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Estimation of Erosion Hazard Levels in the Ulakan Watershed, Padangpariaman

Fadila Mulia Sari[1*], Darwizal Daoed[2], Septi Wila Zarinda[1]
[1*,2,]*Civil Engineering Department, Faculty of Engineering, Andalas University.*
Email : [1*] muliafadila4@gmail.com. [2] darwizaldaoed@gmail.com [3]septiwilazarinda@gmail.com

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A B S T R A C T

High rainfall can trigger flooding and riverbank erosion, particularly in flood-prone areas of Padangpariaman Regency, such as Ulakan Tapakis, Nan Sabaris, and 2x11 Enam Lingkung Districts. This study aims to estimate the level of erosion hazard based on land cover changes in 2015, 2019, and 2024. The analysis was conducted using the Universal Soil Loss Equation (USLE) method integrated with Geographic Information Systems (GIS). The estimation results indicate that the area classified under very low and low erosion categories has decreased, while the moderate, high, and very high erosion categories show a significant increase in erosion potential from year to year. This condition needs to be properly addressed to prevent the occurrence of potentially serious disasters.

1. Introduction

A watershed is a hydrological system that primarily functions as a collector, storage, and conduit for rainfall runoff from the upstream to the downstream areas. The sustainability of watershed functions has a significant impact on ecosystem balance, water resource availability, and the continuity of local community activities[1], [2], [3]. Poorly planned watershed management can trigger various forms of environmental degradation, particularly land degradation, which negatively affects environmental quality and hydrological functions[4], [5].

One of the most common forms of land degradation within a watershed is soil erosion. Erosion is the process of soil particle detachment and transport caused by the continuous action of rainfall or wind energy. Erosion intensity is generally influenced by land cover conditions, land use changes, slope gradient, soil characteristics, and rainfall magnitude. If erosion occurs uncontrolled, it can lead to various negative impacts, including river sedimentation, decreased water quality, damage to aquatic habitats, and increased risk of hydrometeorological disasters such as floods and droughts [6], [7]. Therefore, information on erosion hazard levels is essential as a basis for land conservation planning and sustainable watershed management [8].

To estimate erosion rates, several analytical methods have been developed, one of which is the Universal Soil Loss Equation (USLE). The USLE is an empirical model widely used to estimate soil loss based on several key parameters, namely rainfall erosivity, soil erodibility, topographic factors, land cover, and conservation practices. This approach is considered practical and effective because it provides a quantitative assessment of erosion vulnerability within a region, which can serve as a basis for prioritizing conservation measures [9], The USLE can provide erosion rate estimates over large areas [10], [11].

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The Ulakan Watershed in Padangpariaman plays an important ecological and socio-economic role, serving as a source of irrigation water and supporting local agricultural and settlement activities [12]. However, land conversion from forest to agricultural and settlement areas in several upstream regions increases soil susceptibility to erosion, which can threaten overall watershed functionality if not properly managed [13].

The high population density around the Batang Ulakan watershed area is frequently affected by flooding disasters due to the overflow of the Batang Ulakan River, which is recognized as a flood-prone area every year, particularly in the Sicincin area of 2 x 11 Enam Lingkung District. Based on observations conducted from 2021 to 2024, river discharge has exhibited an increasing trend, which has led to flooding in several areas. It is generally assumed that land cover within the Ulakan Watershed has experienced substantial changes, particularly due to the conversion of forest areas into agricultural land and residential zones. This phenomenon is considered to be closely associated with regional economic development.

Based on these conditions, research is needed to estimate erosion hazard levels in the Ulakan Watershed, Padangpariaman. This study aims to estimate the level of erosion hazard based on land cover changes in 2015, 2019, and 2024. The results are expected to provide information that can inform watershed management strategies, land use planning, and soil and water conservation efforts in Padangpariaman Regency.

2. Research Method

The Ulakan Watershed is one of the river basins located in Padangpariaman Regency, West Sumatra Province. This watershed is geographically situated between the Mangau Watershed and the Tapakis Watershed. The upstream area of the Ulakan Watershed is located on the slopes of Mount Tandikek, while the downstream area lies within Ulakan Tapakis District, Padangpariaman Regency.

The tools used in this study included Microsoft Excel for numerical data processing and ArcGIS 10.8 software for spatial analysis and mapping [14], [15]. The method applied to estimate the rate of soil erosion is the Universal Soil Loss Equation (USLE). This study utilizes rainfall data, soil type maps, slope maps, and land cover maps, which are processed in raster format using ArcGIS software. Each dataset is assigned parameter values according to the USLE factors, namely rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), and land cover and conservation practices (CP). All parameter layers are then integrated through an overlay process using the Intersect method to produce a single composite layer. The erosion rate is calculated by multiplying the USLE factors in the attribute table of the overlay result. Based on these calculations, erosion hazard levels are classified and presented in the form of spatial maps as a representation of the erosion risk distribution within the Ulakan Watershed.

3. Description and Technical

Data Collection

1. Rainfall Data

Daily rainfall data were obtained from the Water Resources Management Agency of West Sumatra Province, covering the period from 1993 to 2022, and derived from the Lubuk Napar rainfall station.

2. Land Cover Data

Land cover classification for the years 2015 and 2019 was conducted using Landsat 8 imagery obtained from USGS, while the classification for 2024 utilized Google Earth imagery, all of which were processed using ArcGIS software.

3. Soil Type

The soil type map was obtained from the Land and Soil Unit Map (1989) published by the Center for Soil Research (PUSLITTANAK), Padang sheet.

4. Slope Data

Slope data were obtained from the 2022 DEMNAS dataset, which was processed using ArcGIS software.

Data Analysis

The equation for the USLE method developed by Wischmeier and Smith (1978) is as follows [16], [17]:

$$E_a = R \times K \times LS \times CP \quad (1)$$

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Where:

E_a = estimated soil loss (ton/ha/year)
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
CP = land cover and conservation practice factor

1. Rainfall Erosivity Factor (R)

Rainfall erosivity refers to the capacity of rainfall to induce soil erosion through its kinetic energy. Higher rainfall intensity and volume result in greater erosive power on the soil. This value can be obtained using the empirical equations developed by Lenvain (1975) and Banuwa (2013) [18]:

$$R = 2{,}21 \times CH^{1{,}36} \quad (2)$$

Where:

R = average annual rainfall erosivity
CH = average rainfall (cm)

2. Soil Erodibility Factor (K)

Soil erodibility refers to the inherent susceptibility of soil to particle detachment due to the impact of raindrops and surface runoff forces. This characteristic is reflected by the soil erodibility factor, which quantifies how easily soil can be detached and transported during erosion processes. Higher values of the erodibility factor indicate greater vulnerability of the soil to erosion, whereas lower erodibility values suggest that the soil is comparatively less prone to erosive detachment[19] [20].

Table 1. Soil Erodibility Value (K)

No	Soil Type	K (ton/ha/MJ.mm)
1	Alluvial	0,29
2	Andosol	0,28
3	Brown Forest	0,28
4	Glei	0,29
5	Grumusol	0,16
6	Latosol	0,26
7	Litosol	0,13
8	Mediteran	0,16
9	Organosol	0,29
10	Podsol Merah	0,20
11	Regosol	0,31

Source: Bappenas (2012:IV-13)

3. Slope Length and Steepness Factor (LS)

The slope length (L) and slope steepness (S) variables can be combined, as both simultaneously influence the rate of erosion. Erosion tends to increase with the rise in surface slope gradient, which leads to greater raindrop impact and increased transport of soil particles by runoff. In addition, the longer the slope, the greater the volume of surface runoff, resulting in higher flow depth and velocity, thereby increasing the potential for erosion. This factor is represented using slope steepness, slope class criteria, and the LS values, which are presented in the following Table 2.

Table 2. Slope Length and Steepness Value (LS)

Slope Class	Slope (%)	LS
I	0-8	0,4
II	8-15	1,4
III	15-25	3,1
IV	25-40	6,8
V	>40	9,5

Source: Kironoto and Yulistiyanto (2000)

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4. Land Cover Factor (CP)

According to the RKLT (Land Rehabilitation and Soil Conservation) 1986 guidelines presented in Book II, the land cover factor values are provided as shown in Table 3.

Table 3. Land Cover Factor (CP)

No	Land Cover	Value (CP)
1	Settlement	0,60
2	Mixed Cropland	0,30
3	Rice Field	0,05
4	Dry Cropland	0,75
5	Plantation	0,40
6	Forest	0,03
7	Bushland	0,30
8	Grassland	0,70

Source: RKLT (Land Rehabilitation and Soil Conservation), Buku II, (1986)

5. Erosion Hazard Level Classification

The classification of erosion hazard levels can be determined based on the calculated soil loss rates, as presented in Table 4. Similar classification approaches have been applied in previous studies, where computed soil loss rates (ton/ha/year) were compared with predefined hazard classes to assess erosion vulnerability across different land use types and watershed conditions [21].

Table 4. Erosion Hazard Level Classification

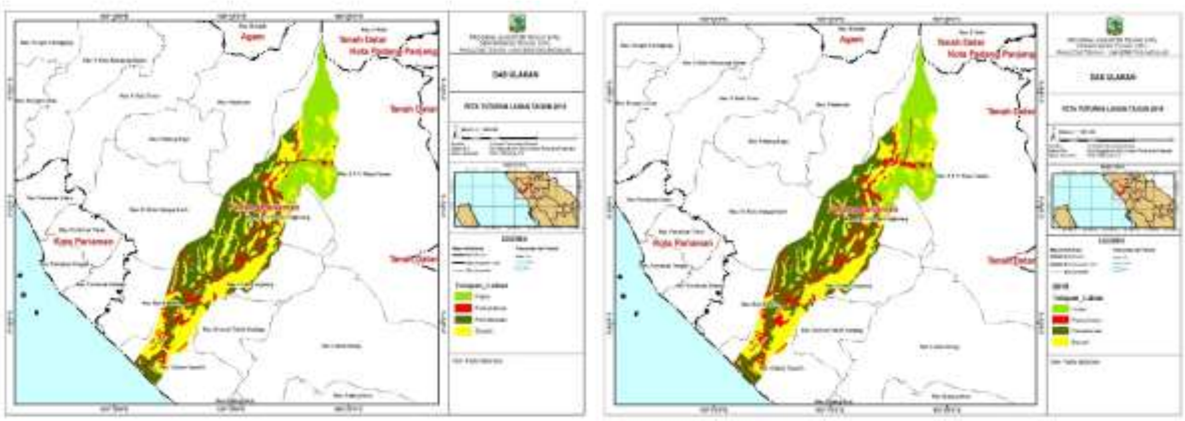
No	Erosion Rate, A (ton/ha/year)	Erosion Hazard Class	Description
1	<15	I	Very Low
2	15-60	II	Low
3	60-180	III	Moderate
4	180-480	IV	High
5	>480	V	Very High

Source: Directorate and Water Resources Conservation (2012)

4. Results and Discussions

1. Land Cover Analysis

Land cover classification was conducted using Landsat 8 satellite imagery downloaded from the USGS and subsequently analyzed using ArcGIS software. The land cover data for 2015 were obtained from satellite imagery downloaded on July 1, while the data for 2019 were obtained on March 22. Both datasets were processed using an RGB band combination of 4–3–2. For 2024, land cover data were obtained from Google Earth imagery dated February 23. The definition of land cover refers to SNI 7645:2010. The land cover types applied in the Ulakan Watershed were determined using the composite band method, as shown in Figure 1. Land cover map for 2015, 2019, and 2024.



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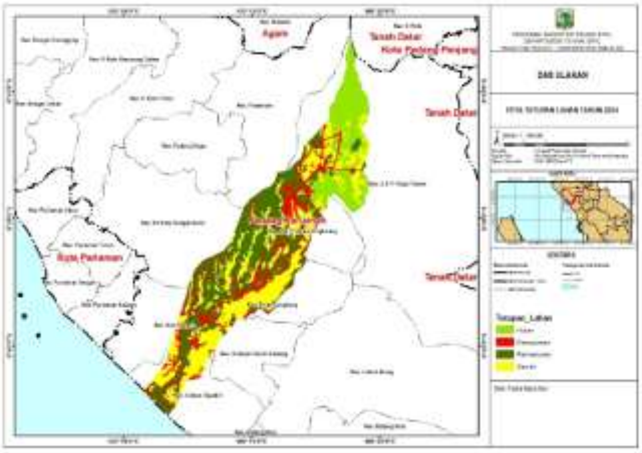

Source: Analysis Results (ArcGIS, 2025).
Figure 1. Land Cover Map for the Year 2015, 2019 and 2024

The classification of land cover changes is presented in Table 5.

Table 5. Recapitulation of Land Cover Changes in the Ulakan Watershed

Land Cover	Year			Description
	2015 (km^2)	2019 (km^2)	2024 (km^2)	
Forest	24,56	22,94	20,97	Decreased by 3,12 %
Settlement	10,99	12,37	16,13	Increased by 4,46 %
Plantation	40,97	42,67	41,29	Increased by 0,28 %
Rice Field	38,67	37,21	36,78	Decreased by 1,46 %
Total	115,20	115,20	115,20	

Source: Analysis Results (2025)

Based on Table 5, the most significant increase in land area occurred in the settlement category, which expanded from 10.99 km² in 2015 to 12.37 km² in 2019, and further to 16.13 km² in 2024. Meanwhile, the land use type that experienced the most significant decrease in area was forest, which declined from 24.56 km² in 2015 to 22.94 km² in 2019, and further decreased to 20.97 km² in 2024.

2. Rainfall Erosivity Factor

The data used in this study consist of rainfall records from the nearest rain gauge station, namely the Lubuk Napar station, with monthly rainfall data covering a period of 30 years. The following is the calculation of rainfall erosivity using the equations developed by Lenvain (1975) and Banuwa (2013) [22]:

$$R = 2{,}21 \times CH^{1{,}36}$$
$$= 2{,}21 \times 175^{1{,}36}$$
$$= 108{,}37$$

3. Soil Erodibility Factor (K)

Soil erodibility represents the level of sensitivity of a soil type to erosion, indicating how easily the soil can be eroded. The soil types within the Ulakan Watershed can be seen in Figure 2, with their respective areas presented in Table 6.

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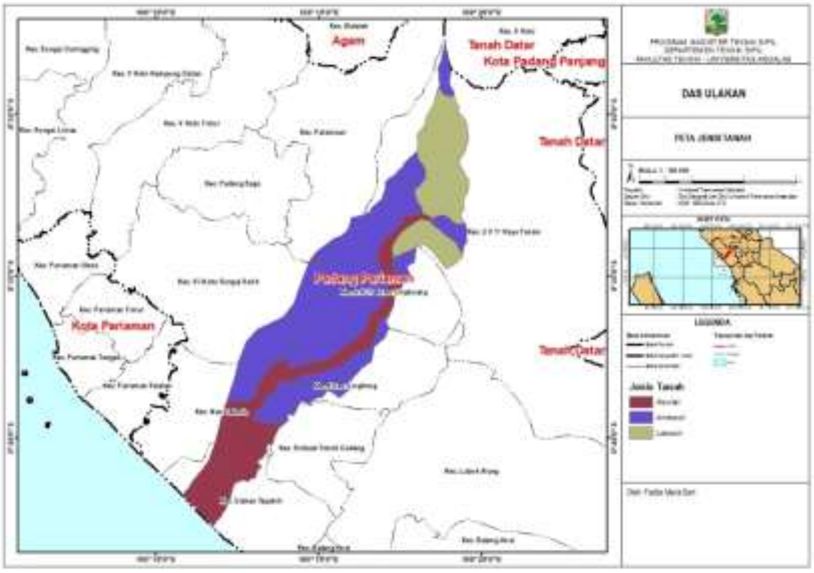


Source: Analysis Results (ArcGIS, 2025).
Figure 2. Map of Soil Types in the Ulakan Watershed

Table 6. Soil Types in the Ulakan Watershed

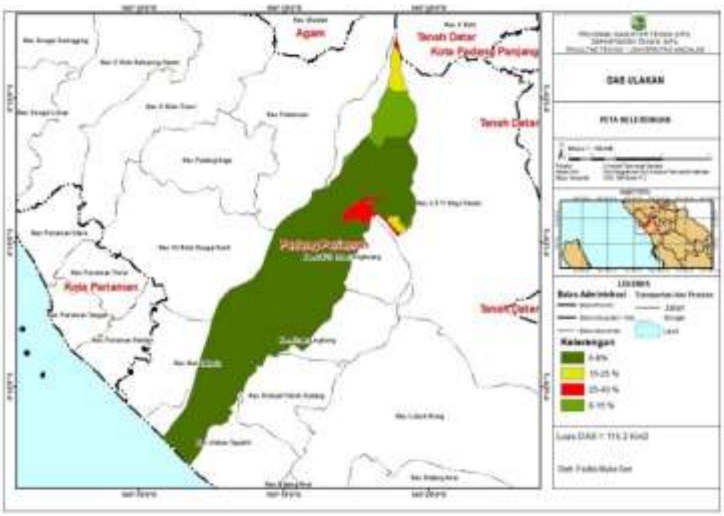
No	Soil Types	Factor (K)	Area (km²)
1	Andosol	0,28	63,52
2	Latosol	0,26	22,18
3	Alluvial	0,29	29,48
	Total		115,20

Source: Analysis Results (2025)

The soil types found in the Ulakan Watershed consist of Alluvial, Andosol, and Latosol. Andosol is the dominant soil type in the Ulakan Watershed, covering an area of 63.52 km² with an erodibility factor (K) value of 0.28. In contrast, Latosol has the smallest area, covering 22.18 km² with an erodibility factor (K) value of 0.26.

4. Slope Length and Steepness Factor (LS)

In this study, the slope map was generated from the processing of DEMNAS 2022 data and can be seen in Figure 3. Based on the slope conditions in the Ulakan Watershed, the slope gradients were classified and subsequently adjusted to the slope factor (LS) values proposed by Kironoto and Yulistiyanto (2000), as presented in Table 7.



Source: Analysis Results (ArcGIS, 2025).
Figure 3. Slope Length and Steepness in the Ulakan Watershed

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Table 7. Value of LS in the Ulakan Watershed

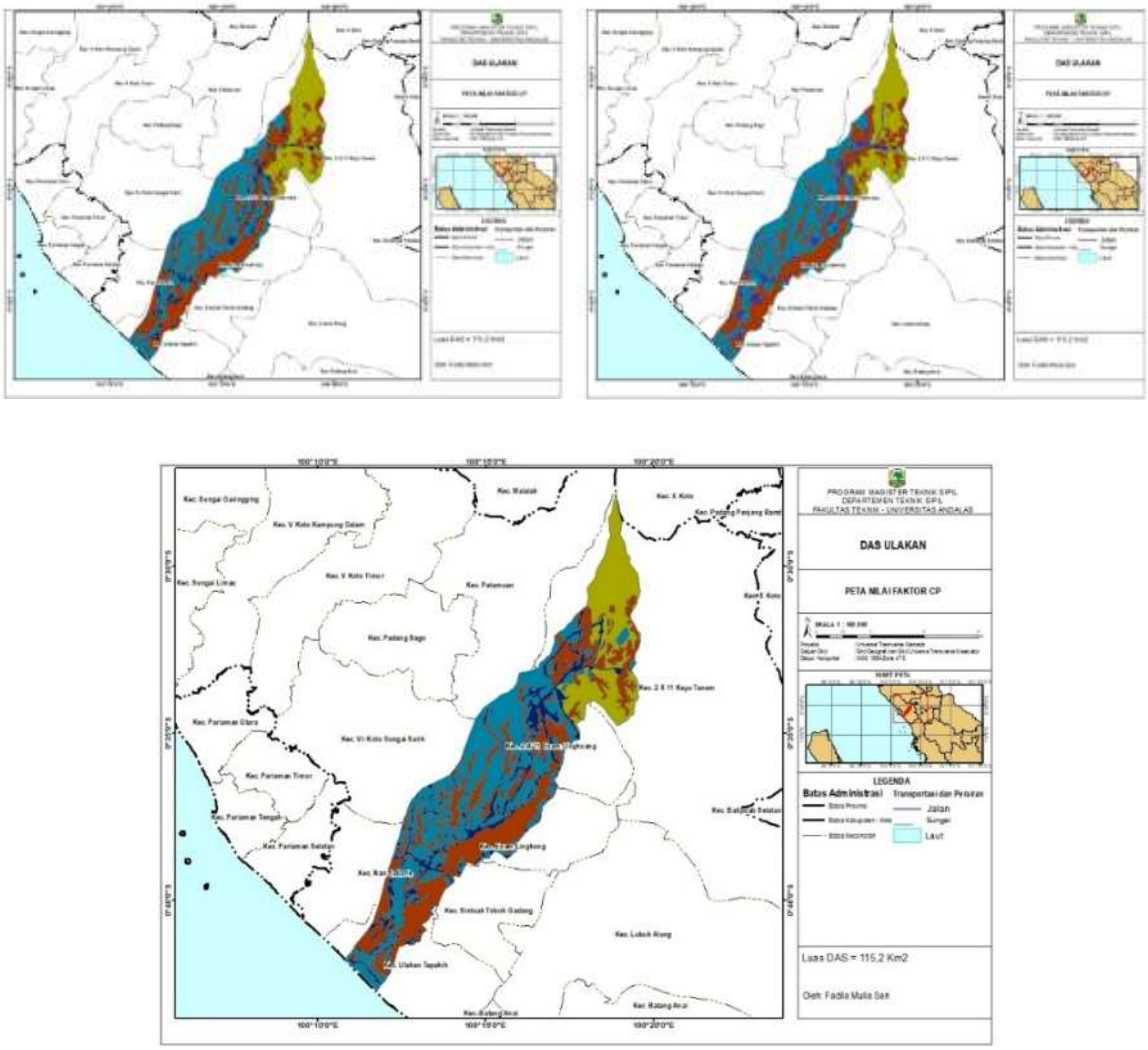
No	Slope Class	Slope Steepness (%)	LS	Area (km^2)
1	I	0-8	0,4	101,64
2	II	8-15	1,4	7,92
3	III	15-25	3,1	2,88
4	IV	25-40	6,8	2,75
		Total		115,20

Source: Analysis Results (2025)

The results of the analysis show that the Ulakan Watershed is predominantly categorized under slope class I, with a slope gradient of 0% to 8%, covering an area of 101.64 km². This is followed by slope class II, with gradients ranging from 8% to 15%, covering an area of 7.92 km²; slope class III, with gradients of 15% to 25%, covering an area of 2.88 km²; and slope class IV, with gradients of 25% to 40%, covering an area of 2.75 km².

5. Cover Land Factor (CP)

Information regarding land cover types in the Ulakan Watershed in 2015, 2019, and 2024 can be seen in figure 4, while the area and CP factor values based on land cover are presented in Table 8 as follows:



Source: Analysis Results (ArcGIS, 2025).

Figure 4. CP Factor Map Based on Land Cover in the Ulakan Watershed, 2015, 2019 and 2024.

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Based on the figure, the color yellow represents forest, dark blue represents settlement areas, light blue represents plantations, and red represents rice fields.

Table 8. CP Factor and Land Cover Area in the Ulakan Watershed.

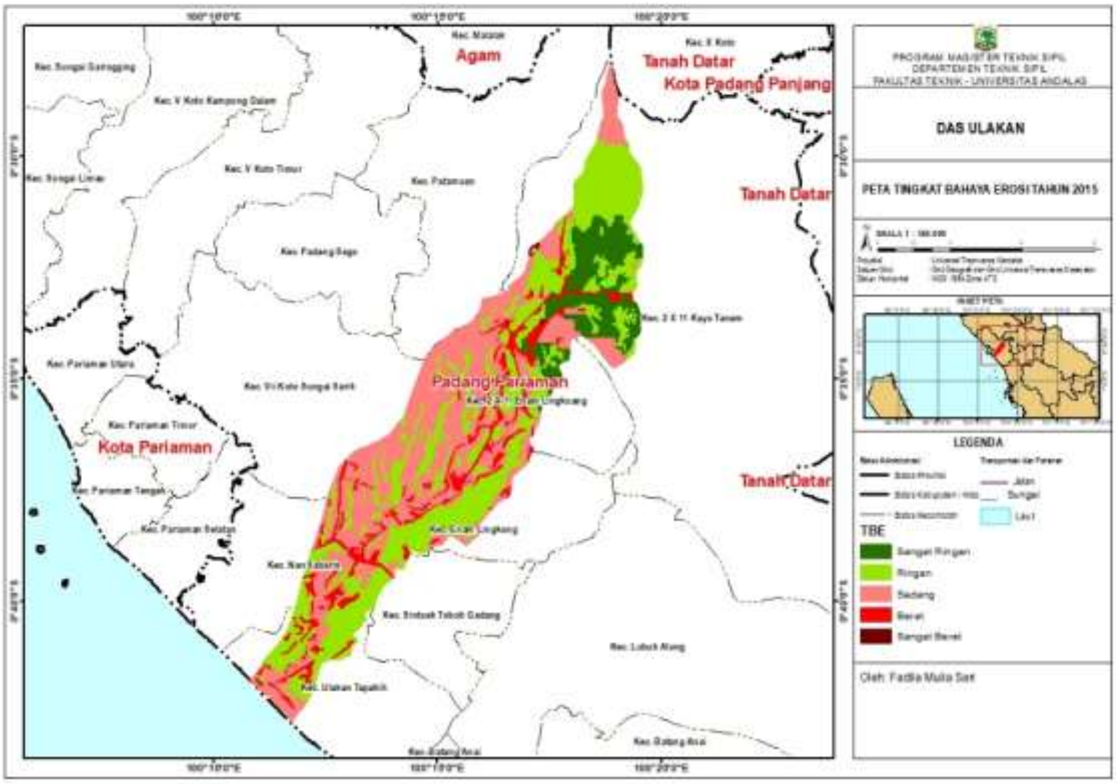
No	Land Cover	CP	Area (Km^2)		
			2015	2019	2024
1	Forest	0,03	24,56	22,94	20,97
2	Settlement	0,6	10,99	42,67	16,13
3	Plantation	0,4	40,97	37,21	41,29
4	Rice Field	0,05	38,67	37,21	36,78
	Total		115,20	115,20	115,20

Source: Analysis Results (2025)

The land cover factor (CP) values obtained based on the types of land cover in the Ulakan Watershed are as follows: forest with a value of 0.03, settlement areas with a value of 0.6, plantations with a value of 0.4, and paddy fields with a value of 0.05.

6. Results Map of Erosion Hazard Levels in the Ulakan Watershed

The erosion hazard map was produced through a data overlay process. All datasets used must be in raster format in order to perform spatial overlay analysis. The raster data include the rainfall erosivity factor (R), soil erodibility factor (K), land use factor (CP), and slope factor (LS). These factors were subsequently multiplied to obtain the erosion rate values for the Ulakan Watershed. The calculated erosion rate values were then classified into erosion hazard levels based on Table 9. The following presents the map and classification table of erosion hazard levels for the Ulakan Watershed:



Source: Analysis Results (ArcGIS, 2025).

Figure 5. Map of Erosion Hazard Classification in 2015

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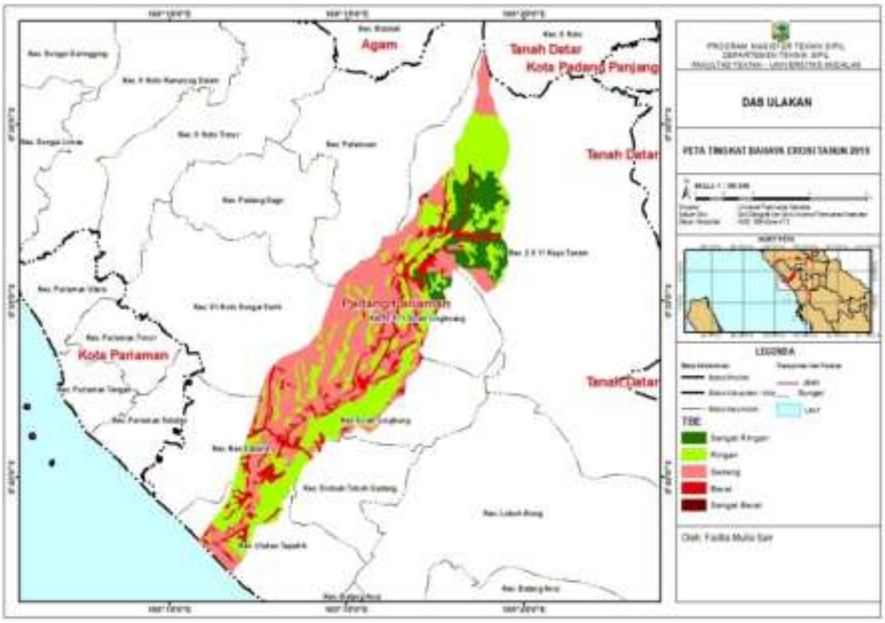
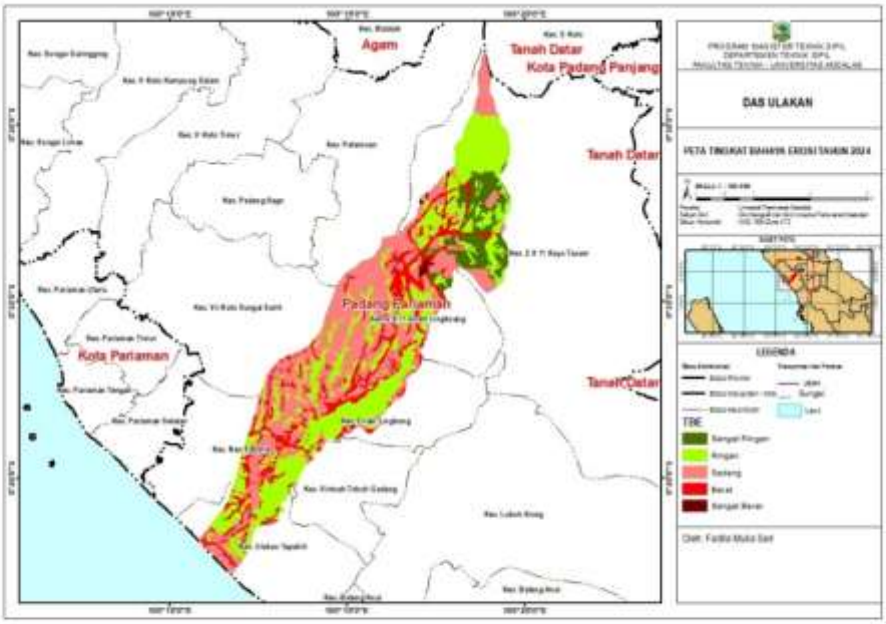


Source: Analysis Results (ArcGIS, 2025).
Figure 6. Map of Erosion Hazard Classification in 2019



Source: Analysis Results (ArcGIS, 2025).
Figure 7. Map of Erosion Hazard Classification in 2024

Table 9. Erosion Hazard Classification Results for 2015, 2019, and 2024

Class	Erosion Rate (t/h/year)	Classification	Area of Land Susceptible to Erosion (ha)					
			2015	%	2019	%	2024	%
I	0-15	Very Low	1200,13	10,42	1062,60	9,22	874,76	7,59
II	15-60	Low	4548,61	39,48	4377,45	38,00	4354,26	37,80
III	60-180	Moderate	4593,80	39,88	4754,18	41,27	4618,14	40,09
IV	180-480	High	1156,69	10,04	1299,40	11,28	1617,73	14,04
V	>480	Very High	19,88	0,17	25,46	0,22	52,71	0,46
	Total		11520	100	11520	100	11520	100

Source: Analysis Results (2025)

The results of the erosion hazard classification for 2015, 2019, and 2024 indicate changes in the area of land susceptible to erosion. The very low category covered 1,200.13 ha in 2015, 1,062.60 ha in 2019, and 874.76 ha in 2024, showing a decrease of 325.37 ha from 2015 to 2024. The low category covered 4,548.61 ha in 2015, 4,377.45 ha in 2019, and 4,345.26 ha in 2024, representing a reduction of 194.35 ha. The moderate category covered 4,593.80 ha in 2015, 4,754.18 ha in 2019, and 4,618.14 ha in 2024, indicating an increase of 24.34 ha. The high category covered 1,156.69 ha in 2015, 1,299.40 ha in 2019, and 1,617.73 ha in 2024, showing an increase of 461.04 ha. The very high category covered 19.88 ha in 2015, 25.46 ha in 2019, and 52.71 ha in 2024, reflecting an increase of 32.83 ha.

The analysis of erosion from 2015 to 2024 revealed a decline in the area classified as very low, accompanied by an expansion of areas with severe to very high erosion potential. The increase in severe to very high erosion occurred primarily in settlement areas and on slopes ranging from 25–40%. These changes indicate a shift toward higher erosion levels in the Ulakan Watershed over the 2015–2024 period and demonstrate that the Ulakan Watershed is highly vulnerable to erosion processes. This estimation is consistent with the findings of a study conducted in the Winongo Watershed, which revealed that areas classified as having moderate, high, and very high erosion increased over a certain period as a result of land-use changes [23].

5. Conclusion and Suggestion

5.1 Conclusion

The estimation results indicate that the area classified under very low and low erosion categories has decreased, while the moderate, high, and very high erosion categories show a significant increase in erosion potential from year to year. Land cover changes show a considerable influence on the potential occurrence of erosion. The intensification of land use, particularly for residential areas and plantations, contributes to the reduction of natural vegetation that plays an important role in protecting the soil surface from erosion processes. In contrast, areas that are still dominated by forest cover generally exhibit lower levels of erosion hazard. This condition is attributed to the role of forest vegetation in reducing surface runoff velocity and enhancing the soil's capacity to absorb water through infiltration.

5.2 Suggestion

The importance of proactive measures in land management and soil conservation is crucial to prevent further environmental degradation in the region. Sustainable land-cover management should be implemented to maintain and increase the forest area. Reforestation and the rehabilitation of degraded lands must be prioritized to restore ecosystem functions and reduce erosion.

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