Analysis of Erosion Hazard Levels using USLE Method in the Bati-Bati Sub-Watershed, Indonesia

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ABSTRACT

The Bati-Bati Sub-Watershed is one of the critical watersheds that is susceptible to soil erosion. Soil erosion poses a significant threat to environmental stability, particularly in tropical regions. This study aims to analyze the level of erosion hazard and provide recommendations for forest and land rehabilitation to minimize the impacts of erosion. The USLE (Universal Soil Loss Equation) method was used to estimate erosion hazard levels in this research. The factors considered in this method include land cover type, slope class, rainfall, soil depth, and soil type. The study was conducted in the upstream and midstream areas of the Bati-Bati Sub-Watershed, which is part of the Maluka Watershed in Bati-Bati District. Thirteen land units were identified, with three main land cover types: plantation (10,186.6 ha), shrubland (7,367.4 ha), and open land (665.1 ha). The slope conditions are categorized into three classes: flat (14,744.9 ha), gentle (2,044.8 ha), and moderately steep (1,419.4 ha). The identified soil types include the Red Podzolic – Lateritic Complex and Organosol Gley Humus. Erosion hazard levels in the study area are distributed as follows: Level I–Low (7,606.7 ha), Level IV–Very Severe (5,369.8 ha), Level III–Severe (2,652.6 ha), and Level II–Moderate (2,579.9 ha). The recommended forest and land rehabilitation (FLR) strategies are grouped into three approaches: maintaining the existing plantation land cover and rehabilitating it with high-quality, site-adapted species; converting shrubland into Indonesian plantation forest models with appropriate species selection based on site suitability; and converting open land into agroforestry planting systems.

Keywords: Agroforestry, Erosion Hazard Level, Forest and Land Rehabilitation, USLE method, Watershed

INTRODUCTION

The rate of deforestation has been continuously increasing year by year. Data from the Ministry of Forestry of the Republic of Indonesia indicates that from 1982 to 2006, the average annual deforestation rate was 1.64 million hectares, and this trend has continued to rise. Furthermore, the extent of national degraded land is substantial, with highly degraded land reaching 5,449,299.21 hectares and critical land covering 24,467,311.8 hectares[1]. These issues necessitate the development of effective strategies for the restoration and enhancement of forest and land functions and productivity, one of which is through well-planned forest and land rehabilitation programs.

Forest and land rehabilitation activities will yield optimal positive impacts if management patterns are based on a watershed unit. This is because the

interaction between human resources and their environment/natural resources does not adhere to administrative (political) boundaries, but rather follows ecological (natural) boundaries, represented by watersheds. Consequently, activities carried out in the upstream areas of the watershed will have significant positive or negative impacts on the middle and downstream areas of the watershed.

The Bati-Bati Sub-Watershed is part of the Maluka Watershed, located in the Tanah Laut Regency and covering an area of 33,152.32 hectares. According to BPDAS-HL Barito[2], the Maluka Watershed, which includes the Bati-Bati Sub-Watershed, has areas with very low carrying and absorption capacity (37,082.18 ha), low (27,361.94 ha), moderate (18,729.57 ha), high (6,112.68 ha), and very high (4.28 ha). Furthermore, the Bati-Bati Sub-Watershed has been classified as a priority watershed for rehabilitation[3]. Based on this information, environmental improvement efforts in the Bati-Bati Sub-Watershed are essential to maintain the sustainability and harmony of watershed components while enhancing the natural resource capacity to support community welfare.

One of the key environmental issues in the Bati-Bati Sub-Watershed is soil erosion. If not properly managed, soil erosion can cause a range of problems that threaten the survival of living organisms in the area. In tropical regions, soil erosion tends to be more severe due to the impacts of extreme climate change and is recognized as one of the most destructive forms of land degradation[4-8]. Soil erosion poses a significant environmental threat that endangers ecosystems, agriculture, and human livelihoods. Moreover, it contributes to exacerbating climate change, declining water quality, increasing flood risks, and triggering various natural disasters[8-12]. Therefore, to develop effective soil erosion mitigation strategies in the Bati-Bati Sub-Watershed, it is crucial to first determine the erosion hazard levels in the area. This information is essential for formulating targeted forest and land rehabilitation plans that are aligned with the identified erosion hazard levels.

MATERIALS & METHODS
Research Location
This research was cinducted in the upper and middle Bati-Bati Sub-Watershed, Bati-Bati Sub-District, Tanah Laut Regency, South Kalimantan Province. This research was conducted over a period of 3 (three) months, which included literature review, preparation of a research proposal, data collection, data verification in the field, data analysis and final report writing. The map of the research location can be seen in Figure 1.
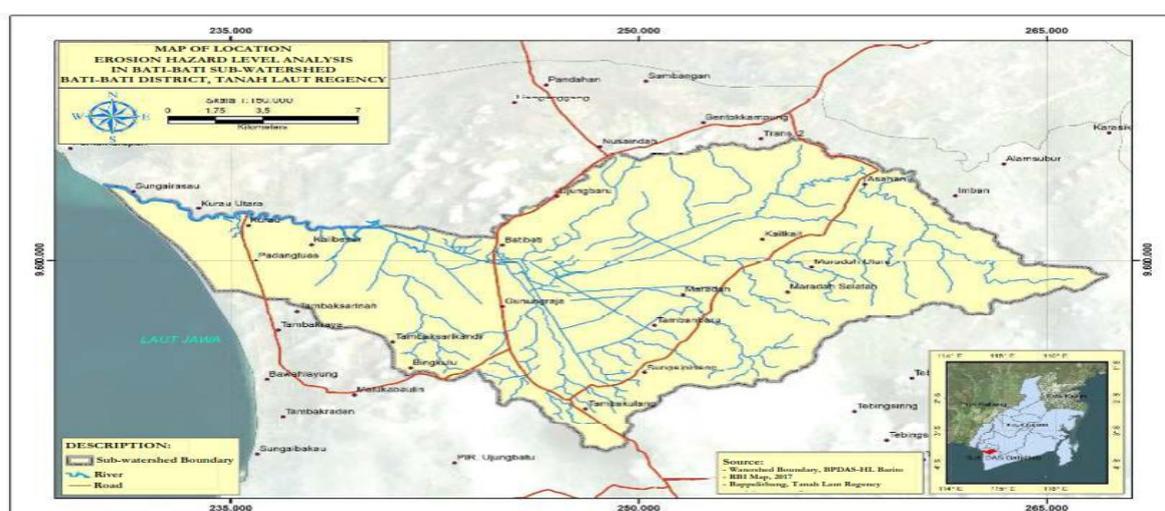

Figure 1 – Map of Research Location in Belangian Village

The materials required for the erosion hazard level analysis in this study include soil samples collected from the research site, plastic bags for storing the soil samples, a topographic map of Indonesia at a 1:250,000 scale, map of land use, soil type, slope class, and land cover. The equipment used in this study comprises a GPS device, clinometer or Abney level, compass, camera, soil auger, soil sample rings, measuring tape, crowbar, machete, knife, stationery, tally sheets, and mapping/GIS software (ArcView 3.2/MapInfo).

Research Procedure
In general, the first step of this study involves preparing spatial data for land units, followed by the collection of primary and secondary data. Subsequently, soil sample analysis is conducted in the laboratory to obtain field data, which are then used to assess erosion hazard levels using the USLE (Universal Soil Loss Equation) method. The spatial data preparation process consists of overlaying several required maps, including the slope class map, soil type map, and land cover map, to delineate land units that will be sampled in this study. Primary data collected include information on vegetation or land cover types and physical soil properties. Secondary data required for this study include general descriptions of the study area, rainfall data from rainfall monitoring stations and the Meteorology, Climatology, and Geophysics Agency (BMKG), as well as satellite imagery and maps used for land unit analysis.

The primary data collection process began with determining the observation points for land cover and soil samples through spatial analysis of the identified land units. Field observations of vegetation cover were conducted using a sampling intensity of 0.1% (standard evaluation of GN-RHL), and the selection of land cover samples was carried out using purposive sampling (sample selection based on specific criteria). The size of the sample plots was adjusted according to the respective land cover types. Within these plots, a general exploratory observation (brief visual assessment) was conducted to document the vegetation cover, including tree or plant species, canopy structure, and litter layer. Soil sampling was also performed using purposive sampling, with two categories: (a) undisturbed soil samples for analyzing soil properties such as soil permeability, and (b) disturbed soil samples for assessing other physical properties and organic matter content[13]. Soil sampling was conducted at depths ranging from 5 cm to 60 cm. Undisturbed soil samples were collected three times for each land unit and land cover type, while disturbed soil samples were collected five times and then combined into a composite sample. These soil samples were then analyzed in the laboratory for texture, permeability, and organic matter content.

Data Analysis
Estimation of Soil Erosion (A)
Soil erosion estimation was performed as a fundamental step in determining the erosion hazard levels. Erosion can be estimated using the USLE (Universal Soil Loss Equation) formula[14], which was calibrated by Ruslan[15] with the following equation:

$$A = R \times K \times L \times S \times C \times P \times 0.61 \qquad (1)$$

Where:
A: amount of soil loss (tons/ha/year)
R: rainfall erosivity factor (MJ.cm/ha/hour/year)
K: soil erodibility factor (tons.ha.hour/ha/MJ.cm)
L: slope length factor (m)
S: slope steepness factor (%)
C: cover and management factor
P: soil conservation practice factor
0.61: correction factor[15]

1. Rainfall Erosivity Factor (R)
The rainfall erosivity factor is calculated using the average value derived from three different rainfall erosivity estimation formulas: the Lenvain formula[16], the

Soemarwoto formula[17,18], and the Utomo and Mahmud formula[19]. The formulas are as follows:

a) Lenvain Formula: $R1 = 2.21 \text{ (Rain)}_i^{1.36}$

b) Soemarwoto Formula: $R2 = 0.41 \text{ (Rain)}_i^{1.09}$

c) Utomo & Mahmud Formula: $R3 = -8.79 + 17.01 \times \text{(Rain)}_i$

The average of these three formulas is calculated as:

$Rm = (R1_i + R2_i + R3_i)/3$

The annual erosivity indeks is given by:

$$R = \sum_{m=1}^{12} (R_m)$$

Where:

R1m, R2m, R3m: monthly average rainfall erosivity indices (units/month)

Dari rumus a), b), dan c) → (Rain)_m : average monthly rainfall (cm/month)

Rm: monthly average rainfall erosivity index (units/month)

R: mean annual rainfall erosivity factor (MJ.cm/ha/hour/year)

2. Soil Erodibility Factor (K)

The soil erodibility factor is determined using the following equation[14]:

$K = \{2.173 \, M^{1.14}(10^{-4}) \times (12 - a) + 3.25(b - 2) + 2.5(c - 3)\}/100$ \hfill (2)

Where:

K   : soil erodibility factor

M   : percentage of silt + very fine sand × (100 – percentage of clay)

a   : organic matter content (%)

b   : soil structure code

c   : permeability class

The soil erodibility factor is significantly influenced by soil physical properties such as texture, structure, permeability, and organic matter content. These soil physical properties were obtained through laboratory tests, using approximate values as provided by the Ministry of Forestry of the Republic of Indonesia[20] and the Directorate General of Reforestation and Land Rehabilitation[21], as detailed in Table 1, Table 2, and Table 3.

Table 1. Soil Structure Value[21]

Structure	Value
Very fine granular	1
Fine granular	2
Medium, coarse granular	3
Blocky, platty, massive	4

Table 2. Soil Permeability Assessment [21]

No.	Permeability type	Cm/hour	P Value
1	Fast	> 12.7	1
2	Medium to fast	6.3 – 12.7	2
3	Medium	2.0 – 6.3	3
4	Medium to low	0.5 – 2.0	4
5	Low	0.125 – 0.5	5
6	Very low	< 0.125	6

Table 3. Percentage Class of Organic Matter Content

Class	Organic matter content	Erodibility level
0	< 1	Very low
1	> 1 – 2	Low
2	> 2.1 – 3	Moderate
3	> 3.1 – 5	High
4	> 5	Very high

According to Dengler and El-Swaify[22] and suggested by Utomo[19] and Directorate General of Reforestation and Land Rehabilitation[21], the magnitude of soil erodibility factor (K) can be classified into 6 (six) classes, the details of which can be seen in Table 4.

Table 4. Classification of Soil Erodibility Factor (K)

Class	K Value	Erodibility level
1	0.00 – 0.10	Very low
2	0.11 – 0.20	Low
3	0.21 – 0.32	Moderate
4	0.33 – 0.43	High
5	0.44 – 0.55	Very high
6	> 0.56	Extremely high

3. Slope Length and Steepness (LS)

The slope length and steepness index is obtained by multiplying the slope length factor (L) with the slope steepness factor (S), resulting in the LS factor. The slope length factor can be calculated using the following equation from the Directorate General of Reforestation and Land Rehabilitation[21]:

$$L = \frac{\sum_{1}^{10} LP}{10} \ x \ \frac{1}{Cos\,\alpha}$$

Where:

L: slope length (m)

LP: horizontal map-based distance (cm)

Cos α: cosine of the slope angle (°)

The values of slope factor (S) and LS factor were obtained through the equation from Asdak[16].

S = (0.433 + 0.043 s²)/6.61

LS = L^{1/2}(0.0138 S² + 0.00965 S + 0.00138)

Where:

L: combined slope length and steepness factor

s: actual slope steepness (%)

S: slope steepness factor (%)

4. Crop Management (C Factor) and Soil Conservation (P Factor)

The value of C and P factors uses the approach of C and P factor values from the results of several researchers[23,24,17,19,16]. The C factor value can be seen in Table 5 and the P factor value can be seen in Table 6.

Table 5. Crop Management Factor Values (C Factor) [14,19]

No	Land Cover/Usage Type	C Factor Value
1.	Cultivated bare soil	1,00
2.	Uncultivated bare soil	0,95
3.	Cassava / ginger	0,90
4.	Low-density soybean	0,94
5.	Low-density peanut / maize	0,93
6.	Burnt alang-alang (Imperata grass)	0,89
7.	Taro	0,86
8.	Low-density alang-alang	0,84
9.	Cassava / rubber / oil palm without cover	0,80
10.	Medium-density maize / sparse elephant grass	0,70
11.	Low-density peanut	0,69
12.	Dense maize	0,637
13.	Maize + tobacco	0,610
14.	Green bean / banana (monoculture) / cotton	0,600
15.	Tobacco + elephant grass + blotong / peanut + stumps	0,57
16.	Dryland rice / medium-density upland rice	0,56
17.	Medium-density citronella	0,56
18.	Low-density mixed garden / pineaple + burned mulch	0,5
19.	Oil palm	0,5
20.	Sugar peanut	0,495
21.	Medium-density citronella / medium-density peanut	0,47
22.	Rice + maize / potato	0,45
23.	Dense citronella	0,43
24.	Rice + soybean	0,417
25.	Dense soybean	0,39
26.	Dense upland rice / rice + sorghum	0,34
27.	Medium-density sorghum	0,33
28.	Shrubland / medium-density mixed garden	0,30
29.	Pineapple + contour + buried mulch / Brachiaria grass type	0,30
30.	High-densiity sorghum	0,24
31.	Sugarcane / coffee + cover / forest with intensive cover crops (TPI)	0,20
32.	Cassava + peanut	0,195
33.	Cassava + soybean	0,18
34.	High-density peanut	0,17
35.	Peanut + peanut stumps	0,16
36.	Peanut + 4 tons/ha straw	0,128
37.	High-density mixed garden / medium-density alang-alang	0,10
38.	High-density field	0,10

39.	Rice + 4 tons/ha straw mulch	0,096
40.	Medium-density field	0,2
41.	High-density alang-alang	0,06
42.	Rainfed rice paddy	0,05
43.	Peanut + 4 tons/ha straw	0,049
44.	Brachiria grass type II	0,02
45.	Irrigated paddy / undisturbed shrubland	0,01
46.	Pineapple / mulch / savanna / undisturbed prairie	0,01
47.	Forest + thin litter	0,005
48.	Forest + thick litter	0,001
49	Forest	0,10
50	Shrubland	0,25
51	Alang-alang	0,25
52	Shrubland with swamp	0,17
53	Rubber plantation with settlement	0,37
54	Grassland with field	0,25
55	Shrubland with dryland crops	0,37
56	Village with fields	0,62
57	Shrubland with rubber plantation	0,22
58	Alang-alang with fields	0,25
59	Reforestation with alang-alang	0,18
60	Fields with dryland crops	0,37
61	Shrubland with village	0,43
62	Paddy field	0,02
63	Irrigated paddy	0,02
64	Rubber plantation with dryland crops	0,30
65	Plantation with village	0,40
66	Dryland farming	0,60
67	Plantation forest	0,15
68	Village with dryland farming	0,73
68	Dryland + field	0,48
69	Field + shrubland	0,25
70	Shrubland with irrigated rice paddy	0,17
71	Mixed garden	0,20
72	Dryland farming + alang-alang	0,48
73	Rubber garden	0,15
74	Rubber plantation with shrubland	0,18

Table 6. Soil Conservation Factor Values (P Factor)

No	Soil Conservation Measure	P Factor Value
1.	No. soil conservation practice	P = 1,0
2.	Contour farming, slope (S) = 0-8%	P = 0,50
3.	Contour farming, slope (S) = 9 – 20 %	P = 0,75
4.	Contour farming, slope (S) > 20 %	P = 0,90
5.	Mulch application 6 tons/ha/year	P = 0,30
6.	Mulch application 3 tons/ha/year	P = 0,50
7.	Mulch application 1 tons/ha/year	P = 0,80
8.	High-density cover crop	P = 0,10
9.	Medium-density cover crop	P = 0,50
10.	Low-density cover crop	P = 0,80
11.	Well-established grass cover	P = 0,04
12.	Ridge terraces	P = 0,14
13.	Traditional terraces	P = 0,40
14.	High-quality bench terrace (Bench Terrace – 1)	P = 0,04
15.	High-quality bench terrace (Bench Terrace – 2)	P = 0,15
16.	High-quality bench terrace (Bench Terrace – 3)	P = 0,35

5. Erosion Hazard Class (EHC) and Erosion Hazard Level (EHL) Analysis

According to the Directorate General of Reforestation and Land Rehabilitation[22], erosion hazard classes are categorized into five levels:

a) EHC I if A < 15 tons/ha/year.
b) EHC II if 15 < A < 60 tons/ha/year
c) EHC III if 60 < A < 180 tons/ha/year
d) EHC IV if 180 < A < 480 tons/ha/year
e) EHC V if A > 480 tons/ha/year

The erosion hazard level is determined by the combination of erosion hazard class (comprising five categories) and soil solum depth (divided into four categories). The matrix illustrating the erosion hazard levels is presented in Table 7.

Table 7. EHL Criteria Matrix [20,25]

Soil Depth (cm)	Erosion Hazard Class				
	I	II	III	IV	V
	Soil Erosion (ton/ha/year)				
	< 15	15 - < 60	60 - < 180	180 - < 480	> 480
	Erosion Hazard Level				
Deep (> 90)	0 – VL	I – L	II – M	III – H	IV – VH
Moderate (> 60 – 90)	I – L	II – M	III – H	IV – VH	IV – VH
Shallow (30 – 60)	II – M	III – H	IV – VH	IV – VH	IV – VH
Very Shallow (< 30)	III – H	IV – VH	IV – VH	IV – VH	IV – VH

Where:
0 – VL : Very Low
I – L   : Low
II – M : Moderate
III – H : Heavy
IV – VH: Very Heavy

RESULT
Erosion Hazard Level

1. Land Units

Land units in the Upper and Middle Bati-Bati Sub-watershed (hereafter referred to as the Bati-Bati Sub-watershed) were determined based on the overlay of soil type maps, slope maps, and land cover maps. The result of this map overlay can be seen in Figure 2.
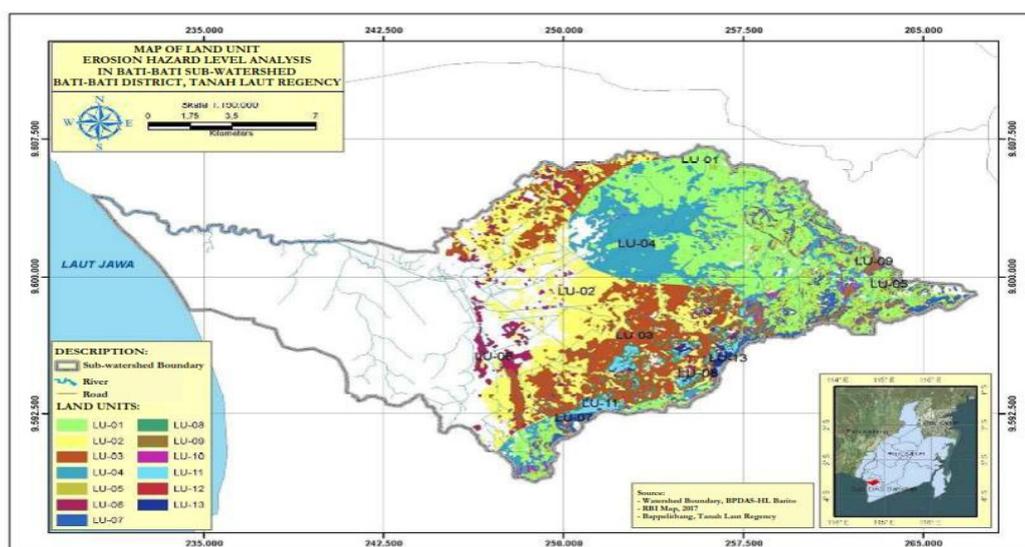

Figure 2. Land Unit Map for Erosion Hazard Level Analysis in the Bati-Bati Sub-watershed

Based on the results shown in Figure 2, it can be concluded that thirteen land units were identified in this study. The codes for the land units and their respective areas under different land cover types are presented in Table 8.

Table 8. Data on Land Units, Slope Classes, Land Cover, and Soil Types in the Bati-Bati Sub-watershed

No	Land Units	Land Cover	Soil Type	Slope (%)	Area (ha)	%
1	LU - 01	Plantation	RPLr	0 – 8	4,583.40	25.2
2	LU - 02	Shrubland	OGH	0 – 8	3,830.50	21
3	LU - 03	Plantation	OGH	0 – 8	3,023.30	16.6
4	LU - 04	Shrubland	RPLr	0 – 8	2,652.60	14.6
5	LU - 05	Plantation	RPLr	>8 – 15	1,192.80	6.6
6	LU - 06	Open Area	OGH	0 – 8	655.1	3.6
7	LU - 07	Plantation	RPLr	>15 - 25	699.4	3.8
8	LU - 08	Plantation	OGH	>8 – 15	402.6	2.2
9	LU - 09	Shrubland	RPLr	>15 - 25	304.4	1.7
10	LU - 10	Shrubland	RPLr	0 – 8	288.6	1.6
11	LU - 11	Plantation	OGH	>15 - 25	285.1	1.6
12	LU - 12	Shrubland	OGH	>8 – 15	160.9	0.9
13	LU - 13	Shrubland	OGH	>15 - 25	130.5	0.7

Where:

LU: Land Units

RPLr: Red Podzolic – Lateritic Complex Soil Type

OGH: Organosol Gley Humus

Table 8 presents the results of the analysis, revealing that there are three types of land cover within the study area: plantations, covering an area of 10,186.6 ha (55.9%); shrubland, covering 7,367.4 ha (40.5%); and open areas, covering 665.1 ha (3.6%). The total area of all land units is 18,209.01 ha. The variation in slope classes within the study area is categorized into three classes: flat slopes (0–8%) encompassing 14,744.9 ha, which accounts for 81% of the total area; gentle slopes (8–15%) with an area of 2,044.8 ha or 11.2%; and moderately steep slopes (15–25%) with an area of 1,419.4 ha or 7.8%.

2. Estimation of Erosion (A)

The data obtained from the analysis of rainfall, soil physical properties, and slope were processed using the mathematical model equations described in the research methodology and analyzed using Microsoft Excel. The rainfall data (R) were based solely on monthly total precipitation, as data on rainfall frequency (number of rainy days) and maximum daily rainfall were not available. The final R value was calculated as the average of the values estimated by the formulas of Lenvain, Utomo and Mahmud, and Soemarwoto. The estimation of the R values is presented in Table 9.

The K factor in this study was obtained through calculation using Equation (2). Laboratory analysis revealed that the percentage of organic matter at the study sites varied widely, ranging from 2.01 to 5.90. The soil structure in the study area was identified as fine granular and medium to coarse granular. The soil permeability in the Bati-Bati Sub-Watershed ranged from medium to medium to low classes. The C factor values in this study were adjusted according to the land cover types listed in Table 5. Plantation areas had a C factor value of 0.17, shrubland had a C factor value of 0.3, and open areas had a C factor value of 0.95. The P factor was determined from secondary data, which indicated that no soil conservation measures were implemented in the study area; therefore, the P factor value was set at 1. The results of this analysis were then entered into the USLE equation to calculate the estimated soil loss (A). A detailed recapitulation of the erosion estimates (A) for each land unit, slope class, and land cover type is presented in Table 10.

Table 9. monthly Rainfall Data and R Values in the Bati-Bati Sub-Watershed

Monthly Rainfall	Average Monthly Rainfall Over the Last 10 Years (cm)	Rainfall Erosivity Factor (R)			
		Lenvain (units/month)	Utomo & Mahmud (units/month)	Soemarwoto (units/month)	Average (units/month)
Jan	33	262.1	561.0	18.8	280.6
Feb	26	181.2	425.7	14.0	207.0
March	23	158.2	384.4	12.6	185.1
April	19	124.6	321.0	10.4	152.0
May	13	72.2	212.1	6.7	97.0
June	10	50.1	160.1	5.0	71.7
Jully	8	38.5	130.2	4.0	57.6
Aug	4	16.8	66.9	2.1	28.6
Sept	6	23.6	88.1	2.7	38.1
Oct	9	45.6	148.6	4.6	66.3
Nov	28	203.9	465.0	15.4	228.1
Dec	36	285.2	597.6	20.2	301.0
Total	216	1,462.0	3,560.6	116.6	1,713.1
Rm = Average Rain Erosivity Index (units/year)					1,713.1

Table 10. Result of Soil Erosion (A) Analysis in the Bati-Bati Sub-Watershed

No	Land Units	Land Cover	Area (ha)	Slope	Soil Type	R	K	LS	C	P	Fk	A
1	LU - 01	Plantation	4,583.4	0 - 8%	RPLr	1,713.1	0.124	0.71	0.17	1.00	0.61	25.55
2	LU - 02	Shrubland	3,830.5	0 - 8%	OGH	1,713.1	0.380	0.74	0.30	1.00	0.61	144.87
3	LU - 03	Plantation	3,023.3	0 - 8%	OGH	1,713.1	0.225	0.72	0.17	1.00	0.61	47.20
4	LU - 04	Shrubland	2,652.6	0 - 8%	RPLr	1,713.1	0.237	0.74	0.30	1.00	0.61	90.29
5	LU - 05	Plantation	1,192.8	8 - 15%	RPLr	1,713.1	0.197	1.79	0.17	1.00	0.61	102.63
6	LU - 06	Open Area	655.1	0 - 8%	OGH	1,713.1	0.380	0.74	0.95	1.00	0.61	458.75
7	LU - 07	Plantation	699.4	15 - 25%	RPLr	1,713.1	0.177	2.81	0.17	1.00	0.61	145.07
8	LU - 08	Plantation	402.6	8 - 15%	OGH	1,713.1	0.195	1.64	0.17	1.00	0.61	92.84
9	LU - 09	Shrubland	304.4	15 - 25%	RPLr	1,713.1	0.307	2.81	0.30	1.00	0.61	444.35
10	LU - 10	Shrubland	288.6	8 - 15%	RPLr	1,713.1	0.297	1.79	0.30	1.00	0.61	273.81
11	LU - 11	Plantation	285.1	15 - 25%	OGH	1,713.1	0.207	2.61	0.17	1.00	0.61	157.53
12	LU - 12	Shrubland	160.9	8 - 15%	OGH	1,713.1	0.296	1.64	0.30	1.00	0.61	249.15
13	LU - 13	Shrubland	130.5	15 - 25%	OGH	1,713.1	0.308	2.61	0.30	1.00	0.61	413.85

Where:

LU: Land Units

RPLr: Red Podzolic – Lateritic Complex Soil Type

OGH: Organosol Gley Humus

R: Rainfall Erosivity Factor

K: Soil Erodibility Factor

LS: Slope Length and Steepness

C: Crop Management

P: Mechanical Soil Conservation Factors

Fk: Correction Factor[15]

A: Soil Erosion (tons/ha/year)

The results of the erosion calculations in the Bati-Bati Sub-Watershed varied widely, with the lowest erosion value observed in land unit 01 (Plantation) at 25.55 tons/ha/year, while the highest erosion value was recorded in land unit 06 (Open Area) at 458.75 tons/ha/year. A bar chart illustrating the distribution of erosion across various land units in the Bati-Bati Sub-Watershed is presented in Figure 3.
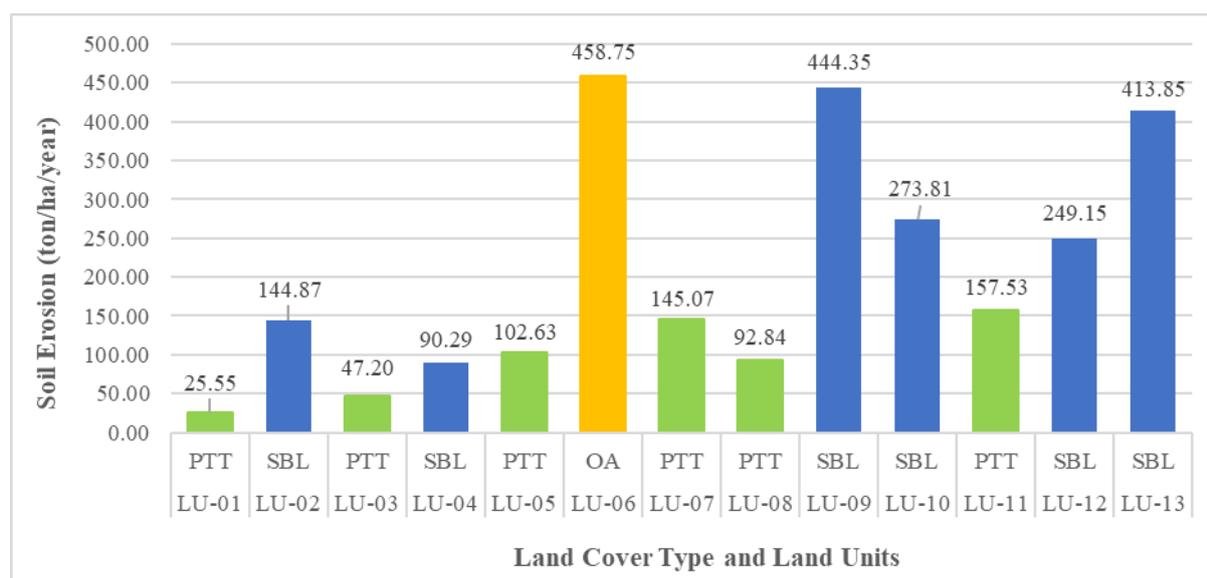
Figure 3. Bar Chart of Erosion in Various Land Units in the Bati-Bati Sub-Watershed

3. Analysis of Erosion Hazard Level

Based on the data presented in Table 10 and Figure 3, the erosion hazard level was analyzed with consideration of the soil solum depth. The results of this analysis are presented in Table 11.

Table 11. Actual erosion, EHC, and EHL for various land units and land cover types in the Bati-Bati Sub-Watershed

No	Land Unit	Land Cover Type	Area (ha)	Soil Depth	Estimated Erosion (A) (ton/ha/year)	Erosion Hazard Class (EHC)	Erosion Hazard Level (EHL)
1	LU-01	Plantation	4,583.4	Deep	25.55	II	I – Low
2	LU-02	Shrubland	3,830.5	Shallow	144.87	III	IV – Very Heavy
3	LU-03	Plantation	3,023.3	Deep	47.20	II	I – Low
4	LU-04	Shrubland	2,652.6	Moderate	90.29	III	III – Heavy
5	LU-05	Plantation	1,192.8	Deep	102.63	III	II – Moderate
6	LU-06	Open Area	655.1	Shallow	458.75	IV	IV – Very Heavy
7	LU-07	Plantation	699.4	Deep	145.07	III	II – Moderate
8	LU-08	Plantation	402.6	Deep	92.84	III	II – Moderate
9	LU-09	Shrubland	304.4	Shallow	444.35	IV	IV – Very Heavy
10	LU-10	Shrubland	288.6	Moderate	273.81	IV	IV – Very Heavy
11	LU-11	Plantation	285.1	Deep	157.53	III	II – Moderate
12	LU-12	Shrubland	160.9	Moderate	249.15	IV	IV – Very Heavy
13	LU-13	Shrubland	130.5	Shallow	413.85	IV	IV – Very Heavy

Based on the data in Table 11, the lowest erosion value was observed in land unit LU-01 with plantation land cover (25.55 tons/ha/year), while the highest erosion value occurred in land unit LU-06 with open area land cover (458.75 tons/ha/year). The erosion hazard classes derived from field data analysis ranged from Class II to Class IV. Class II erosion hazard was predominantly associated with plantation land cover (LU-01 and LU-03), Class III was mainly found in plantation and shrubland land covers, and Class IV was primarily associated with shrubland and open area land covers. The erosion hazard levels also varied, ranging from Level I (Low) to Level IV (Very Heavy). Low erosion hazard levels were identified in land units LU-01 and LU-04, whereas very high erosion hazard levels were found in land units LU-02, LU-06, LU-09, LU-10, LU-12, and LU-13. A summary of the erosion hazard levels across different land cover types, based on Table 11, is presented in Table 12.

Table 12. Summary of Erosion Hazard Levels in the Bati-Bati Sub-Watershed

Land Cover Type	Land Units	Slope (%)	Erosion Hazard Level (EHL)	Area		Total Area	
				Ha	%	Ha	%
Plantation	LU-01, LU-03	0 – 8	I – Low	7,606.6	41.8	10,186.6	55.9
	LU-05, LU-08, LU-07, LU-11	8 – 15, 15 – 25	II – Moderate	2,579.9	14.2		
Shrubland	LU-04	0 – 8	III – Heavy	2,652.6	14.6	7,367.4	40.5
	LU-02, LU-10, LU-12, LU-09, LU-13	0 – 8, 8 – 15 15 – 25	IV – Very Heavy	4,714.8	25.9		
Open Area	LU-06	0 – 8	IV – Very Heavy	655.1	3.6	655.1	3.6

The analysis results indicate that the dominant land cover in the Bati-Bati Sub-Watershed is plantation, covering an area of 10,186.6 ha or 55.9% of the total study area. The lowest erosion hazard levels were found in plantation land cover (LU-01 and LU-03), while the highest erosion hazard levels were observed in shrubland (all land units except LU-04) and open area (LU-06). The study also revealed that steeper slopes within the same land cover type exhibited higher erosion hazard levels; for example, plantation areas with slopes of 8%–25% demonstrated moderate erosion hazard levels, compared to plantations with slopes of 0%–8%, which showed low erosion hazard levels. Based on Table 10, a summary of erosion hazard levels in the Bati-Bati Sub-Watershed is presented in Figure 4.
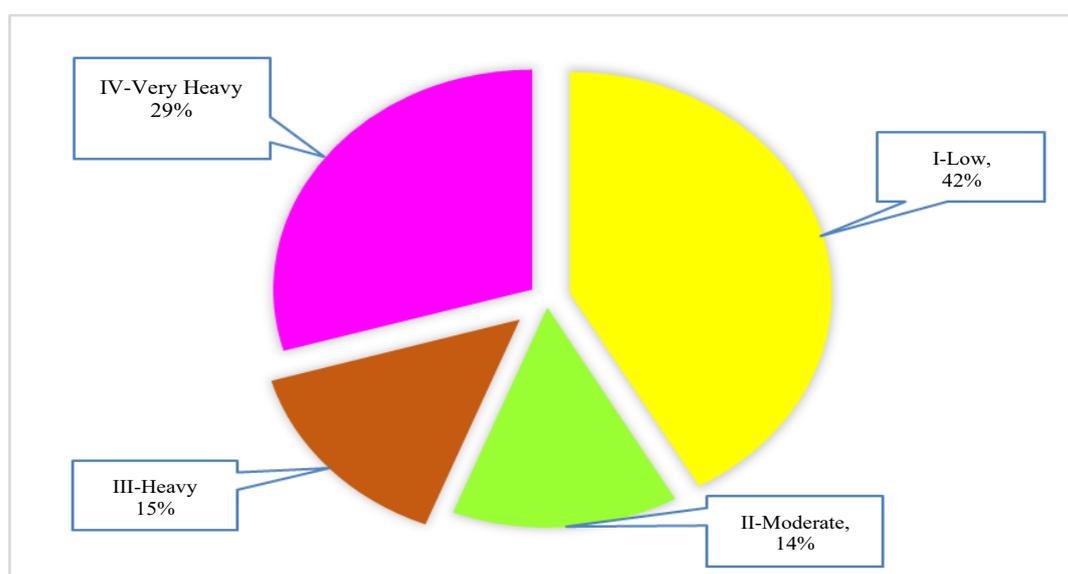

Figure 4. Pie Chart of Erosion Hazard Levels in the Bati-Bati Sub-Watershed

Figure 4 illustrates the distribution of erosion hazard levels in the Bati-Bati Sub-Watershed, which includes low, moderate, severe, and very severe hazard categories. The erosion hazard is predominantly low, covering 42% of the area (7,606.7 ha), followed by a very severe hazard level occupying 29% of the area (5,369.8 ha). The severe and moderate hazard levels account for 15% and 14% of the area, corresponding to 2,652.6 ha and 2,579.9 ha, respectively. The spatial distribution of erosion hazard levels shown in Figure 4 is presented on the map in Figure 5.
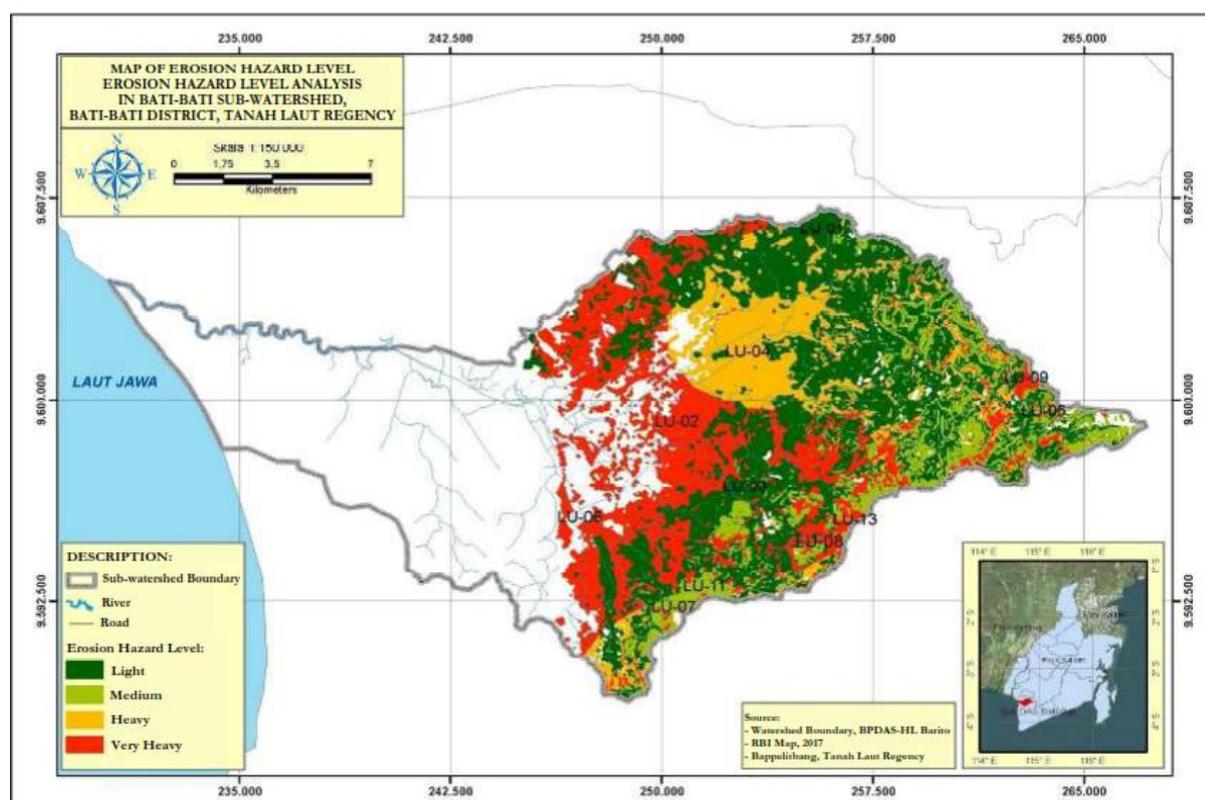
Figure 5. Map of Erosion Hazard Levels in the Bati-Bati Sub-Watershed

Badaruddin[26] reported that the erosion hazard index tends to be higher on shrubland cover compared to forest and plantation land covers. The findings of this study are consistent with this observation, as the erosion hazard index was found to be lower on plantation land cover relative to shrubland and open area covers. Furthermore, slope gradient significantly influences the magnitude of the erosion hazard index in the Bati-Bati Sub-Watershed. For instance, land units LU-01 and LU-05 share the same land cover type; however, due to differences in slope steepness, their erosion hazard indices vary accordingly.

Rehabilitation Guidance for Forest and Land Areas

The summary of rehabilitation guidelines for forest and land areas or watershed rehabilitation for each land unit, land cover type, and slope class in the Bati-Bati Sub-Watershed is based on data from Tables 11, 12, and Figure 4. The results of the analysis and the corresponding summary are presented in Table 13.

Table 13. Recommended Forest and Land Rehabilitation Patterns in the Bati-Bati Sub-Watershed

EHL	Land Cover	Land Unit	Slope (%)	FLR Guidance	Area		Total Area	
					Ha	%	Ha	%
I-L	Plantation	LU-01, LU-03	0 – 8	Plantation	7,606.7	41.8	10,186.6	55.9
II-M	Plantation	LU-05, LU-08	8 – 15	Plantation	2,579.8	14.2		
		LU-07, LU-11	15 – 25	Plantation				
III-H	Shrubland	LU-04	0 – 8	Forest Plantation	2,652.6	14.6	7,367.4	40.5
IV-VH	Shrubland	LU-02, LU-10	0 – 8	Forest Plantation	4,714.8	25.9		
	Shrubland	LU-09, LU-12	8 – 15	Forest Plantation				
	Shrubland	LU-13	15 – 25	Forest Plantation				
	Open Area	LU-06	0 – 8	Agroforestry	655.1	3.6	655.1	3.6
Total					18,209	100	18,209	100

Where:
EHL: Erosion Hazard Level
I-L: Low
II-M: Moderate
III-H: Heavy
IV-VH: Very Heavy
FLR: Forest and Land Rehabilitation
LU-i: i-th Land Unit (i=1,2,3,....,13)

The rehabilitation guidance analysis in the Bati-Bati Sub-Watershed, as presented in Table 11, identifies three distinct Forest and Land Rehabilitation (FLR) patterns. The FLR recommendation for plantation land cover is to maintain its current condition, whereas the other two land cover types should ideally be transformed or converted. Shrubland areas are suggested to be managed or converted into planted forests, with species selection tailored to site-specific growing conditions. Open area land cover is recommended to be converted into agroforestry systems or forest farming enterprises, incorporating a diversity of perennial and annual food crops. The spatial distribution of the rehabilitation guidance in the Bati-Bati Sub-Watershed is illustrated in Figure 6.
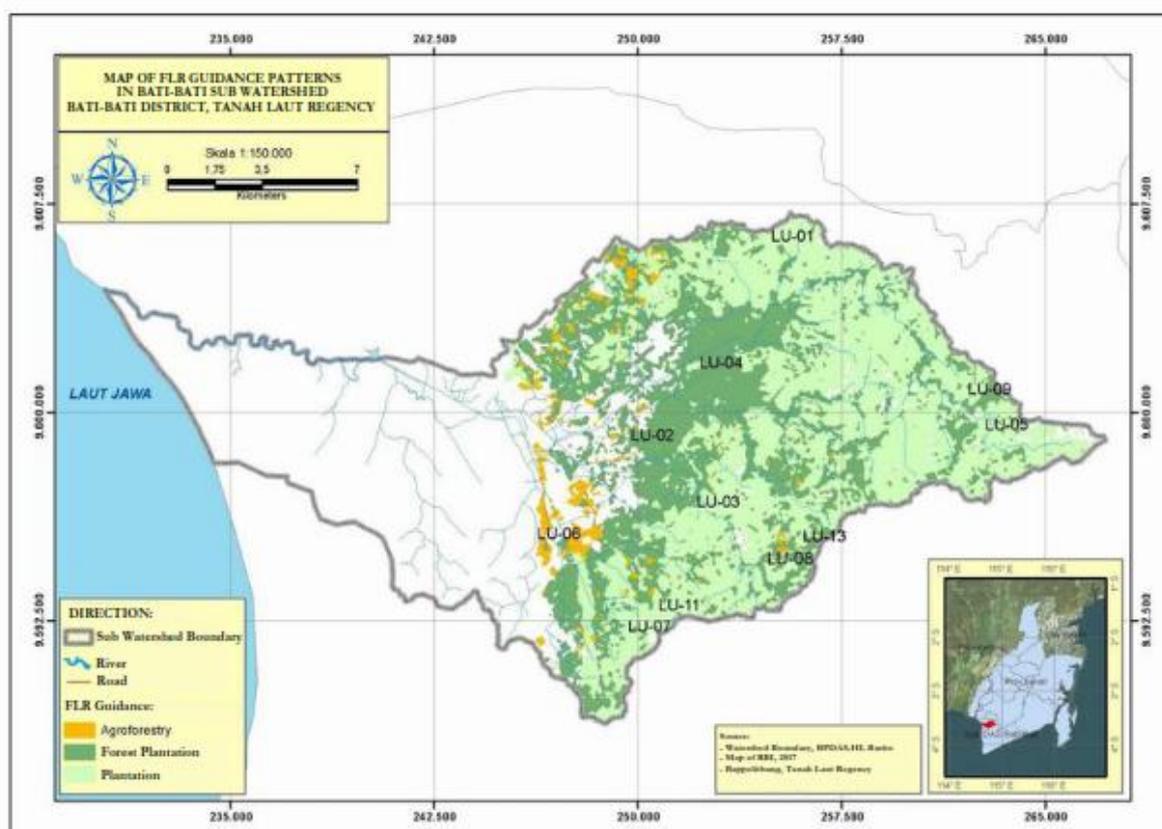

Figure 6. Map of FLR Guidance Patterns in the Bati-Bati Sub-Watershed

DISCUSSION

Erosion Hazard Level

The land cover identified at the study site is categorized into three types: plantations, shrubland, and open areas. These findings are consistent with previous studies by Pratiwi[27] and Ilmi[28], which reported that the land cover in the Bati-Bati Sub-Watershed consists predominantly of plantations, shrubland, and alang-alang grassland. The soil types observed in the study area include complex red-yellow podzolic-lateritic soils and humic gley organosols. The complex red-yellow podzolic-lateritic soil represents a mixture of two main soil types: red podzolic soil (sometimes referred to as red-yellow podzolic soil) and lateritic soil, each possessing distinct characteristics. This soil mixture is characterized by low fertility, hard structure, and high susceptibility to degradation, necessitating appropriate management and conservation measures to optimize land use and sustain productivity in the area.

Data presented in Table 10 indicate that three land units exhibit erosion rates exceeding 400 tons/ha/year, specifically LU-06 (458.75 tons/ha/year), LU-09 (444.35 tons/ha/year), and LU-13 (413.85 tons/ha/year). These units are characterized by open area and shrubland land covers, both of which lack woody vegetation. The absence of deep-rooted plants results in a deficiency of strong root systems capable of stabilizing soil particles and preventing displacement. High erosion values are strongly influenced by land cover type[29]. This observation aligns with the current study's findings, where land covers without woody vegetation showed significantly higher erosion rates compared to those with woody vegetation.

Comparative analysis with other studies reveals that erosion rates in the Bati-Bati Sub-Watershed are substantially higher than those reported in the Riam Kanan Sub-Watershed. Sumaryono[30] documented the highest erosion rate in Riam Kanan Sub-Watershed at 58.26 tons/year for secondary forest and plantation land cover, markedly lower than the 458.75 tons/ha/year observed in this study. However, the erosion values here are lower than those reported for the Citarum Watershed, where Kardhana[31] found peak erosion rates reaching 522 tons/ha/year in the Cikao sub-catchment.

The elevated erosion rates observed in this study are also attributed to the soil conservation factor (P factor). Although the P factor is often considered the most uncertain parameter in erosion modeling[32,33], it can be derived through direct observation, remote sensing data, prior research, or expert judgment[33,34]. According to Table 6, the P factor equals 1 when no mechanical soil conservation practices are implemented. In the present study (Table 10), the P factor is set at 1, indicating the absence of soil conservation measures in the Bati-Bati Sub-Watershed, thus increasing the erosion hazard index. Pham[33] further emphasize that in the absence of erosion control measures, the P factor should be assigned a value of 1.

Data presented in Tables 11 and 12 indicate that land cover plays a significant role in the analysis of erosion hazard levels. Denser vegetation cover in an area correlates with a lower likelihood of erosion occurrence. Although the study area is predominantly characterized by flat slopes, erosion hazard levels in this research vary widely, with steeper slopes exhibiting higher erosion indices. These findings align with the assertion by May & Lisle[35] that steeper terrain results in increased erosion due to elevated surface runoff, which facilitates soil particle detachment and transport.

Furthermore, soil depth in the Bati-Bati Sub-Watershed, which ranges from shallow (30–60 cm) to moderate (>60–90 cm), also influences erosion hazard levels and plant productivity. According to Hirzel & Matus[44], an effective soil depth of 20 cm (classified as shallow) has a significant impact on land productivity, in addition to climatic and soil chemical properties. This is consistent with findings from the Riam Kanan Sub-Watershed, where shallow

effective soil depth (UL.1) corresponds to a high erosion hazard level (III-B: Heavy). Similarly, in the present study, shallow soil depth areas generally fall into the very high erosion hazard category (IV–Very Heavy).

Based on Figure 4, it can be concluded that most of the land in the Bati-Bati Sub-Watershed in this study falls within the low erosion hazard category (42%). However, without appropriate conservation and management efforts, the very high erosion hazard level (29%) could increase further and pose a significant threat in the future. The results of this study are consistent with findings from similar studies in Desa Banua Riam and the Citarum Watershed, where the majority of erosion hazard levels were categorized as low (31%) in Desa Banua Riam and very low (45%) in the Citarum Watershed[30,31]. A similar pattern was observed in the A Sap Basin, Central Vietnam, where the two highest erosion hazard classes were very low (47%) and high (28%). As in this study, if proper land management is not implemented in the A Sap Basin, the high erosion hazard level could increase[33].

Rehabilitation Guidance for Forest and Land Areas

Watersheds located in the upper and middle reaches serve critical ecological functions, including protection, buffering, and hydrological regulation, all of which significantly influence water availability in the downstream areas. Based on this premise, two essential considerations must be emphasized in the utilization of dryland areas: (1) the broad-scale enhancement of agricultural productivity, and (2) the implementation of soil, water, and vegetation conservation efforts aimed at environmental restoration.

The selection of forest and land rehabilitation (FLR) pattern directions must consider various factors, including land cover type, slope conditions, and erosion hazard levels. Based on the spatial distribution of the FLR pattern directions presented in Figure 6, two main groups can

be distinguished: (1) the group of land covers maintained with specific treatments, and (2) the group of land covers converted into plantation forests or agroforestry systems.

The land cover group maintained with specific treatments comprises plantation areas. In contrast, the land cover group to be converted into industrial plantation forests (HTI) and agroforestry includes shrubland and open land. For both FLR pattern groups, soil management practices should include contour planting and the construction of ridge terraces to reduce erosion and improve the effectiveness of land rehabilitation efforts.

The recommended FLR patterns align with the views of Badaruddin[26] and Ruslan[36], which state that the core activities of FLR consist of reforestation, plantation forests, agroforestry, and the implementation of vegetative and civil engineering soil conservation techniques on critical and unproductive lands. If the recommended FLR patterns employing vegetative and mechanical (civil engineering) methods are successfully implemented, theoretically, both the crop management factor (C) and the conservation support practice factor (P) will be reduced, thereby decreasing the estimated soil loss (A). Research in the catchment area of the Jaing Sub-Watershed, Negara Sub-District, South Kalimantan Province, has demonstrated that the conversion of shrubland to forest through reforestation following contour planting and ridge terrace construction can reduce the erosion hazard level from very high to low or very low, and also decrease flood vulnerability from vulnerable to less vulnerable.

The mechanisms by which primary and secondary forest vegetation (including plantation forests) influence surface runoff and erosion processes include: a) interception by the tree canopy and forest floor litter, which reduces the kinetic energy of raindrops and minimizes their impact on soil particles[14,37]; b) the presence of litter layers that slow down the velocity of

surface runoff and reduce the erosive power of water[38,39]; c) the role of roots, humus, and biological soil activity in enhancing soil structure stability and porosity, thus limiting soil particle displacement and preventing erosion[40,41]; and d) transpiration processes that utilize groundwater absorbed by roots, increasing soil infiltration and decreasing surface runoff[15-16,42-43]. Based on these findings, the Forest and Land Rehabilitation (FLR) guidelines proposed for the Bati-Bati Sub-Watershed are highly relevant, particularly if implemented effectively. The successful implementation of these FLR guidelines is expected to restore, maintain, and improve forest and land functions, thereby supporting the sustainability, productivity, and essential ecological roles of these landscapes in maintaining life-support systems[45-46].

CONCLUSION

The study area comprises 13 land units with three main land cover types: plantations covering 10,186.6 ha (55.9%), shrubland covering 7,367.4 ha (40.5%), and open areas covering 665.1 ha (3.6%). The slope conditions are categorized into three classes: flat (0–8%) covering 14,744.9 ha (81%), gentle slope (8–15%) covering 2,044.8 ha (11.2%), and moderately steep (15–25%) covering 1,419.4 ha (7.8%). The analyzed erosion hazard levels in this study include class I–Low covering 7,606.7 ha (41.8%), class IV–Very Heavy covering 5,369.8 ha (29.5%), class III–Heavy covering 2,652.6 ha (14.6%), and class II–Moderate covering 2,579.9 ha (14.2%). The recommended restoration patterns for Forest and Land Rehabilitation (FLR) activities are divided into three groups: a) shrubland cover is converted into plantation forest through the establishment of Indonesian Plantation Forests (IPF) covering 7,367.4 ha (40.5%), with vegetation types selected based on their growing conditions, high resilience, and good productivity; b) open land is converted into agroforestry systems with various perennial crops and seasonal food crops covering 665.1 ha (3.6%); and c) plantation land cover is maintained and rehabilitated with superior species suited to local growth conditions covering 10,186.6 ha (55.9%).

REFERENCES

1. Kementerian Kehutanan Republik Indonesia. (2011). *Kebijakan Rehabilitasi Hutan dan Lahan [Forest and Land Rehabilitation Policy]*. Direktorat Jenderal Bina Pengelolaan DAS dan Perhutanan Sosial. Jakarta.
2. BPDAS-HL Barito (Balai Pengelolaan DAS-Hutan Lindung Barito). (2013). *Updating data spasial lahan kritis Wilayah Kerja Balai Pengelolaan DAS Barito [Updating spatial data of critical land in the working area of the Barito Watershed Management Centre]*. Banjarbaru.
3. Kementerian Kehutanan Republik Indonesia. (2014). *Peraturan Menteri Kehutanan No, P.60/Menhut-II/2014 tentang Kriteria Penetapan Klasifikasi Daerah Aliran Sungai [Minister of Forestry Regulation No. P.60/Menhut-II/2014 on Criteria for Determining the Classification of Watersheds]*. Jakarta.
4. Gharibreza, M., Bahrami Samani, A., Arabkhedri, M., Zaman, M., Porto, P., Kamali, K., Sobh-Zahedi, S. (2021). Investigation of on-site implications of tea plantations on soil erosion in Iran using 137Cs method and RUSLE. *Environ. Earth. Sci. 80 (1)*, 1–14. https://doi.org/10.1007/s12665-020-09347-y
5. Chakrabortty, R., Pradhan, B., Mondal, P., Pal, S.C. (2020a). The use of RUSLE and GCMs to predict potential soil erosion associated with climate change in a monsoon-dominated region of eastern India. *Arab. J. Geosci. 13 (20)*, 1073. https://doi.org/10.1007/s12517-020-06033-y
6. Chakrabortty, R., Pal, S.C., Chowdhuri, I., Malik, S., Das, B. (2020b). Assessing the importance of static and dynamic causative factors on erosion potentiality using SWAT, EBF with uncertainty and plausibility, logistic regression and novel ensemble model in a sub-tropical environment. *J.*

Indian Soc. Remote Sens. 48, 765–789. https://doi.org/10.1007/s12524-020-01110-x

7. Chakrabortty, R., Pal, S.C., Sahana, M., Mondal, A., Dou, J., Pham, B.T., Yunus, A.P. (2020c). Soil erosion potential hotspot zone identification using machine learning and statistical approaches in eastern India. *Nat. Haz. 104*, 1259–1294. https://doi.org/10.1007/s11069-020-04213-3

8. Taloor, A.K., Khajuria, V., Parsad, G., Bandral, S., Mahajan, S., Singh, S., Sharma, M., Kothyari, G.C. (2025). Geospatial assessment of soil erosion in the Basantar and Devak watersheds of the NW Himalaya: A study utilizing USLE and RUSLE models. *Geosystems and Geoenvironment, 4(2)* 100355. https://doi.org/10.1016/j.geogeo.2025.100355

9. Das, B., Paul, A., Bordoloi, R., Tripathi, O.P., Pandey, P.K. (2018). Soil erosion risk assessment of hilly terrain through integrated approach of RUSLE and geospatial technology: a case study of Tirap District, Arunachal Pradesh. *Model. Earth Syst. Environ. 4 (1)*, 373–381. https://doi.org/10.1007/s40808-018-0435-z

10. Miller, S.N., Kepner, W.G., Mehaffey, M.H., Hernandez, M., Miller, R.C., Goodrich, D.C., Kim Devonald, K., Heggem, D.T., Miller, W.P. (2002). Integrating landscape assessment and hydrologic modeling for land cover change analysis 1. *JAWRA J. Am. Water Res. Assoc. 38 (4)*, 915–929. https://doi.org/10.1111/j.1752-1688.2002.tb05534.x

11. Taloor, A.K., Sharma, R., Kothyari, G.C. (2023). Tectono-geomorphic and active deformation studies in the Ujh basin of Northwestern Himalaya. Qua*ternary Sci. Advances 12*, 100121. https://doi.org/10.1016/j.qsa.2023.100121

12. Delgado, D., Sadaoui, M., Ludwig, W., Méndez, W., Ortiz-Hernández, E., Farfán Intriago, P. (2025). Assessment of soil erosion by RUSLE in the Ecuadorian basins (2001− 2020) based on GIS and high-resolution satellite data: main drivers and changes on soil erosion. *Geomorphology 469*, 109515. https://doi.org/10.1016/j.geomorph.2024.109515

13. Hardjowigeno, S. (1985). *Klasifikasi Tanah. Survei Tanah Evaluasi Kemampuan Lahan [Soil Classification. Soil Survey Land Capability Evaluation]*. Improvements of the original text. IPB. Bogor. 283 Hal.

14. Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning (No. 537)*. Department of Agriculture, Science and Education Administration. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning - Walter H. Wischmeier, Dwight David Smith - Google Buku

15. Ruslan, M. (1992). *Sistem Hidrologi Hutan Lindung DAS Riam Kanan di Kabupaten Banjar, Kalimantan Selatan [Hydrological System of Protected Forest of Riam Kanan Watershed in Banjar Regency, South Kalimantan]*. Dissertation at the Graduate Faculty of IPB. Bogor.

16. Asdak, C. (2010). *Hidrologi dan Pengelolaan Daerah Aliran Sungai, Cetakan ke-5 [Hydrology and Watershed Management, 5th Edition]*. Gadjah Mada University Press, Yogyakarta.

17. Soemarwoto, O. (1997). *Ekologi Lingkungan Hidup dan Pembangunan [Environmental Ecology and Development]*. Jakarta: Djambatan.

18. Rahim, S.E. (2006). *Pengendalian Erosi Tanah: Dalam Rangka Pelestarian Lingkungan Hidup [Soil Erosion Control: In the Framework of Environmental Preservation]*. Jakarta: Bumi Aksara.

19. Utomo, W.H. (1994). *Erosi dan Konservasi Tanah [Soil Erosion and Conservation]*. Malang: IKIP, Malang.

20. Departemen Kehutanan. (1994). *Petunjuk Memperkirakan Besarnya Erosi pada Suatu Lahan dengan Menggunakan Metode USLE [Instructions for Estimating the Amount of Erosion on Land Using the USLE Method]*. Ministry of Forestry of the Republic of Indonesia, Jakarta.

21. Direktorat Jenderal Reboisasi dan Rehabilitasi Lahan. (1998). *Keputusan Direktur Jenderal Reboisasi dan Rehabilitasi Lahan (Ditjen RRL) Nomor 041/Kpts/V/1998 Tanggal 21 April 1998 tentang Pedoman Penyusunan Rencana Teknik Lapangan rehabilitasi Lahan dan Konservasi Tanah Daerah Aliran Sungai [Decree of the Director General of Reforestation and Land Rehabilitation (DG RLR) No. 041/Kpts/V/1998 Dated 21 April 1998 on Guidelines for the Preparation of*

Field Technical Plans for Land Rehabilitation and Soil Conservation of Watersheds]. Directorate General of Reforestation and Land Rehabilitation. Ministry of Forestry of the Republic of Indonesia, Jakarta.

22. Dangler, E.W., & El-Swaify, A. (1976). Erosion of Selected Hawaii Soils by Simulated Rainfall. *Soil Science Society of America Journal, 40*: 769-773. https://doi.org/10.2136/sssaj1976.03615995004000050040x

23. Abdurachman, A., Abuyamin, S., & Kurnia, U. (1984). *Pengelolaan tanah dan tanaman untuk usaha konservasi tanah [Soil and crop management for soil conservation]*. Pemberitaan Penelitian Tanah dan Pupuk, 3: 7-12.

24. Ambarwati, R., & Patandean, A.J. (2018). Evaluasi Perubahan Perilaku Erosi Daerah Aliran Sungai Ramang-Ramang Dengan Pemodalan Spasial [Evaluation of Erosion Behaviour Change of Ramang-Ramang Watershed with Spatial Modelling]. *Jurnal Sain dan Pendidikan Fisika, 14(1)*: 98-105. https://doi.org/10.35580/jspf.v14i1.6327

25. Kadir, S. (2016). *Soil and Water Conservation Module (20162-FMKB-103) Soil Erosion*. Lambung Mangkurat University

26. Badarudin. (2014). *Kemampuan dan Daya Dukung Lahan di Sub DAS Kusambi DAS Batulicin Kabupaten Tanah Bumbu, Provinsi Kalimanatan Selatan [Land Capability and Supportability in Kusambi Sub-watershed of Batulicin Watershed, Tanah Bumbu Regency, South Kalimanatan Province]*. Dissertation of Graduate Programme, Faculty of Agriculture, Brawijaya University. Malang.

27. Pratiwi, Y.E., Kadir, S., Badaruddin. (2021). Analisis Infiltrasi pada Berbagai Tutupan Lahan di Sub DAS Bati-Bati DAS Maluka Kalimantan Selatan [Analysis of Infiltration on Various Land Cover in Sub DAS Bati-Bati DAS Maluka South Kalimantan]. *Jurnal Sylva Scienteaa*, 4(5): 928-937. http://dx.doi.org/10.20527/jss.v4i5.4217

28. Ilmi, Z., Badaruddin, Suyanto, Fithria, A. (2023). Analisis Estimasi Laju Erosi di DAS Maluka Provinsi Kalimantan Selatan dengan Model E30 [Analysis of Erosion Rate Estimation in DAS Maluka South Kalimantan Province with the E30 Model].

EnviroScienteae, 19(4): 36-44. http://dx.doi.org/10.20527/es.v19i4.17795

29. Ruslan, M, Fithria, A., Peran, B.S., Syam'ani. (2016). *Pola Arahan Rehabilitas Hutan Dan Lahan Di Sub Sub DAS Amandit Kabupaten Hulu Sungai Selatan [Patterns of Land and Forest Rehab Directions in the Amandit Subwatershed of Hulu Sungai Selatan Regency]*. UNLAM Fakultas Kehutanan. Banjarbaru. https://repo-dosen.ulm.ac.id//handle/123456789/9325

30. Sumaryono, Badaruddin, Ruslan, M. (2024). Analisis Kelas Kemampuan Penggunaan Lahan di Areal Sub DAS Riam Kanan Kabupaten Banjar Provinsi Kalimantan Selatan [Land Use Capability Class Analysis in the Riam Kanan Sub Watershed Area, Banjar District, South Kalimantan Province]. *Jurnal Hutan Tropis, 12(4)*: 585-601. http://dx.doi.org/10.20527/jht.v12i4.21454

31. Kardhana, H., Solehudin, Wijayasari, W., Rohmat, F. I. W. (2024). Assessing basin-wide soil erosion in the Citarum watershed using USLE method. Result in Engineering, 22 (102130): 1-10. https://doi.org/10.1016/j.rineng.2024.102130

32. Morgan, R. P. C., & Nearing, M. A. (2011). *Handbook of erosion modelling*. Blackwell Publishing (ISBN 9781444328455). Handbook of Erosion Modelling - Google Buku

33. Pham, T. G., Degener, J., Kappas, M. (2018). Integrated universal soil loss equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in A Sap basin: Central Vietnam. *International Soil and Water Conservation Research, 6:* 99-110. https://doi.org/10.1016/j.iswcr.2018.01.001

34. Panagos, P., Borelli, P., Meusburger, K. (2015). A new European slope length and steepness factor (LS-Factor) for modelling soil erosion by water. *Journal of Geosciences, 5:* 117-126. https://doi.org/10.3390/geosciences5020117

35. May, C. Lm, and Lisle, TE. (2012). River Profile Controls on Channel Morphology, Debris Flow Disturbance and The Spatial Extent of Salmonids In Steep Mountain Streams. *Journal of Geophysial Research. Earth Surface, 117*. https://doi.org/10.1029/2011JF002324

36. Ruslan, M., Kadir, S., & Sirang, K. (2013). *Pengelolaan Daerah Aliran Sungai Barito. Cetakan 1 [Barito River Watershed Management. 1st ed.]*. Universitas Lambung Mangkurat Press: Banjarmasin.

37. Hudson, N. (1995). *Soil conservation (3rd ed.)*. Iowa State University Press.

38. Morgan, R. P. C. (2005). *Soil erosion and conservation (3rd ed.)*. Blackwell Publishing.

39. Bonell, M., & Bruijnzeel, L. A. (Eds.). (2004). *Forest, water and people in the humid tropics: Past, present and future hydrological research for integrated land and water management*. Cambridge University Press.

40. Lal, R. (1998). Soil erosion impact on agronomic productivity and environment quality. *Critical Reviews in Plant Sciences, 17(4)*: 319–464. https://doi.org/10.1080/0735268989130424 9

41. Pimentel, D., & Kounang, N. (1998). Ecology of soil erosion in ecosystems. *Ecosystems, 1(5)*: 416–426. https://doi.org/10.1007/s100219900035

42. Arsyad, S. (2010). *Pengawetan Tanah dan Air [Soil and Water Conservation]*. Department of Soil Sciences, Faculty of Agriculture, IPB, Bogor.

43. Kartasapoetra, A.G., & Sutedjo, M.M. (1985). *Teknologi Konservasi Tanah dan Air [Soil and Water Conservation Technology]*. Jakarta: P.T Rineka Cipta.

44. Hirzel, J., & Matus, I. (2013). Effect of soil depth and increasing fertilization rate on yield and its components of two durum wheat varieties. *Journal Chilean of Agricultural Research, 73(1), 55-59*. Retrieved from http://search.proquest.com/docview/145861 5108?accountid=38628.

45. FAO. (2015). *Global guidelines for the restoration of degraded forests and landscapes in drylands: Building resilience and benefiting livelihoods*. Food and Agriculture Organization of the United Nations.

46. Pandit, R., Scholes, R., Montanarella, L., Brainich, A., Barger, N., ten Brink, B., Cantele, M., Erasmus, B., Fisher, J., Gardner, T., Holland, T., Kohler, F., Kotiaho, J., Von Maltitz, G., Nangendo, G., Parrotta, J., Potts, M., Prince, S., Sankaran, M., & Willemen, L. (2018). *Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. The Intergovernmental Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net/system/tdf/spm_3bi_l dr_digital.pdf?file=1&type=node&id=2833 5

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