samarinda, 2017). To achieve a sustainable sub-watershed state, intense management efforts must be made continuously while combining the objectives of soil and water conservation (Hadi & Shrestha, 2011; Oluwasegun, 2017).

The management and development of Sub-watershed in a sustainable manner are carried out with an appropriate land use allocation approach (Oluwasegun, 2017). To achieve this, a classification of land capabilities study that establishes the pattern of land use in line with its carrying capacity is required (Harini et al., 2016). Land capability classification is an attempt to evaluate land use, while land capability evaluation is a systematic assessment of land (land components) and grouping them into several categories based on the characteristics that are potential and their limitations to their sustainable use (Arsyad, 2010; See et al., 2018; Wegscheider et al., 2018). This study seeks to develop a classification of the land capability of the Karang Mumus Sub-watershed using spatial analysis. The wise use of natural resources to get optimum productivity over an endless period and minimize land damage is known as good and sustainable sub-watershed management (Nugraha & Damen, 2013; Rasyid et al., 2018; Rawat, 2018).

Methods

Research sites The Karang Mumus Sub-watershed is located at latitude N0°21'81"–N1°09'16" and longitude E116°15'16"–E117°24'16" with an area of 31,444.99 ha and administratively located in Samarinda City. The Karang Mumus Sub-watershed is partly a depression (basin area) and water catchment area, which flows directly into the Karang Mumus River. The Karang Mumus sub-watershed is located on the island of Kalimantan, East Kalimantan Province, Samarinda City (Figure 1).

Materials Topographic maps, maps of distropept, paleudult, and tropaquipts soil types, land use maps of shrubs, forests, open fields, built land, wet agriculture, dryland agriculture, swamps, and water bodies, rainfall data < 2,000 mm and 2,000-2,500 mm from the last ten years, and secondary data were tools used in this study (BPDAS Mahakam Berau, 2017). A collection of surveying tools, such as a working map, GPS, Abney level, or clinometer, were utilized as the research instrument.

Data obtained from BAPEDA of Samarinda City includes a map of land use (existing) 1:25,000 in 2020, a soil type map 1:25,000 in 2020, an erosion map 1:25,000, a map of spatial planning of Samarinda City 2011–2030 (Figure 2).

Land use mapping (1) Processing data by superimposing maps with themes (contours, soil, vegetation). (2) Applying the land capacity class criteria provided by Hockensmith and Steel in 1943 and Klingebiel and Montgomery in 1973 to the findings of thematic map overlays to analyze land use (Arsyad, 2010; Purwandari et al, 2011; Saida et al., 2013). (3) Using Systematic criteria for classifying a land capacity (Table 1). The method used is a spatial analysis by collecting maps (spatial data). Spatial analysis of map overlay outcomes as a visualization from the results of land capability classification.

Based on a number of key hindering characteristics, such as soil texture (t), permeability (p), drainage (d), surface slope (l), level of erosion/erosion danger (e), and effective depth, the land capacity class may be divided into subclasses (k). The parameters of texture, permeability, surface slope, effective depth, drainage, and erosion are used to classify land capability at the subclass level based on State Minister of the Environment Regulation Number 17/2009 concerning guidelines for determining environmental carrying capacity in spatial planning areas. Texture (t) is broken down into five categories: fine (t_1), which includes clayey to clayey or heavy clay; slightly fine (t_2), which includes sandy and loamy textures; medium (t_3), which includes coarse sandy clay textures, fine clays, and dusty clays; slightly coarse (t_4), which includes coarse to fine sandy loam texture; and coarse (t_5), which includes sandy and coarse to fine sandy loam textures. The several categories of permeability (p) are as follows: p_1 (slow: 0.5 cm hour^{-1}); p_2 (somewhat slow: 0.5–2.0 cm hour^{-1}); p_3 (medium: 2.0–6.25 cm hour^{-1}); p_4 (slightly fast: 6.25–12.5 cm hour^{-1}); and p_5 (fast: >12.5 cm hour^{-1}). Slope/surface slope (l) is divided: l_1 (03 %: flat); l_2 (3–8%: gentle); l_3 (8–15%: slightly inclined/wavy); l_4 (15–30%: hilly slope); l_5 (30–45%: slightly steep); l_6 (45–65%: steep); l_7 (>

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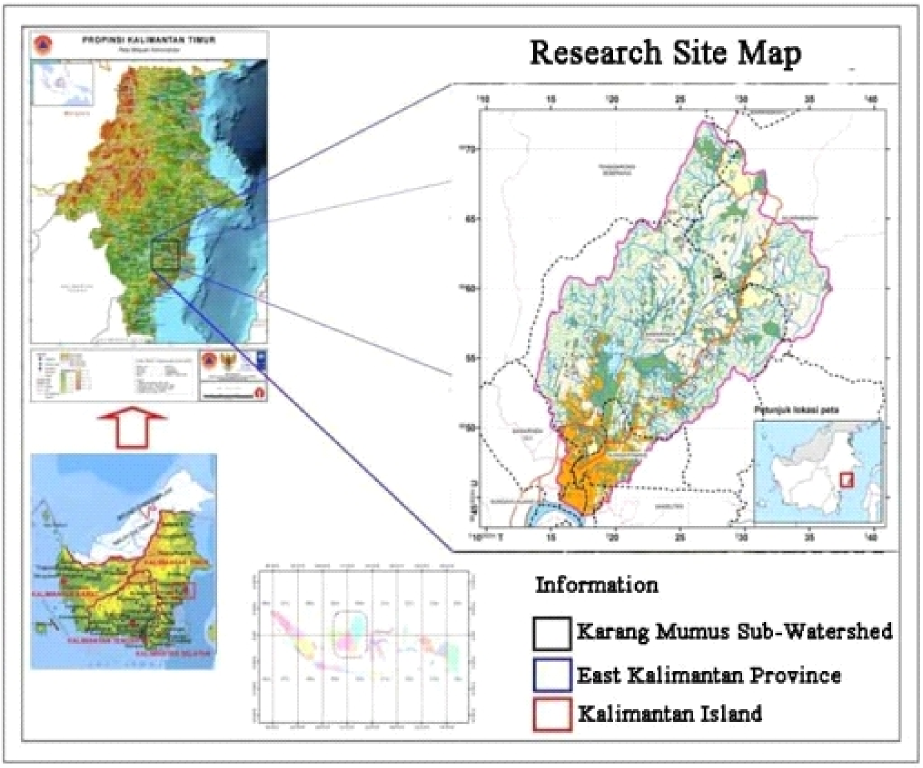

Figure 1 Research sites.

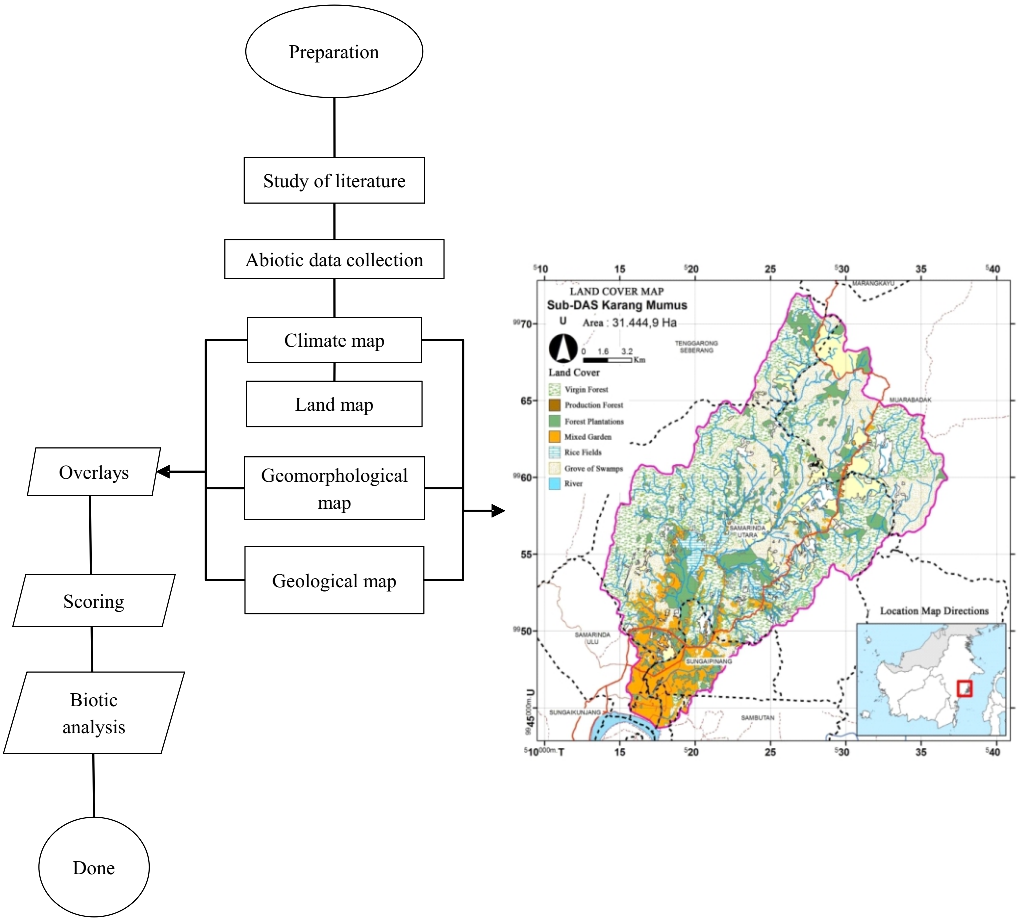

Figure 2 Materials and methods.

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Table 1 Land capability class criteria (Arsyad, 2010)

Sub class	Land ability class							
	I	II	III	IV	V	VI	VII	VIII
Soil texture								
a. Upper layer	t_2/t_3	t_1/t_4	t_1/t_4	(*)	(*)	(*)	(*)	t_5
b. Bottom layer	t_2/t_3	t_1/t_4	t_1/t_4	(*)	(*)	(*)	(*)	t_5
Surface slope (%)	l_0	l_1	l_2	l_3	(*)	l_4	l_5	l_6
Drainage	d_0/d_1	d_2	d_3	d_4	(**)	(*)	(*)	(*)
Effective depth	k_0	k_0	k_1	k_2	(*)	k_3	(*)	(*)
Erosion state	e_0	e_1	e_1	e_2	(*)	e_3	e_4	(*)
Permeability	p_2/p_3	p_2/p_3	p_2/p_3	p_3	p_1	(*)	(*)	p_3

Note: (*) = can have a distribution of inhibiting factors from a lower class, (**) = the soil surface is always flooded. Soil texture: t_1 = fine, t_2 = moderately fine, t_3 = medium, t_4 = slightly coarse, t_5 = coarse; Effective depth: k_0 = >90 cm, k_1 = 9050 cm, k_2 = 5025 cm, k_3 = <25 cm; Permeability: p_1 = 0.5 cm h^{-1}, p_2 = 0.52.0 cm h^{-1}, p_3 = 2.06.25 cm h^{-1}; Drainage: d_0 = good, d_1 = moderately good, d_2 = somewhat poor, d_3 = poor, d_4 = very bad; Erosion: e_0 = no erosion, e_1 = very light, e_2 = light, e_3 = moderate, e_4 = large, e_5 = very large; Surface slope: l_0 = 0–3%, l_1 = 3–8%, l_2 = 8–15%, l_3 = 15–30%, l_4 = 30–45%, l_5 = 45–65%, l_6 = >65% .

65%: very steep). Effective depth (k) is classified in: k_0 (> 90 cm: deep); k_1 (90–50 cm: medium); k_2 (50–25 cm: shallow); k_3 (< 25 cm: very shallow). Erosion (e) is classified in: e_0 (no erosion); e_1(very small: 0–12.50 tons ha^{-1} $year^{-1}$); e_2 (small: 12.50–50.00 tons ha^{-1} $year^{-1}$); e_3 (medium: 50.00–125.00 tons ha^{-1} $year^{-1}$); e_4 (weight: 125.00–330.00 tons ha^{-1} $year^{-1}$); e_5 (very heavy: > 330.00 tons ha^{-1} $year^{-1}$).

Drainage (d) belongs to d_0 (good) where the soil has good air circulation. The entire soil profile from top to bottom (150 cm) is uniformly light in color and has no yellow, brown, or gray spots; d_1 (somewhat good) the soil has good air circulation in the root area, and there are no yellow, brown or gray spots on the top layer and the top of the bottom layer (up to about 60 cm from the soil surface); d_2 (slightly poor) the top layer of soil has good air circulation and there are no yellow-brown or gray spots, which are usually found throughout the bottom layer (about 40 cm from the soil surface); d_3 (bad) the bottom of the top layer near the surface has yellowish, brown, or gray color or spots; d_4 (very bad) all layers until the soil surface is gray and the subsoil is gray or there are bluish spots, or there is water pooling on the soil surface at the same time that inhibits plant growth.

Results and Discussion

Characteristics of Karang Mumus Sub-watershed land units The results of the study of the Karang Mumus Sub-watershed obtained 26 land units (Table 4).

Based on Table 2, the characteristics of the land are dominated by shrubs covering an area of 13,634.21 ha (43.36%), with the slope ranging between 3–45%. The distribution of wet farmland in the Karang Mumus sub-watershed is generally spread on a slope of 0–30% covering an area of 786.42 ha (2.50%), and land built on a slope of 15–30% covering an area of 3,382.05 ha (10.76%). Dryland farming activities on steep land without adequate application of soil and water conservation technology lead to high erosion and runoff.

Analysis of Karang Mumus Sub-land watershed's capability The findings revealed that the distribution of land capability classes is as follows: land capability class III covers 15,864 ha (or 50.45%), followed by land capability class IV, which covers 8,751.14 ha (or 27.83%), and finally, land capability class VI, which covers 6,829.85 ha (or 21.72%). The results also revealed that land capability classes are inhibited by slopes that are "undulating steep" by moderate erosion and rocks on the ground, and by drainage (Tables 3, Table 4, Table 5, and Figure 4).

Land units 14 and 16 have 5,226.16 ha (16.62%) of land class III-e_2, b_1 with erosion damage limitation factor (e_2), according to Table 3. It is necessary to take conservation measures since soil with a class III ability has limitations on how time, energy, and plant species may be used. Arsyad (2010), suggested that measures to prevent erosion or conserve soil can include minimizing rain energy, reducing surface runoff scours, reducing runoff volume, slowing runoff pace, and enhancing soil properties that are vulnerable to erosion. Making mound terraces is one method of using soil and water conservation to stop soil erosion in land units 3, 10, 11, 19, 20, 21, and 23 which are in class III-e_2 (Arsyad, 2010). Mulch application is another method for preventing erosion. Mulch may improve the environment for the activity of microorganisms while also preserving the soil and minimizing evaporation.

Pratiwi and Narendra (2012), indicated that mahogany plants' growth might be increased by up to 66% by using vertical mulch in the demonstration plot. The application of vertical mulch spaced at 6 m intervals can reduce soil nutrient loss by up to five times and erosion and runoff by up to 50%. Mulching also aids in the retention of soil particles and improves the aggregation and stability of soil aggregates, which minimizes the effects of soil erosion (Ping et al., 2012). Class III-l_2, e_2 land with slope limiting factors, and erosion factors are found in land units 12, 15, and 17 covering an area of 4,263.94 ha (13.56%). One of the soil properties that affect erosion is the soil sensitivity factor (soil erodibility).

A soil's susceptibility to erosion increases with its soil erodibility rating. The stability of soil aggregates and infiltration rate are two soil properties that have a significant impact on how easily soil erodes. The degree of soil erodibility is significantly influenced by soil treatment parameters in addition to soil attributes (Nezami, 2013). Purwandari et al. (2011) found that the easiest soils to erode are those with a high dust concentration. The stability of soil aggregates is maintained, but the application of organic matter needs to be a limiting factor for soil erodibility.

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Table 2 Biophysical characteristics of Karang Mumus Sub-watershed land units

Land use	Type of soil	Tilt (%)	Area (ha)	Proportion (%)
Shrubs	Dystropepts, Tropaquepts	3–45	13,634.21	43.36
Forest	Dystropepts	30–45	7,806.57	24.83
Open field	Dystropepts	15–45	2,691.67	8.56
Land built	Dystropepts	15–30	3,382.05	10.76
Wet farm	Dystropepts, Paleudults, Tropaquepts	0–30	786.42	2.50
Dryland farming	Dystropepts, Tropaquepts	3–30	2,094.92	6.66
Swamp	Dystropepts, Tropaquepts	0–8	484.30	1.54
Water body	Fluvaquents, Tropaquepts	0–3	564.84	1.80
Total area			31,444.99	100.00

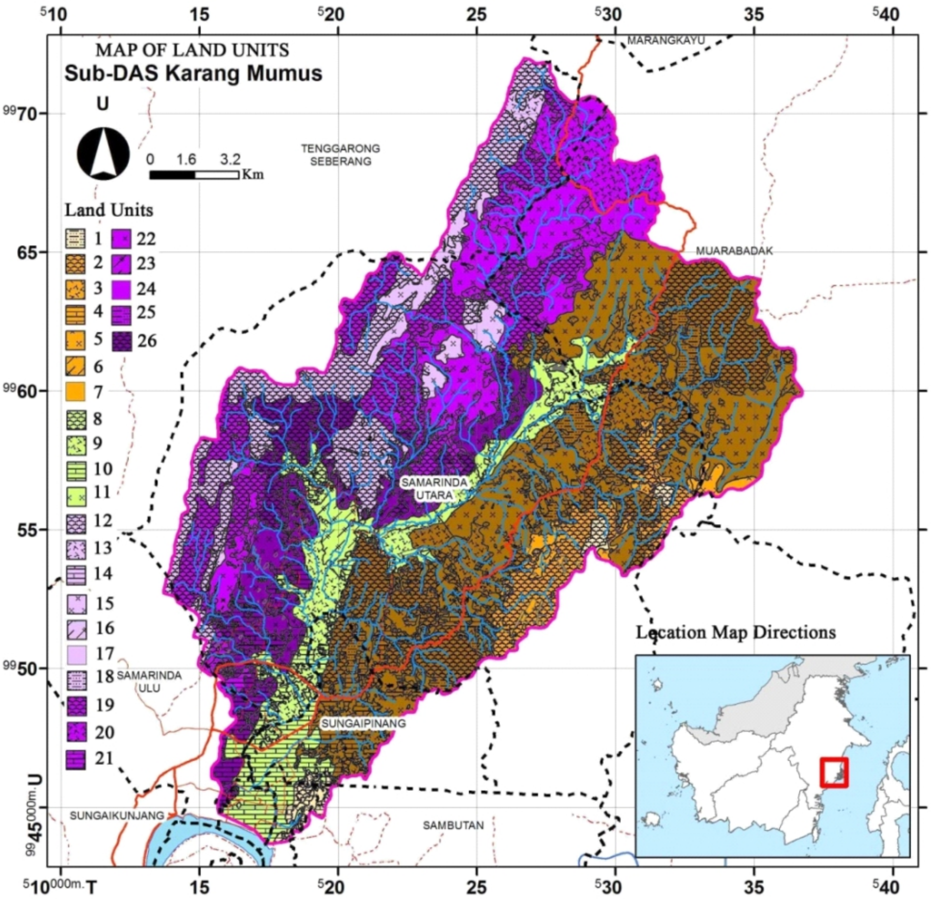

Figure 3 Map of the land unit in Karang Mumus sub-watershed.

Table 3 Land capability class Karang Mumus sub-watershed

Land capability classification	Land unit	Total	
		Area (ha)	Proportion (%)
III – I_2, e_2	3, 10, 11, 19, 20, 21, 22, 23	5,763.87	18.33
III – d_3	24, 25	610.03	1.94
III – e_2	14, 16	5,226.16	16.62
III – e_2, b_1	12, 15, 17	4,263.94	13.56
IV – 13	1, 5, 7, 9, 13, 18	8,751.14	27.83
VI – 14	2, 4, 6, 8	6,829.85	21.72
Total		31,444.99	100.00

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Table 4 Physical and morphological characteristics of the Karang Mumus sub-watershed

Land unit	Slope	Erodibility	Erosion	Soil depth	Texture	Permebility	Drainage	Rock	Flood
1	Slightly steep	Moderate	Moderate	Deep	Slightly fine	Moderate	Fine	Slightly	None
2	Steep	Slightly high	Moderate	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
3	Slightly steep	Moderate	Moderate	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
4	Steep	Slightly high	Moderate	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
5	Slightly steep	Moderate	Moderate	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
6	Steep	Slightly high	Mild	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
7	Slightly steep	Moderate	Mild	Deep	Slightly fine	Moderate	Fine	Slightly	None
8	Steep	Moderate	Mild	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
9	Slightly steep	Moderate	Mild	Deep	Slightly fine	Moderate	Fine	Slightly	None
10	Flat	Slightly high	Mild	Deep	Slightly fine	Slightly Slow	Fine	Slightly	None
11	Sloping	Moderate	Moderate	Moderate	Fine	Slightly Slow	Fine	Slightly	None
12	Slightly steep	Slightly high	Moderate	Moderate	Slightly fine	Moderate	Fine	Moderate	None
13	Slightly steep	Moderate	Moderate	Deep	Slightly fine	Moderate	Fine	Slightly	None
14	Sloping	Moderate	Moderate	Moderate	Slightly fine	Moderate	Fine	Slightly	None
15	Slightly steep	Slightly high	Moderate	Moderate	Slightly fine	Moderate	Fine	Moderate	None
16	Sloping	Moderate	Moderate	Moderate	Fine	Moderate	Fine	Moderate	None
17	Slightly steep	Slightly high	Moderate	Moderate	Fine	Moderate	Fine	Moderate	None
18	Slightly steep	Moderate	Moderate	Deep	Fine	Moderate	Fine	Slightly	None
19	Sloping	Moderate	Moderate	Moderate	Fine	Slightly Slow	Fine	Slightly	Sometimes
20	Slightly steep	Moderate	Moderate	Deep	Slightly fine	Moderate	Fine	Slightly	Sometimes
21	Sloping	Moderate	Moderate	Moderate	Fine	Slightly Slow	Fine	Slightly	None
22	Slightly steep	Moderate	Moderate	Moderate	Fine	Slightly Slow	Somewhat good	Slightly	None
23	Sloping	Moderate	Moderate	Deep	Slightly fine	Moderate	Somewhat good	Slightly	None
24	Sloping	Moderate	Moderate	Deep	Slightly fine	Moderate	Somewhat good	Slightly	None
25	Flat	Moderate	Mild	Deep	Fine	Slow	Slightly poor	Slightly	Sometimes
26	Flat	Moderate	Mild	Deep	Fine	Slow	Slightly poor	Slightly	Sometimes

Table 5 Land use directions and soil and water conservation practices in the Karang Mumus sub-watershed.

Area status	KKL	SL	Recommendations		Total	
			LU	KTA	Area (ha)	Proportion (%)
APL	III-d_3	12	Br	-	610.03	1.94
	III-e_2	3, 10, 11, 19, 20	Pt	TG	1,257.80	4.00
	III-e_2	21, 22, 23	Sw	-	4,502.92	14.32
	III-e_2,b_1	14, 16	Kc	TG	5,226.16	16.62
	III-l_2, e_2	12, 15, 17	Kc	*Rorak*	4,182.18	13.30
	IV-l_3	1, 13	Ht	Ti	2,248.32	7.15
	VI-l_4	2	Ht	Ti	40.88	0.13
HP	III-l_2, e_2	12	HP	Ti	6.29	0.02
	IV-l_3	1, 7, 9, 13, 18	HP	Ti	3,631.90	11.55
	VI-l_4	2, 4, 8	HP	Ti	871.03	2.77
HL	III-e_2	21	HL	Ti	3.14	0.01
	III-l_2, e_2	12	HL	Ti	75.47	0.24
	IV-l_3	5, 7, 9, 13, 18	HL	Ti	2,867.78	9.12
	VI-l_4	4, 6, 8	HL	Ti	5,921.09	18.83

Note: APL = other use area; HP = production forest; HL = protection forest; KKL = land capability class; SL = land unit; LU = land cover; Br = shrubs; Pt = built-up land; Sw = rice field; Kc = mixed garden; Ht = forest; KTA = soil and water conservation; Ti = bush forest; TG = *gulud* terraces (mound terracing); *Rorak* = *rorak* terraces (basin terracing)

The results of other studies showed that soils with high organic matter content have high erodibility (Ping et al., 2012). Class III-e_2, b_1 land with erosion limiting factors and moderate rock percentage characterized by difficult soil processing and slightly disturbed plant growth, spread over land units 14 and 16 covering an area of 5,226.16 ha (16.62%). If this land unit is used for agricultural cultivation, it is necessary to take soil conservation measures such as making channeled mound terraces, planting in strips, and using mulch. Meanwhile, to overcome the obstacles to the distribution of rocks on the soil surface, the action that needs to be taken is to develop a planting method with an intensive silvicultural pattern. Oluwasegun (2017) stated that the intensive silviculture system (SILIN) is a silvicultural technique that seeks to integrate the three main elements of silviculture, specifically: breeding target species, environmental manipulation, and integrated pest control.

Slope (topography) is one of the factors that encourage

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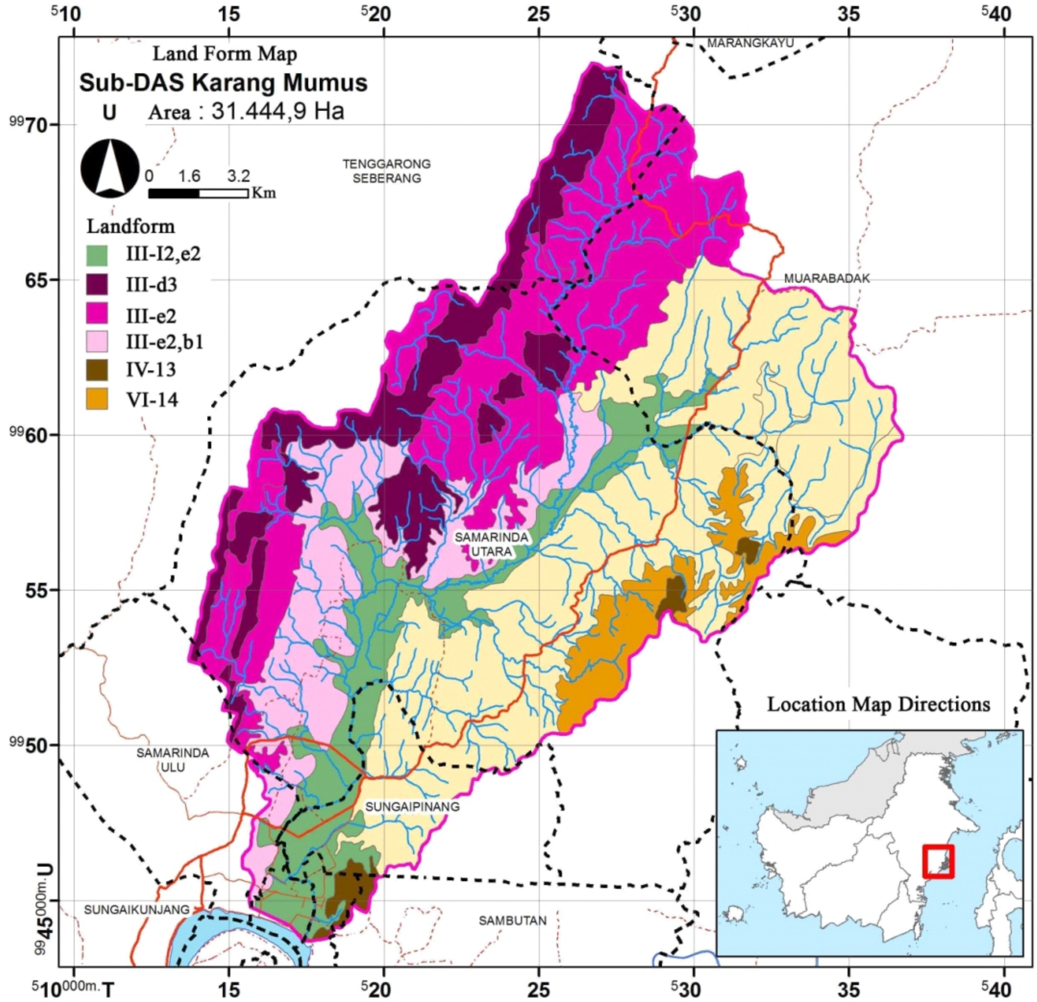

Figure 4 Map of land capability class in Karang Mumus Sub-watershed.

land erosion. The steepness of the slope affects the size of the amount of surface runoff and the energy of carrying water on soil particles, if the slope is greater then landslides will occur easily. This is due to the greater gravity in line with the slope of the soil surface from the horizontal plane so that the top soil layer is eroded more and more. If the slope of the soil surface is twice as steep, then the amount of erosion per unit area will be 2.0–2.5 times more (Wegscheider et al., 2018). Land use in the form of permanent vegetation and forests on land with slope and erosion limiting elements will lessen the impact of precipitation on the soil over time. Land management with slope and erosion limiting factors needs the use of mechanical and vegetative soil conservation (See et al., 2018).

Table 5 displays land classes IV-l_3 with an area of 8,748.00 ha (27.82%) distributed over land units 1, 5, 7, 9, 13, and 18 with a slope limiting factor of 15–25%. Land units face challenges and dangers. Land class IV has more capacity than Land class III, but the variety of plants is also more constrained. Land units 2, 4, 6, and 8 are Class VI-l_4 land with a slope limitation factor of 30–45 % and a total size of 6,833.00 ha (21.73 %). Land with class VI capacity that has severely constrained soils is only appropriate for perennial plants and woods. It is not suitable for agricultural operations.

Recommendation for Karang Mumus Sub-watershed It is possible to develop 8 (eight) directions for land use, including the usage of paddy fields, swamp shrubs, farmland, plantation forests, mixed agricultural/gardens, and forests, based on the results of the forest area map overlay and the land capability analysis map. While land classes IV and VI in other-use areas (APL) are advised for forest development, class III land in APL is advised for seasonal crop farming and mixed gardens together with the creation of mound terraces and the application of mulch up to 6 tons ha^{-1} and for work crops like agroforestry and communal forests together with the construction of individual terraces. Rasyid et al. (2018) claimed that the vertical mulch-equipped *gulud* and *rorak* terraces are able to drastically reduce the quantity of dirt suspended in the water flow (suspended load).

The mound treatment still had a greater impact than the treatment without using the method, but the *rorak* treatment with vertical mulch on oil palm trees had the best effect on sediment load in the water flow (8.3 kg ha^{-1}) compared to the mound treatment 11.9 kg ha^{-1}. Additionally, Ping et al. (2012) discovered that the surface runoff from plots treated with vertical mulch and mound terraces was 12.8 and 87.8 mm, respectively, as opposed to 508.3 mm in plots not treated with soil and water conservation measures (the control). In the upstream watershed, the predominant types of land use are forest and permanent vegetation/plantation forests (Figure 5), dry land agriculture and mixed gardens are practiced in the center of the watershed, and rice fields and inundation regions are found in the downstream portion (swamp scrub). This land use proposal should be able to sustain variations in water discharge in the Karang Mumus Sub-watershed while reducing land erosion to become less than the acceptable erosion.

Conclusion

Land use is dominated by land capability class III with the limiting factors being moderate erosion and moderate soil sensitivity to erosion covering an area of 15,864 ha (50.45%). Land capability class IV with a slope limiting factor (steep) covers an area of 8,751.14 ha (27.83%), and land capability class VI with a slope limiting factor (steep) covers an area of 6,829.85 ha (21.72%). Land with capability class III (III-e$_2$; III-d$_3$; III-e$_2$, b$_1$; III-l$_2$; KE 4, e$_2$; III-KE 3, e$_2$), can still be used for dry land agricultural cultivation and mixed gardens with the application of agro technology and proper soil and water conservation.

Recommendation

Dry land agriculture, forest, and land rehabilitation in the Karang Mumus Sub-watershed require the application of mechanical soil and water conservation by making *gulud* terraces, *rorak*, and individual terraces and applying 6 tons ha^{-1} of mulch. The recommended land use directives aim to reduce the rate of runoff and erosion.

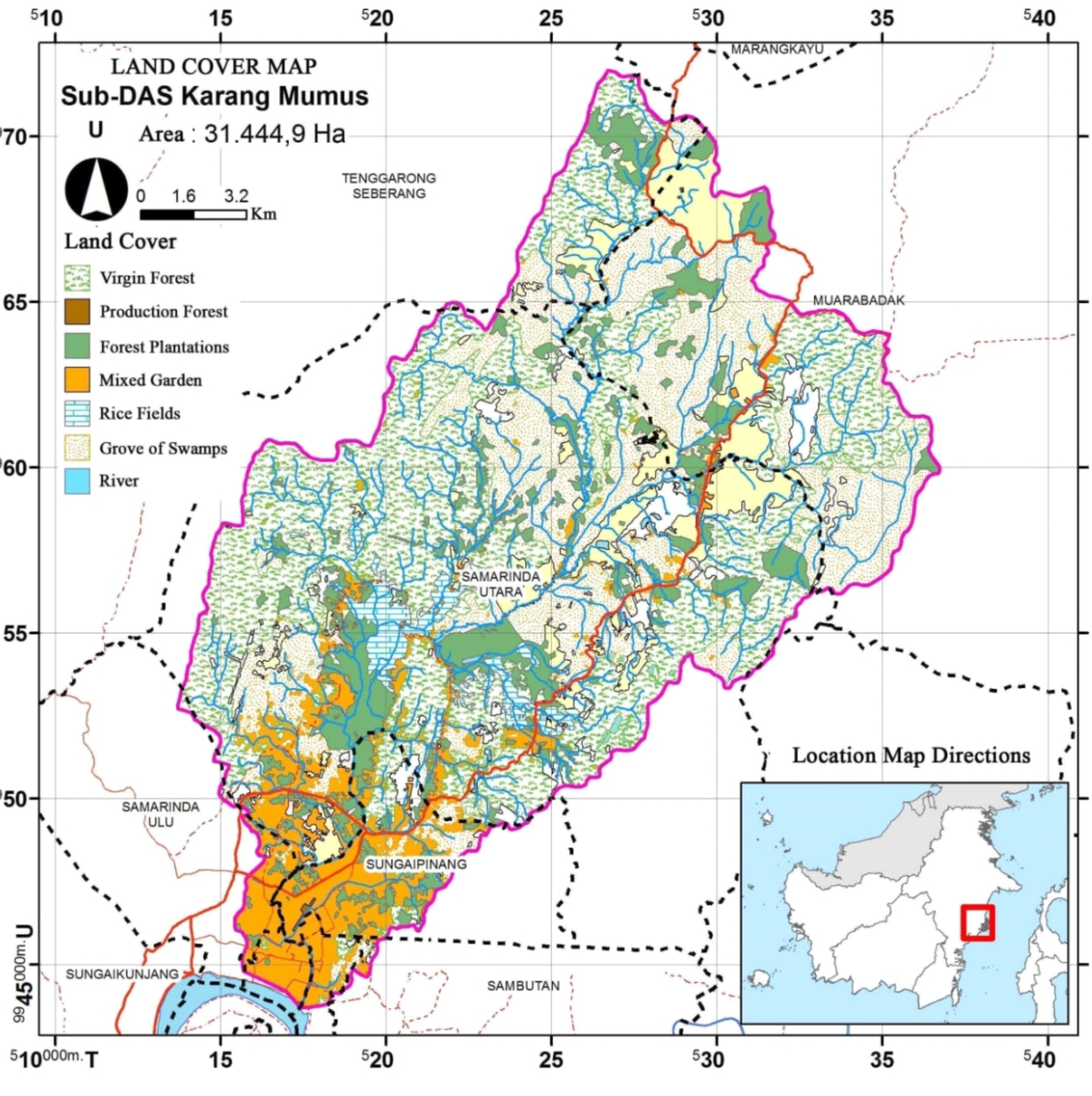

Figure 5 Map of land use direction for Karang Mumus Sub-watershed.

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