International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 6; June 2025
Website: www.ijrrjournal.com
Research Paper *E-ISSN: 2349-9788; P-ISSN: 2454-2237*

Assessment of Erosion Hazard Levels in the Watershed Rehabilitation Area of PT Arutmin Indonesia, Bunglai V Block, Riam Kanan Sub-Watershed, South Kalimantan

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DOI: https://doi.org/10.52403/ijrr.20250677

ABSTRACT

Soil erosion represents a critical issue in the forestry sector due to its detrimental effects on water quality and the sustainability of rehabilitation activities. This concern becomes particularly urgent in upstream watershed areas, where erosion can trigger cascading negative impacts throughout the entire watershed system. This study aims to estimate the erosion hazard class (EHC) and level of erosion hazard occurring in rehabilitated watershed areas, specifically in the Riam Kanan sub-watersheds located in Bunglai V Village. The Universal Soil Loss Equation (USLE) method was applied to estimate erosion hazard, taking into account additional influencing factors such as slope class, land cover type, rainfall intensity, and soil solum depth. The study was conducted in Bunglai V Block, which is divided into two sections: the Upper Road Block (Block A, comprising three land units) and the Lower Road Block (Block B, comprising four land units). The results indicate that Block A contains three distinct EHC: Light (I-L) with an erosion rate of 48.45 tons/ha/year, Moderate (II-M) with 165.18 tons/ha/year, and Heavy (III-H) with 122.25 tons/ha/year. Similarly, Block B also exhibits three classes: Light (I-L) at 61.71 tons/ha/year, Moderate (II-M) at 145.34 tons/ha/year, and Heavy (III-H) at 86.21 tons/ha/year. The erosion hazard levels were influenced by soil solum depth, where severe hazard areas (III-H) had shallower solum compared to areas with light and moderate hazard levels, indicating higher erosion risks in shallow soils. Based on these findings, several management strategies are recommended, including maintaining land cover as plantation forest, constructing ridge terraces, and planting along contour lines. In areas with gentle slopes, understory vegetation should be established using an agroforestry system, while areas with moderately steep to steep slopes should utilize cover crops, which help stabilize the soil through their extensive root systems and reduce erosion impact.

Keywords: Erosion Hazard Level, erosion control strategies, soil erosion, USLE method, watershed rehabilitation

INTRODUCTION

Soil serves as the foundation for all terrestrial life, underpinning ecological stability, agricultural productivity, and human well-being[1]. However, widespread soil erosion and the consequent degradation of soil resources have emerged as major global challenges, severely affecting agricultural sustainability, ecosystem functionality, and environmental resilience [2]. These issues pose substantial barriers to the achievement of the Sustainable Development Goals (SDGs), particularly those related to food security, climate action, and land degradation neutrality. Soil erosion—recognized as one of the most pervasive physical and geomorphological processes on the Earth's surface—is a naturally occurring phenomenon that is increasingly intensified by anthropogenic activities such as deforestation, overgrazing, and unsustainable land use [3].

Soil erosion in agriculture and forestry constitutes an urgent concern, particularly in relation to water quality degradation[4-6] and the long-term sustainability of agricultural production systems[6-9]. In South Kalimantan, one of the critical areas of concern regarding soil erosion is the Riam Kanan sub-watershed, which has been the focus of extensive land and forest rehabilitation activities, notably by PT Arutmin Indonesia, a company holding a Forest Area Utilization Permit (Persetujuan Penggunaan Kawasan Hutan/PPKH). In Indonesia, companies involved in mining operations—designated as PPKH holders—are not only mandated to conduct post-mining reclamation but are also obligated to restore critical lands through watershed rehabilitation programs. However, the effectiveness and feasibility of watershed rehabilitation initiatives can be significantly compromised if soil erosion is not properly mitigated through integrated management strategies.

The watershed rehabilitation area managed by PT Arutmin Indonesia—specifically Bunglai V Block—was selected as the study site due to its strategic position within the upstream region of the Riam Kanan sub-sub watershed, located in Bunglai Village[10]. This area is characterized by plantation forest land cover and a wide range of slope gradients, indicating a potentially high level of erosion hazard. If not properly addressed, this condition may result in significant environmental degradation within the sub-sub watershed, underscoring the urgent need for targeted mitigation measures and sustainable land management strategies.

The analysis employed to estimate the erosion hazard class and erosion hazard level in Bunglai V Block is based on a quantitative approach using the empirical model developed by Wischmeier and Smith[11], namely the Universal Soil Loss Equation (USLE). This analysis incorporates several influencing factors that affect the severity and classification of erosion hazard, including land cover, soil solum depth, slope gradient, and rainfall intensity. Once the erosion hazard class and level have been determined through the study, appropriate management recommendations and mitigation strategies can be proposed to reduce the adverse impacts of soil erosion in the area.

MATERIALS & METHODS

Research Location

This research was conducted in the Forest and Land Rehabilitation or Watershed Rehabilitation area of PT Arutmin Indonesia, precisely in Bunglai V Block located in Aranio District, Banjar Regency, South Kalimantan Province, Indonesia. Research on Erosion Hazard Level Analysis in Bunglai V Block Watershed Rehabilitation was carried out for 3 (three) months from June to September 2024 starting from preparation, data collection, data processing to report preparation. The map of the research location can be seen in Figure 1.

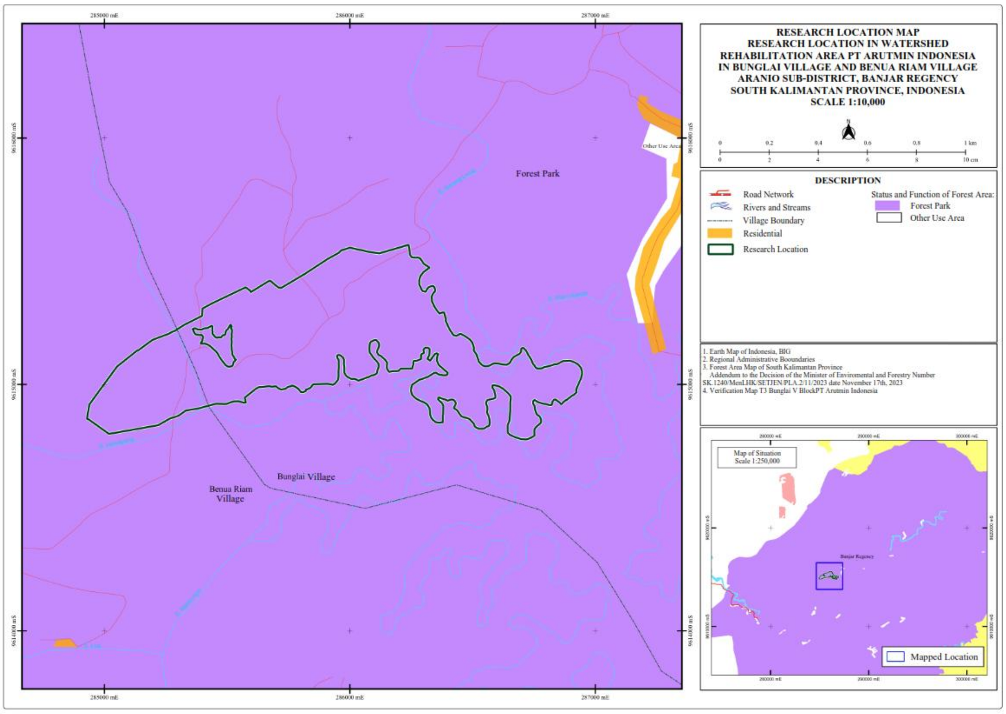

Figure 1. Research Location Map in Watershed Rehabilitation Area of PT Arutmin Indonesia in Bunglai V Block, Aranio Sub-District, Banjar Regency, South Kalimantan Province, Indonesia

The materials used in this research are soil samples at the research location, plastic bags for placing soil samples, maps such as the map of the Indonesian earth form at a scale of 1:250,000, land use maps (provincial spatial plans or district / city spatial plans), soil type maps, slope class maps, and land cover maps. The equipment needed for data collection were GPS, clinometer/abney level, compass/sunto, camera, soil drill, sample ring, meter, crowbar, machete, knife, stationery, tally sheet, and ArcGIS map processing program (Arc View 3.2/Map Info).

Research Procedure

The research procedure began with the development of spatial data for land units. This stage involved overlaying the soil type map with the slope class map. Subsequently, the resulting map was further overlaid with the land cover map, producing a land unit map that reflects various land cover types. These maps are presented in Figures 2, 3, 4, and 5. The next step involved the collection of both primary and secondary data. The secondary data utilized in this study included a general overview of the research site, ten-year rainfall records, and maps and satellite imagery used for data analysis. Primary data were collected through direct field observations and included vegetation or land cover conditions and soil physical properties.

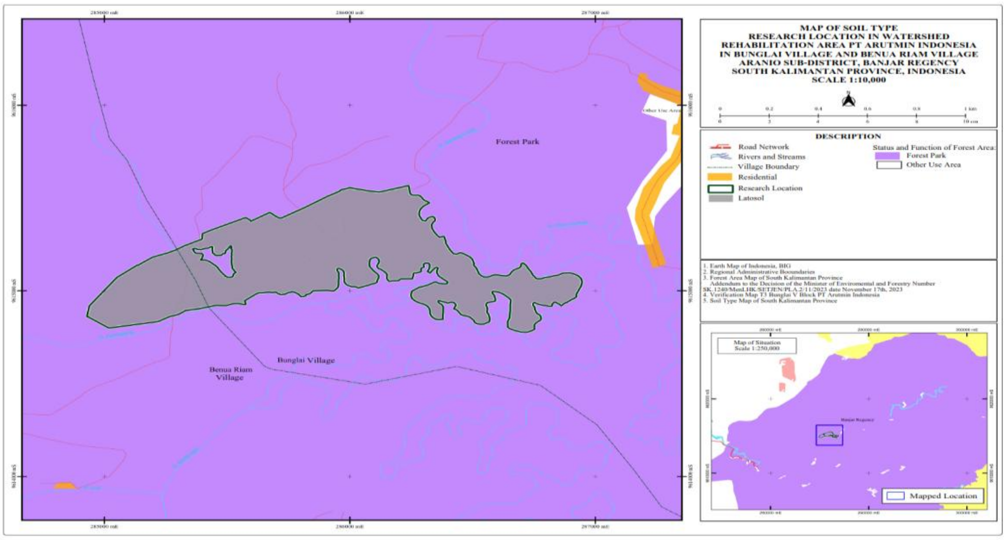

Figure 2. Soil Type Map of Bunglai V Block Aranio Sub-district

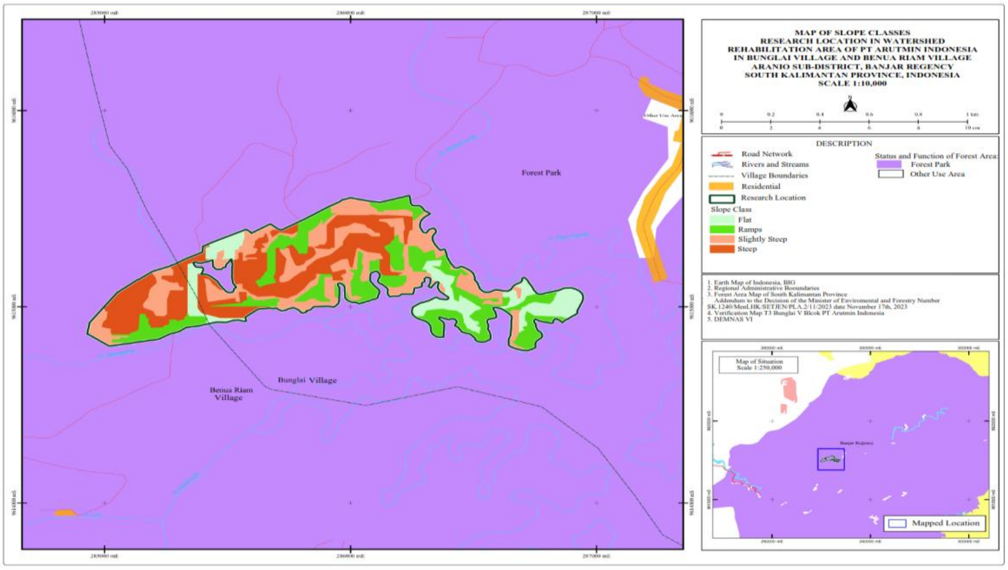

Figure 3. Slope Class Map of Bunglai V Block Aranio Sub-district

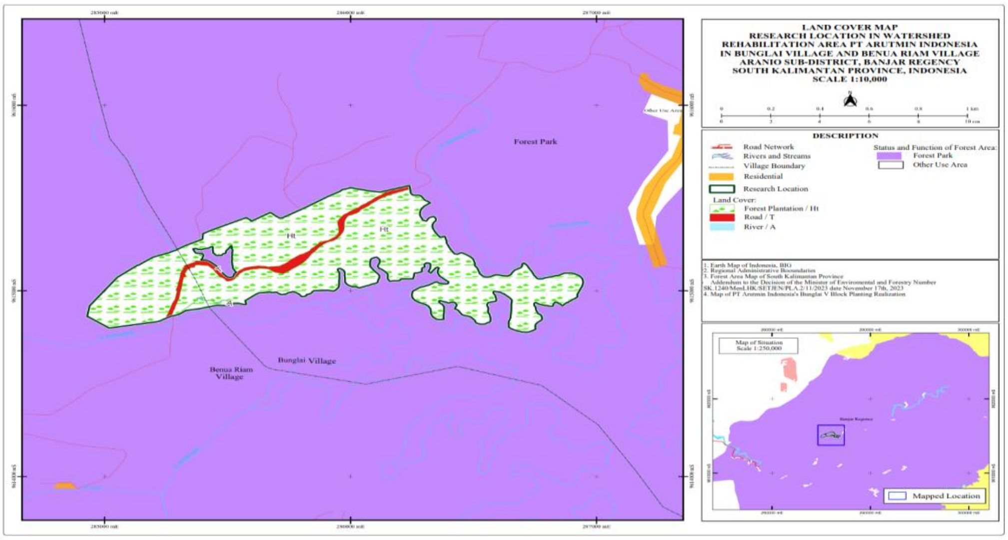

Figure 4. Land Cover Map of Bunglai V Block Aranio Sub-district

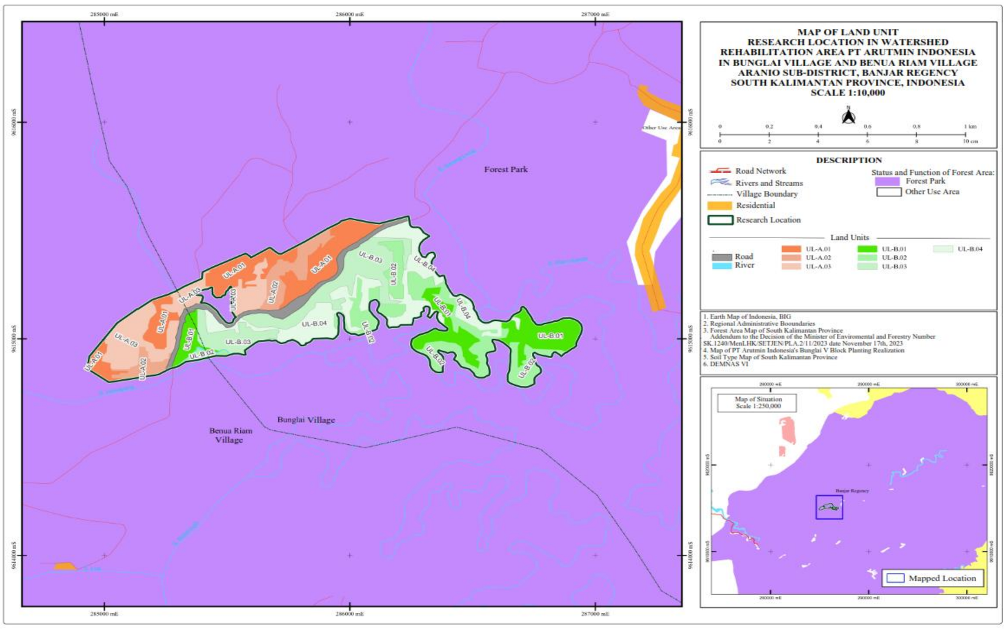

Figure 5. Land Unit Map of Bunglai V Block Aranio Sub-district

The process of collecting primary data began by identifying observation points for land cover and soil sampling. Field observations of vegetation cover were conducted with a sampling intensity of 0.1%, following the GN-RHL evaluation standard. Land cover sampling was performed using a purposive sampling technique to ensure the selected plots accurately represented existing conditions. Similarly, soil samples were collected purposively to reflect diverse field characteristics—such as flat surfaces, depressions, undulating, and hilly terrains—observed during the study. Two types of soil samples were collected: (a) undisturbed soil samples, used for analyzing soil properties such as permeability, and (b) disturbed soil samples, used for analyzing other physical properties and organic matter content. Sampling was conducted at the center of each land unit[12]. Soil samples were taken at a depth of 5–60 cm and collected three times for each land unit and land cover type.

Data Analysis

Estimation of Soil Erosion (A)

The estimation of soil loss, which serves as a basis for determining the Erosion Hazard Level (EHL), was calculated using the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith[11], with a correction factor introduced by Ruslan[13]. The equation is expressed as follows:

$$A = R \times K \times L \times S \times C \times P \times 0.61$$

Where:

A : estimated annual 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 : crop management factor
P : soil conservation practice factor
0.61 : calibration correction factor[13]

1. Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) was calculated using the average of three rainfall erosivity estimation formulas, as follows:

Lenvain formula[14], namely:

$$Rm = 2.21\,(Rain)^{1.36}$$

The annual erosivity indeks is:

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

Where:

Rm : each average rainfall erosivity index (units/month)
Rain : average monthly rainfall (cm/month)
R : sum of Rm for 12 months

2. Soil Erodibility Factor (K)
Erodibility shows the value of the sensitivity of a soil type to the crushing and washing power of rainwater[15]. The value of the K factor is determined by analyzing the physical properties of the soil which include texture, structure, permeability and organic matter content.
The results of the analysis of soil physical properties including texture, structure, soil permeability and organic matter content are entered with an approach number as proposed by the Indonesian Ministry of Forestry[16], which is as in Table 1.

Table 1. 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

Table 2. Soil structure value[17]

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

Table 3. Soil permeability assessment[17]

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

Soil samples collected in the field were analyzed to determine the soil erodibility factor (K). The K value was then calculated using the equation proposed by Wischmeier and Smith[11], as follows:

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

Where:
K : soil erodibility factor
M : %silt + %very fine sand x (100 - %clay)
a : organic matter content (5)
b : soil structure code
c : soil permeability class

According to Arsyad[18], the soil erodibility factor (K) can be classified into six classes, as presented 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)
After determining the slope, it is then classified into slope classes expressed in percentage (%). For each land unit, the horizontal distance (map-based distance)

from the highest to the lowest point was measured ten times, and the average was calculated. The slope length (L) was determined using the following formula from the Ministry of Forestry of the Republic of Indonesia[16]:

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

Where:
L : slope length (m)
LP : horizontal map-based distance (cm)
Cos α : cosine of the slope angle (º)

The slope length factor (L) and slope steepness factor (S) are integrated into the LS factor, which is calculated using the empirical formula proposed by Asdak[14]:

$S = (0.433 + 0.043\ s^2)/6.61$
$LS = L^{1/2}(0.0138\ S^2 + 0.00965\ S + 0.00138)$
Where:
LS : 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 determination of the crop management factor (C) is expressed as a ratio representing the relative erosion occurring on land with vegetation cover compared to bare land under identical conditions. The better the soil surface is protected by vegetation, the lower the erosion rate. Land cover is a common data source for C values[19-22]. Majhi et al.[23] showed that USLE-based soil erosion modeling can be significantly more accurate and reliable. The determination of the soil conservation factor (P) is based on field observations for each land unit to assess whether any conservation practices are applied or not. In some existing references[19, 21-22, 24], P values can be determined based on agricultural land management conditions.

5. Erosion Hazard Class (EHC)

Erosion hazard for each land unit and land cover type is determined by evaluating the estimated soil loss (A), which is then classified into specific Erosion Hazard Classes. According to the Directorate General of Reforestation and Land Rehabilitation[17], the EHC is divided into five categories, as presented in Table 5.

Table 5. Erosion Hazard Classification

Erosion Hazard Class	Soil Erosion (A) (ton/ha/year)
I	< 15
II	15 - < 60
III	60 - < 180
IV	180 - < 480
V	> 480

6. Erosion Hazard Level (EHL) Analysis

The classification of the Erosion Hazard Level (EHL) is based on grouping the estimated soil loss (A) into five Erosion Hazard Classes (EHC) and integrating them with soil depth (solum) grouped into four classes. These two variables are combined in a matrix commonly referred to as the Erosion Hazard Level Matrix (EHL Matrix). A detailed format and classification of the EHL matrix are shown in Table 6.

Table 6. EHL Criteria Matrix[16,25]

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 Light
I – L : Light
II – M : Moderate
III – H : Heavy
IV – VH : Very Heavy

RESULT

Erosion Hazard Level (EHL)

1. Land Units

Land units were delineated by overlaying the soil type map, slope class map, and land cover map. Based on this spatial analysis, a total of seven land units were identified within the Bunglai V Block of PT Arutmin Indonesia, comprising three land units located above the road (Block A) and four land units located below the road (Block B). The codes and respective areas of each land unit, along with their slope classes, land cover types, and soil types, are presented in Table 7.

Table 7. Land Unit Data, Slope Class, Land Cover, and Soil Type in Bunglai V Block, PT Arutmin Indonesia

No.	Block/Land Units	Land Cover	Soil Type	Slope Class (%)	Area (ha)	Land Unit Total Area (ha)
Block A (Above the Road)						
1	LUA-01	SF(PF)	Latosol	> 8 – 15	4.59	24.73
2	LUA-02	SF(PF)	Latosol	> 15 – 25	11.56	
3	LUA-03	SF(PF)	Latosol	> 25 – 40	8.58	
Block B (Bellow the Road)						
1	LUB-01	SF(PF)	Latosol	0 – 8	8.75	41.51
2	LUB-02	SF(PF)	Latosol	> 8 – 15	11.66	
3	LUB-03	SF(PF)	Latosol	> 15 – 25	11.35	
4	LUB-04	SF(PF)	Latosol	> 25 – 40	9.75	
Total (A + B)						66.24

Where:
LUA-0i : Land Unit Block Above i-th Road (i = 1,2,3)
LUB-0i : Land Unit Block Below i-th Road (i = 1,2,3,4)
SF(PF): Secondary Forest (Planted Forestry)

2. Erosion Estimation

Rainfall data used to calculate rainfall erosivity (R) for erosion prediction using the USLE model was limited to monthly total precipitation, due to the unavailability of data on the number of rainy days and monthly maximum daily rainfall. Consequently, the rainfall erosivity (R) was estimated using the Lenvain model[14]. The monthly rainfall data employed in this analysis consisted of a 10-year historical record for the Aranio Subdistrict, Banjar Regency. The results of the erosion analysis for Bunglai V Block of PT Arutmin Indonesia are presented in Table 8.

Table 8. Erosion analysis results (A) in Bunglai V Block, PT Arutmin Indonesia

Land Unit	Land Cover	Area (ha)	Slope (%)	R	K	LS	C	P	Fk	A
Block A (Above the road)										
LUA-01	SF(PF)	4.59	> 8-15	1782.81	0.1656	1.7932	0.15	1	0.61	48.45
LUA-02	SF(PF)	11.56	> 15-25	1782.81	0.2588	2.8956	0.15	1	0.61	122.25
LUA-03	SF(PF)	8.58	> 25-40	1782.81	0.2125	4.7658	0.15	1	0.61	165.18
Block B (Bellow the road)										
LUB-01	SF(PF)	8.75	0 - 8	1782.81	0.2418	0.7316	0.15	1	0.61	28.85
LUB-02	SF(PF)	11.66	> 8-15	1782.81	0.1123	1.7932	0.15	1	0.61	32.86
LUB-03	SF(PF)	11.35	> 15-25	1782.81	0.1825	2.8956	0.15	1	0.61	86.21
LUB-04	SF(PF)	9.75	> 25-40	1782.81	0.1869	4.7658	0.15	1	0.61	145.34
Total		66.24								

Where:
LUA-0i : Land Unit Block Above i-th Road (i = 1,2,3)
LUB-0i : Land Unit Block Below i-th Road (i = 1,2,3,4)
SF(PF) : Secondary Forest (Planted Forestry)
R : Rainfall Erosivity Factor
K : Soil Erodibility Factor
LS : Slope Length and Steepness
C : Crop Management
P : Mechanical Soil Conservation Factors
Fk : correction factor[13]
A : Soil Erosion (ton/ha/year)

The magnitude of erosion occurring across various land units with identical Forest Plantation land cover but differing slope classes (Table 8) varies from low to high. In Block A, the lowest erosion rate (48.45 tons/ha/year) was observed in Land Unit LUA-01, while the highest erosion (165.18 tons/ha/year) occurred in Land Unit LUA-03. In Block B, the lowest erosion rate (28.85 tons/ha/year) was found in Land Unit LUB-01, and the highest (145.34 tons/ha/year) was recorded in Land Unit LUB-04. The graphical representation of erosion across land units in Bunglai V Block of PT Arutmin Indonesia is presented in Figure 6.

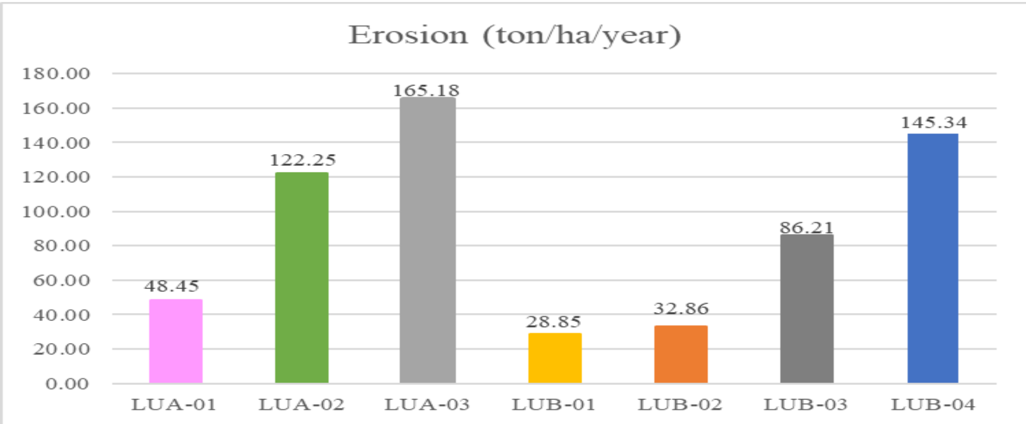

Figure 6. Erosion graphs for various land units at PT Arutmin Indonesia Bunglai V Block

3. Erosion Hazard Level (EHL)

The magnitude of erosion (A) presented in Table 8 can be categorized into several Erosion Hazard Classes (EHC). The classification of EHC is influenced by the soil depth of each land unit and its land cover type. The soil depth observed across the various land units, soil covers, and soil types includes: (a) deep class (>90 cm), (b) moderate class (60 – >90 cm), and (c) shallow class (30 – <60 cm). A summary of the Erosion Hazard Classes (EHC) and the corresponding Erosion Hazard Levels (EHL) in this study is presented in Table 9.

Table 9. Erosion and EHL on various land units at PT Arutmin Indonesia Bunglai V Blcok Aranio Sub-district

Land Unit	Land Cover	Slope (%)	Area (ha)	Soil Depth		A (ton/ha/year)	EHC	EHL
				(cm)	Class			
Block A								
LUA-01	SF(PF)	> 8 – 15	4.59	> 90	Deep	48.45	II	I – L
LUA-02	SF(PF)	> 15 – 25	11.6	60 – 90	Medium	122.25	III	III – S
LUA-03	SF(PF)	> 25 – 40	8.58	> 90	Deep	165.18	III	II – M
Block B								
LUB-01	SF(PF)	0 – 8	8.75	> 90	Deep	28.85	II	I – L
LUB-02	SF(PF)	> 8 – 15	11.7	> 90	Deep	32.86	II	I – L
LUB-03	SF(PF)	> 15 – 25	11.4	60 – 90	Medium	86.21	III	III – S
LUB-04	SF(PF)	> 25 – 40	9.75	> 90	Deep	145.34	III	II – M
Jumlah			66.24					

Where:
LUA-0i: Land Unit Block Above i-th Road (i = 1,2,3)
LUB0i : Land Unit Block Below i-th Road (i = 1,2,3,4)
SF(PF) : Secondary Forest (Planted Forestry)
A : Soil Erosion (ton/ha/year)
EHC : Erosion Hazard Class
EHL : Erosion Hazard Level
I – L : Light EHL
II – M : Moderate EHL
III – H : Heavy EHL

The data presented in Table 9 indicate that the dominant slope classes in the study area are moderately steep and steep, with an average slope of 30.40% in Block A and 31.35% in Block B. This condition contributes to a higher level of erosion hazard at the site, which aligns with Kadir[25], who stated that a high Erosion Hazard Level (EHL) tends to occur in areas with steep to very steep slopes. A bar chart summarizing the distribution of erosion hazard levels across Block A and Block B at PT Arutmin Indonesia, Bunglai V Block, is illustrated in Figure 7.

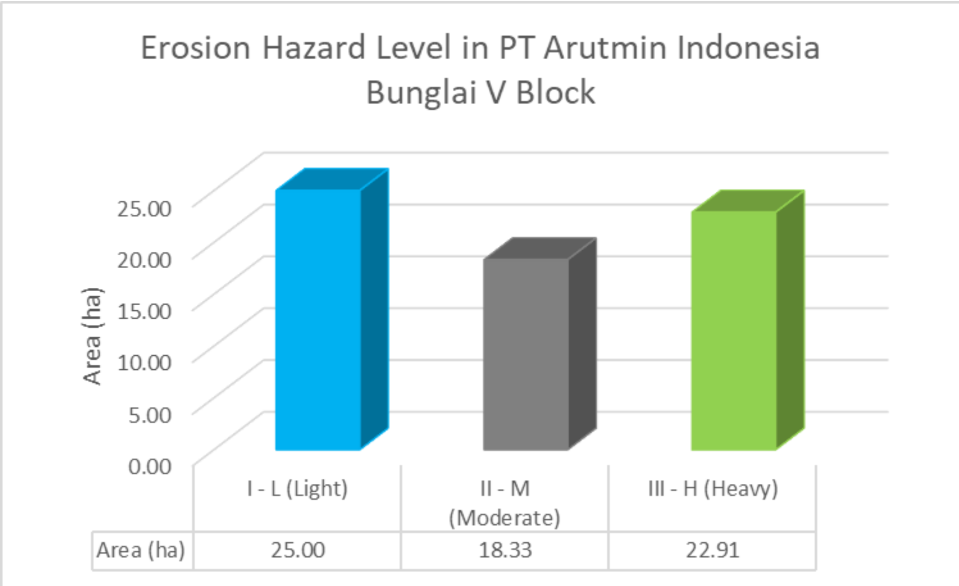

Figure 7. Area Distribution of Erosion Hazard Levels

From the data in Figure 7, it is known that the total area of light erosion hazard level is 25 ha, moderate is 18.33 ha, and heavy is 22.91 ha. In detail, the percentage of erosion hazard classes in Bunglai V Block A and Block B are presented in Figure 8.

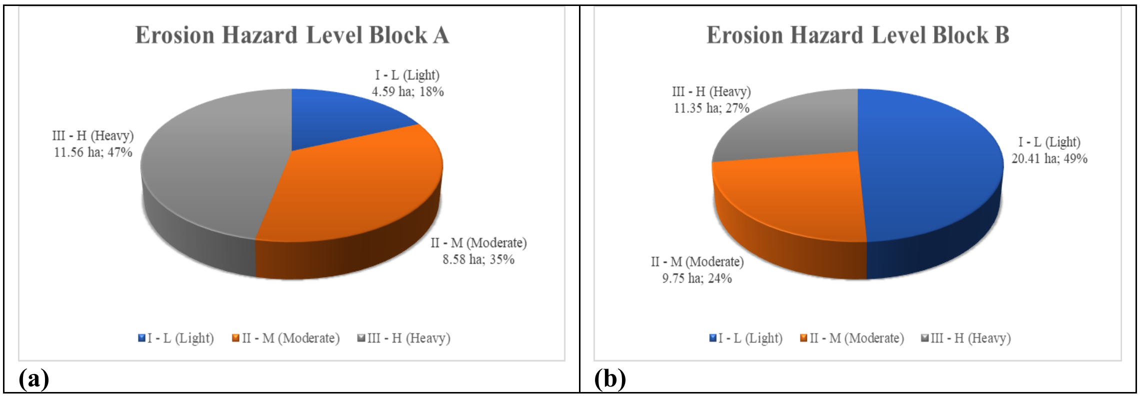

Figure 8. Pie chart of different classes of erosion hazard level in Bunglai V Block PT Arutmin Indonesia, (a) Block A; (b) Block B

Based on the variation in erosion hazard levels observed in Figures 8 and 9, the erosion hazard levels in PT Arutmin Indonesia Bunglai V Block range from Light, Moderate, to Heavy. The empirical data presented in Figures 7 and 8 can be utilized to determine the spatial distribution of erosion hazard levels in the field, covering light, moderate, and heavy classes across various land units, slope gradients, and forest cover types. The spatial distribution of erosion hazard levels is illustrated in Figure 9.

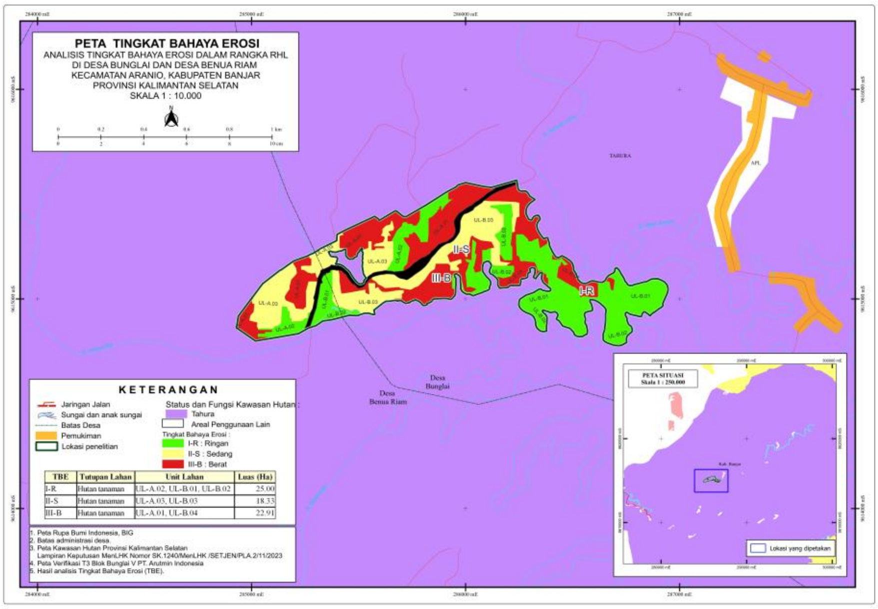

Figure 9. Map of erosion hazard level at PT Arutmin Indonesia Bunglai V Block (Block A and Block B) Aranio District, Banjar Regency

Table 9 and Figure 9 show that the same amount of land cover, namely Plantation Forest with medium (60-90 cm) and deep (>90 cm) soil solum in Bunglai Block A, the Erosion Hazard Level is classified as class II-M (Moderate) and III-H (Heavy) covering an area of 20.14 Ha (30.40%). in Bunglai V Block B, the Erosion Hazard Level is classified as class II-M (Moderate) and III-H (Heavy) covering an area of 21.10 Ha (31, 35%).

EHL conditions in Bunglai V Village classified as II-M (Moderate) and III-H (Heavy) erosion hazard levels in Block A are found in two land units (LUA-03 and LUA-02) with an area of 20, 14 Ha (30.40%), while in Block B there are two land units (LUB-03 and LUB-02) with an area of 21.10 Ha (31, 35%). The total area of the four land units is 41.24 ha (61.75%).

The relatively high level of erosion hazard (II-M (Moderate) and III-H (Heavy)) in Bunglai Village Block A and Block B, is thought to be influenced by the slope gradient factor. This is in accordance with the opinion of Badaruddin[26] and Arsyad[18] which states that erosion that occurs in the land expanse is influenced by the level of steep and very steep land slopes, so that run off is greater, as a result the erosion that occurs is high.

Forest and Land Rehabilitation (FLR) Guidelines

Based on the analysis of the level of erosion hazard in Table 9 and Figure 8, a recapitulation of the direction of forest and land rehabilitation (watershed rehabilitation) for each land unit can be seen in Table 10.

Tabel 10. Arahan Rehabilitasi Hutan dan Lahan di Blok Bunglai V A dan B PT Arutmin Indonesia

Land Unit Land Cover	Slope (%)	EHL	FLR Direction	Area		Total Area	
				Ha	%	Ha	%
Block A (Above the Road)							
LUA-01 SF(PF)	> 8 – 15	I – L	Keep forest plantation as land cover + agroforestry (food crops) for underground crops + terrace mound pattern	4.59	6.93	4.59	6.93
LUA-02 SF(PF)	> 15 – 25	III – H	Keep forest plantation as land cover + cover crops for underground crops + terrace mounds pattern	11.56	17.45	20.1	30.40
LUA-03 SF(PF)	> 25 – 40	II – M		8.58	12.95		
Block B (Bellow the Road)							
LUB-01 SF(PF)	> 0 - 8	I – L	Keep forest plantation as land cover + agroforestry (food crops) for underground crops + terrace mound pattern	8.75	13.21	20.4	30.81
LUB-02 SF(PF)	> 8 – 15			11.66	17.60		
LUB-03 SF(PF)	> 15 – 25	III – H	Keep forest plantation as land cover + cover crops for underground crops + terrace mounds pattern	11.35	17.12	21.1	31.85
LUB-04 SF(PF)	> 25 – 40	II – M		9.75	14.72		
Total Block A & Block B				**66.24**	**100**	**66.24**	**100**

Form the results of Table 10, a recapitulation of the spatial distribution of Land and Forest Rehabilitation direction patterns in Bunglai V Block A and Bunglai V Block B can be made. The result of the recapitulation analysis of the spatial distribution of Forest and Land Rehabilitation direction patterns in Bunglai V Block can be seen in Figure 10.

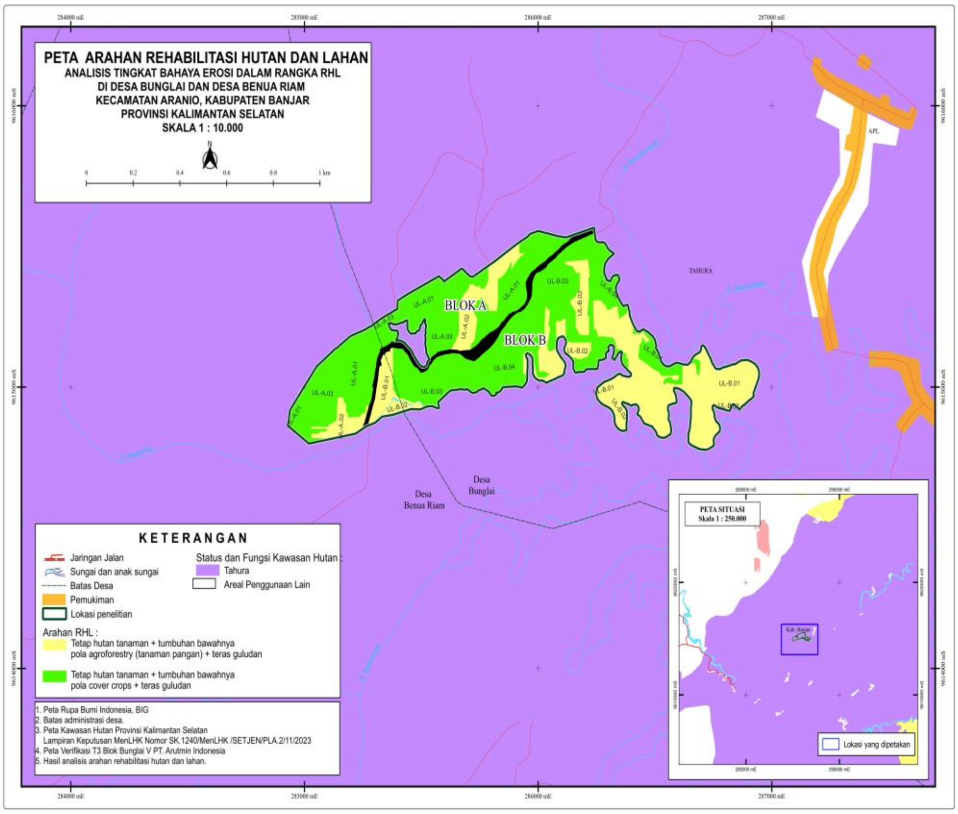

Figure 10. Map of Forest and Land Rehabilitation Pattern Direction in Bunglai V Block PT Arutmin Indonesia

DISCUSSION

1. Land Units

This study was conducted in an area where watershed rehabilitation activities are being implemented by PT Arutmin Indonesia. As a result, the land cover across the study site consists entirely of plantation forests established on previously degraded secondary forest or critical land. A previous drought analysis conducted in the same area revealed that nearly half of the region experienced drought conditions, with the most severe drought observed in the Aranio Subdistrict[27]. Based on field observations, the dominant soil type in both Block A and Block B is latosol. Similar findings were reported by Sumaryono et al.[28], who studied the same sub-watershed and rehabilitation site managed by PT Arutmin Indonesia under a forest area utilization permit, where latosol soils and land cover comprising secondary and plantation forests were also identified.

2. Soil Erosion Analysis

Based on the data presented in Table 8 and Figure 6, the highest estimated erosion rate in Block A occurred in Land Unit 03, while in Block B it was observed in Land Unit 04. This condition is likely due to the steep slope gradients in LUA-03 and LUB-04, which increase the susceptibility to erosion. Steeper slopes tend to accelerate surface runoff, thereby intensifying soil erosion and potentially leading to land degradation[29]. The steep gradient facilitates the rapid movement of runoff, which carries essential soil elements such as nutrients and water, resulting in surface erosion and the loss of soil fertility. According to Ruslan et al.[30], high erosion rates are also influenced by sparse canopy cover. Kartasapoetra & Sutedjo[15] identified the key factors affecting erosion as vegetation density, slope gradient, soil management practices, and the implementation of soil conservation measures.

Table 9 presents the results of erosion hazard level (EHL) analysis at the study site. The findings indicate that Block A, with varying slope gradients, exhibits a range of erosion hazard levels, with the majority falling into the moderate to high categories. Similarly, Block B predominantly exhibits moderate to high erosion hazard levels. The severity of erosion hazard increases where soil solum on specific slopes tends to be shallower than on others. This study demonstrates that the deeper the soil solum, the lower the erosion hazard level. This result is consistent with the findings of Masduq et al.[31], which reported higher erosion hazard classes associated with shallower soil depths. Furthermore, these findings align with previous studies by Ruslan et al.[30] and Kadir[25], who emphasized that erosion hazard levels are influenced by slope gradients—ranging from flat, gentle, moderately steep, to steep—and soil solum depth—categorized as moderate and deep.

Badaruddin[26] stated that areas covered by shrub vegetation tend to experience relatively higher erosion hazard levels compared to those with forest or plantation cover. This observation is supported by Ruslan et al.[30], who noted that shrublands and open areas with sparse vegetation, often subject to frequent fires, undergo significant degradation of soil physical properties—including structure, texture, and permeability—resulting in increased surface runoff and elevated erosion hazard levels. According to Herawati[32], in watershed environments with moderately steep to very steep slopes, erosion rates are primarily driven by flow velocity and sediment characteristics. This is consistent with findings from the Citarum Watershed, where increasing erosion hazard levels have led to significant sediment deposition, subsequently impairing reservoir functionality[22].

Forest and Land Rehabilitation Guidelines (Watershed Rehabilitation)

The primary objective of forest and land rehabilitation efforts is to restore degraded or critical drylands located within a watershed area. Lands situated in the upstream and midstream zones of a watershed serve essential functions, including ecological protection, buffer zones, and water regulation, all of which significantly influence water availability in downstream regions. Consequently, when drought occurs or land degradation intensifies in the upstream and midstream zones, these functions are disrupted, directly impacting the sustainability of livelihoods in the downstream watershed.

The recommended approach to forest and land rehabilitation combines vegetative and mechanical methods. In areas with gentle to moderately steep slopes, mechanical methods that are cost-effective and relatively easy to implement are preferred, such as contour planting. Specifically, the use of ridge terraces is emphasized, particularly in agroforestry and reforestation activities.

The rehabilitation guidelines proposed for the sub-watersheds of the Riam Kanan Watershed in Aranio District align with the view of Badaruddin[26], who stated that the core activities of forest and land rehabilitation consist of reforestation, plantation forests, agroforestry, and the application of both vegetative and mechanical (engineering) soil conservation techniques on degraded and unproductive lands. The rehabilitation strategy that integrates vegetative and mechanical methods is closely related to the estimated magnitude of erosion or erosion hazard level (EHL), as assessed using the USLE model. This is due to the direct correlation between vegetative approaches (land cover management = C factor) and mechanical or civil engineering-based soil and water conservation practices = P factor.

If the implementation of vegetative and mechanical rehabilitation methods is successful, then theoretically, the C and P factors in the USLE model will be reduced, thereby decreasing the estimated rate of erosion and ultimately resulting in a lower erosion hazard level (EHL). This is consistent with the findings of Kadir[33] in his study of the Jaing Catchment Area, Negara Sub-watershed, South Kalimantan Province, which demonstrated that converting shrubland into forest through reforestation techniques—such as contour planting and the construction of ridge terraces—can effectively reduce land degradation status from "Highly Critical" to "Potentially Critical" and "Non-Critical."

CONCLUSION

The land units within the study area are divided into three units in Block A and four units in Block B. The erosion hazard levels in Block Bunglai V A vary across classes: light (4.59 ha), moderate (8.58 ha), and severe (11.56 ha). Similarly, Block Bunglai V B exhibits varied erosion hazard classes: light (20.41 ha), moderate (9.75 ha), and severe (11.35 ha). The variation in erosion hazard levels is primarily influenced by slope gradient factors, and this variability serves as a critical consideration in formulating targeted forest and land rehabilitation strategies in Block Bunglai V, PT Arutmin Indonesia. The recommended watershed rehabilitation directions are categorized into two groups: a) For land units LUA-01, LUB-01, and LUB-02 with gentle slopes, the existing forest plantation cover should be maintained, complemented by seasonal food crops as understory vegetation, ridge terracing, and contour planting techniques; b) For land units LUA-02, LUA-03, LUB-03, and LUB-04 with moderately steep to steep slopes, forest plantations should be maintained with cover crops as the understory vegetation, the implementation of ridge terracing, and planting aligned with contour lines.

Declaration by Authors

Acknowledgement: None
Source of Funding: None
Conflict of Interest: No conflicts of interest declared.

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How to cite this article: Eko Nor Hardanto, Muhammad Ruslan, Kissinger. Assessment of erosion hazard levels in the watershed rehabilitation area of PT Arutmin Indonesia, Bunglai V Block, Riam Kanan Sub-Watershed, South Kalimantan. *International Journal of Research and Review*. 2025; 12(6): 675-690. DOI: *https://doi.org/10.52403/ijrr.20250677*

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