Jurnal Pembelajaran Dan Biologi Nukleus p-ISSN: 2442-9481
Vol 12 (2): 620 - 637, June 2026 e-ISSN: 2685-7332

Land-Use Driven Soil Erosion and Conservation Priorities in Tropical Highlands: *A USLE-Based Analysis from Ngantang, Indonesia*

Afif Ramadhan Gymnastiar, Purwadi Purwadi(*), Purnomo Edi Sasongko

Departement of Agrotechnology, Faculty of Agriculture,
Pembangunan Nasional "Veteran" Jawa Timur University,
Jl. Rungkut Madya No. 1, Surabaya 60294, East Java, Indonesia

***Corresponding Author:** purwadi.agro@upnjatim.ac.id

Submitted March 04 Th 2026, and Accepted June 06 Th 2026

Abstract

Background: *Despite various soil conservation efforts, comprehensive spatial analysis of erosion hazards across different land uses in volcanic mountainous regions remains limited. This study aims to estimate the erosion rate and Erosion Hazard Level (EHL) across various land uses in Ngantang Sub-district, Malang Regency, utilizing field measurements combined with Geographic Information System (GIS) based Universal Soil Loss Equation (USLE) modeling.* **Methodology:** *The research was conducted using a purposive sampling method based on land use types and slope gradient classes. The parameters analyzed included the factors R, K, LS, C, and P.* **Findings:** *The results showed that dryland (tegalan) and scrubland on steep slopes exhibited the highest erosion rates of up to 405.16 tons/ha/year and 379.05 tons/ha/year respectively (Very Severe category), while forested land had the lowest erosion rates (0.16 - 0.94 tons/ha/year). The LS and C factors are the primary determinants of erosion rates. These findings indicate that land cover (C factor) plays a more dominant role in mitigating erosion than slope gradient alone, providing a targeted spatial framework for local governments to prioritize conservation strategies. Recommended conservation measures include terrace rehabilitation, land conversion to agroforestry, and the implementation of grass strips to sustainably reduce erosion rates.* **Contribution:** *This study contributes a spatially explicit framework for identifying erosion hotspots and prioritizing land-use-specific conservation strategies in tropical highlands.*

Keywords: *Geographic Information System; Land Use; Soil Conservation; Soil Erosion; USLE*

https://doi.org/10.36987/jpbn.v12i2.9262

INTRODUCTION

Globally, land degradation and climate change have escalated the urgency of addressing soil erosion, which severely threatens environmental sustainability, food security, and land productivity (Malik et al., 2025). Erosion is the process by which soil particles are moved from one location to another, driven by water, wind, or the force of gravity (Seran, 2022). This process results in the soil surface becoming more exposed and the loss of the nutrient-rich topsoil, thereby reducing soil fertility and land productivity. Furthermore, the material transported and subsequently deposited as sediment can disrupt the functioning of waterways, rivers, and reservoirs, ultimately reducing the quality and availability of clean water (Srivastava et al., 2023). Erosion also reduces the soil's ability to absorb and store water, thereby increasing the risk of both flooding and drought (Guimarães et al., 2024).

Ngantang Sub-district, Malang Regency, forms part of the Konto Sub-Watershed within the Brantas Watershed, an area with bio-physical conditions vulnerable to land degradation. The Ngantang region is characterised by high annual rainfall, with over 150 days of rain. The Ngantang topography varies from flat to steep, with the dominant soil types being andosols and gle humus, which are classified as easily eroded. This combination of climatic, soil and topographical factors makes Ngantang a region prone to erosion and surface runoff. In recent years, this area has frequently experienced floods and landslides, particularly during the rainy season with high rainfall intensity.

While previous studies have estimated erosion using USLE, there is a lack of research specifically analyzing the correlation between quantitative USLE factors and actual erosion rates across varied agroforestry and dryland systems in highly vulnerable mountainous terrains. Ngantang Sub-district features a hilly topography comprising peaks, upper slopes, middle slopes, lower slopes, and valleys. The steeper the slope, the higher the surface flow velocity, thereby increasing the kinetic energy of rainwater and resulting in a greater volume of soil being eroded or transported (Zhang et al., 2022). Changes in land use from forest to dry fields, plantations, or settlements, without the implementation of adequate soil conservation techniques, can accelerate erosion processes (Pawar et al., 2020). This situation further increases the land's vulnerability to erosion when land-use conversion is not balanced by appropriate conservation efforts (Suprayogi et al., 2024). The USLE approach is used to provide a quantitative assessment of potential soil loss, so that the results can serve as a basis for formulating appropriate soil conservation strategies.

Slope gradient is one of the key factors influencing the emergence of problems in Ngantang Sub-district. Saputra et al., (2022) The steeper the slope, the higher the surface flow velocity, thereby increasing the kinetic energy of rainwater and resulting in a greater volume of soil being eroded or transported. Ngantang Sub-district features a hilly topography comprising peaks, upper slopes, middle slopes, lower slopes, and valleys. The combination of land use that is unsuitable for the land's capacity and high slope gradients makes erosion analysis or estimation a crucial aspect of planning for the sustainable management of land resources. Through erosion estimation, the severity of erosion in a given area and the factors influencing it can be determined.

One approach that can be used to estimate the extent of erosion on a plot of land is via the Universal Soil Loss Equation (USLE) calculation model. This model was developed by Wischmeier & Smith (1978) to assist in estimating soil erosion rates under specific conditions, Taslim et al., (2019) such as variations in slope gradient, rainfall, crop type, and the application of soil management or conservation techniques. To date, the USLE equation has been widely used as a method for predicting erosion potential. Erosion estimation using the USLE method is carried out by combining several factors, these factors include rainfall erosivity, soil erodibility, topographic conditions in the form of slope length and gradient, vegetation cover, and soil management or conservation practices.

The Ngantang sub-district is characterised by high rainfall, steep slopes, and soil types that are susceptible to erosion, making this area highly vulnerable to erosion and sedimentation. This vulnerability has increased due to changes in land use and management practices that have not taken soil conservation principles into account, which in recent years have also contributed to an increase in the incidence of floods and landslides. Therefore, erosion research in this area is necessary to determine the severity of erosion across various land uses. The USLE approach is used to provide a quantitative assessment of potential soil loss, so that the results can serve as a basis for formulating appropriate soil conservation strategies.

METHOD

This research utilized a descriptive exploratory design with spatial analysis using Geographic Information System (GIS) ArcGIS 10.8 and DEM SRTM 30m resolution. The study was conducted from October 2025 in Ngantang Sub-district, Malang Regency, located at 7°51'23,1" S dan 112°22'09,9" E, covering a total area of 147.70 Km^2. The location possesses an agroclimate characterized by an altitude ranging from 400 to 2,100 meters above sea level and a high average rainfall erosivity of 1490.59 kJ/ha.

Tools and Material

Soil sampling in the field uses GPS, sample rings, a soil auger, a support stand, mesh, plastic, rubber, a camera, a tape measure, an oven, scales, and a spectrophotometer. Meanwhile, data processing was carried out using a computer system with the aid of software such as *Microsoft Excel, Microsoft Office*, and *ArcGIS*. Soil samples from several points in Ngantang Sub-district and reagents used in laboratory analysis, as well as supporting materials for the survey, namely topographic maps, land use maps, slope maps, and rainfall data for Ngantang Sub-district.

Soils Sampling

Sample points were selected using a purposive sampling method based on land use units. The selection of sample points was carried out in a targeted manner based on a combination of land use type and slope class, obtained through the overlay of land use maps and slope maps derived from spatial data processed using ArcGIS. A purposive random sampling method was used to determine the sample points based on 4 land use types (forest, scrubland, dryland, and plantation) and 4 slope classes (0-8%, 8-15%, 15-25%, and 25-40%). A total of 16 main sample points were established across the location, each with 3 replications, yielding a total of 48 samples taken at a depth of 0-30 cm. Sampling was carried out in two types: undisturbed soil using a sampling ring for bulk density and permeability, and disturbed soil.

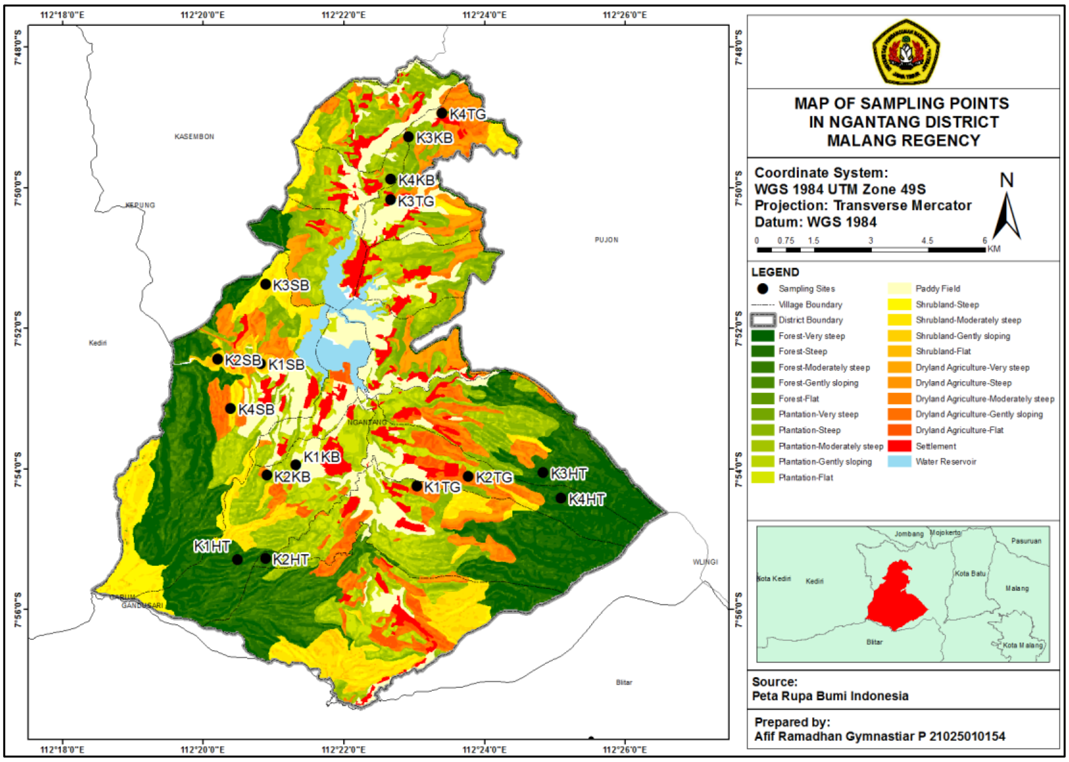

Figure 1. Sampling Map

Laboratory Analysis

Soil samples were analysed at the Soil Laboratory, Faculty of Agriculture, Universitas Brawijaya. Soil organic carbon was determined using the Walkley–Black wet oxidation method Walkley & Black (1934). Soil permeability was measured using the Constant Head Permeameter following ASTM D2434-22. Soil texture was determined using the Pipette Method according to Gee & Bauder (1986), whereas soil moisture content was measured using the gravimetric oven-drying method following ASTM D2216-19.

Observation Parameters

Parameters observed in this study include the main factors influencing the extent of soil erosion, namely rainfall erosivity (R), soil erodibility (K), slope length and slope gradient (LS), vegetation cover (C), and land management practices (P). Analysis was conducted using the Universal Soil Loss Equation (USLE) approach to calculate soil loss, which was then used as the basis for determining the level of erosion risk and formulating soil conservation measures appropriate to the conditions of the study area. Erosion rates (tons/ha/year) were calculated using the USLE (Universal

Soil Loss Equation) method developed by Wischmeier & Smith (1978), using the following equation (1) :

$$A = R \times K \times LS \times C \times P \quad (1)$$

A is the predicted soil erosion rate in units of (tons/ha/year), The Rainfall Erosivity (R) was calculated using the Bols equation utilizing daily rainfall data spanning 5 consecutive years (2021-2025) sourced from NASA Power Data Access. Equation (2) (Auliyani & Wijaya, 2017):

$$Rm = 6.119\, x\, (RAIN)^{1.211}\, x\, (DAYS)^{-0.47}\, x\, (MAXP)^{0.526} \quad (2)$$

Rm is Rainfall Erosivity Index (kJ/ha), RAIN is Average monthly rainfall (cm), DAYS is Average number of rainy days per month (days), MAXP is Maximum daily rainfall (cm). The soil erodibility factor (K) or soil erosion sensitivity factor is calculated using equation (3) (Wischmeter and Smith, 1978):

$$K = \frac{2{,}71\, M^{1{,}14}(10^{-4})(12-OM)+4{,}20\,(s-2)+3{,}23\,(p-3)}{100} \quad (3)$$

K is the soil erodibility factor (ton·kJ^{-1}), M is (% silt and very fine sand) × (100 – % clay), OM is organic matter (%), s is the soil structure rating, p is the soil permeability class. Calculation of slope gradient in the field is performed using the equation by Asdak (2010); the slope length is determined using equation (4) :

$$LS = \sqrt{\frac{L}{100}}\,(0{,}0138 + 0{,}00965\, S + 0{,}00138\, S^2) \quad (4)$$

LS represents the length and slope of the slope, L represents the length of the slope (m), and S represents the slope (%). Management of crop or vegetation (C) and conservation measures (P) were determined based on the table provided by Shoumik et al., (2023). Determination of erosion hazard classes based on erosion results and soil depth, in accordance with Regulation of the Director General of Watershed Management and Social Forestry No. P.4/V-SET/2013 (2013).

Table 1. Erosion Hazard Classification

Solum (cm)	**I** ≤15	**II** 15-60	**III** 60-180	**IV** 180-480	**V** ≥480
Deep ≥ 90	SR	R	S	B	SB
Moderate 60-90	R	S	B	SB	SB
Shallow 30-60	S	B	SB	SB	SB
Very Shallow ≤ 30	B	SB	SB	SB	SB

(Source: Indonesian Regulation of the Director General of Watershed Management and Social Forestry, 2013)
Notes: (SR) Very Light, (R) Light, (S) Moderate, (B) Severe, and (SB) Very Severe

Data Analysis

Data obtained from laboratory analysis were processed and analyzed using multiple linear regression in SPSS to determine the effect of erosion factors on the erosion rate at a significance level of α = 0.05 after assuming data normality. The multiple linear regression model used was:

$$Y = a + b1X1 + b2X2 + b3X3 + b4X4 + b5X5$$

RESULT AND DISCUSSION

Land Use in Ngantang Sub-District

Land use in the study area comprises several main types, namely forest, plantations, dry fields and scrubland. Dry fields are generally planted with various types of crops in a single plot, with a high dependence on rainfall and minimal vegetation cover. Management of these fields is carried out through the construction of bench terraces, though they tend to be poorly maintained. On plantation land, the community practises a coffee-based agroforestry system divided into multi-strata coffee and shade-grown coffee.

The multi-strata system has greater plant diversity, comprising coffee alongside other crops such as coconut, durian, avocado, banana, and taro, whilst the shade-grown system is dominated by shade trees with a more limited number of species. Meanwhile, the forest area within the study region consists of natural forest with a thick layer of litter, playing a crucial role in maintaining environmental balance, particularly in reducing the risk of erosion and enhancing water infiltration. As for the scrubland, it is dominated by dense vegetation without specific management, featuring a relatively shallow root system that is less effective in strengthening soil structure and tends to increase surface runoff (Holisah & Prijono, 2022).

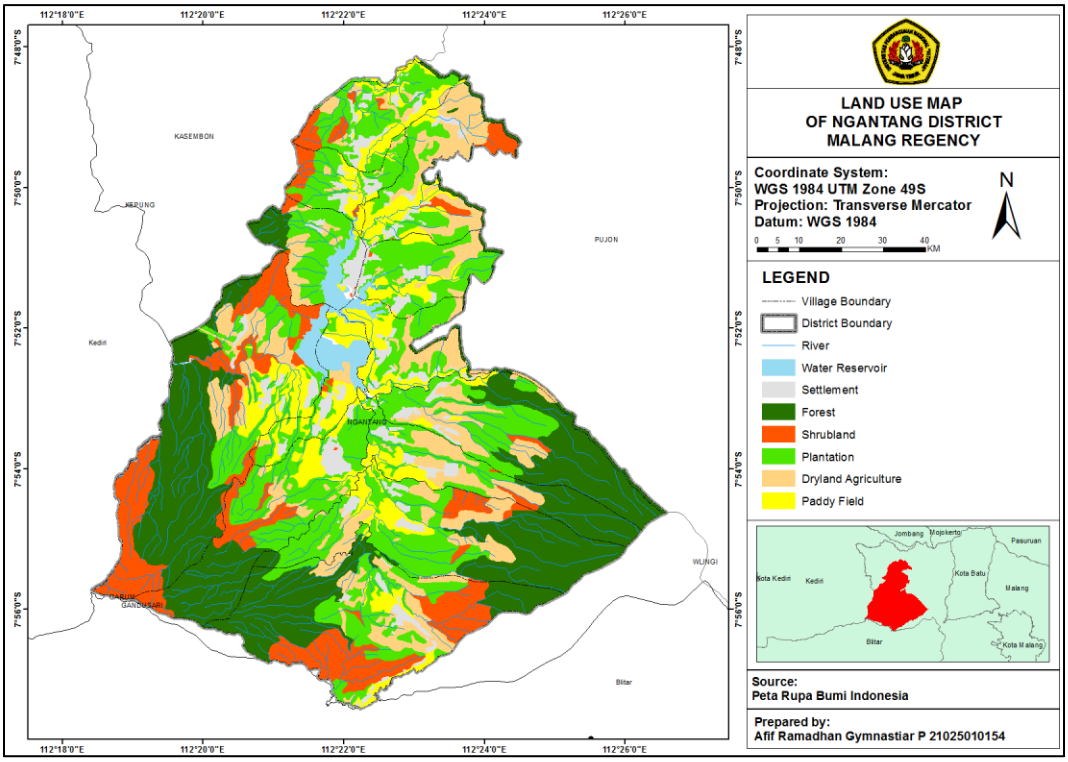

Figure 2. Land-Use Map

Erosion Factors

Erosivity indicates the ability of rainfall to erode soil layers and is a key factor in both geomorphological and hydrological processes (Thomas et al., 2018). The rainfall data used in this study were obtained from daily rainfall records for the last five years (2021–2025), retrieved via the Power Data Access Viewer released by NASA at the study location's coordinates. The data obtained was then processed using the Bols equation.

Table 2. Rainfall Erosivity Calculation

No	Year	Rainy Days	Rainfall (cm)	R (kJ/ha)
1	2021	364	256.08	1363.82
2	2022	365	267.40	1269.39
3	2023	324	232.29	2198.67
4	2024	340	203.04	1078.08
5	2025	361	270.34	1542.98
Average erosivity				1490.59

Source: NASA Power Data Access (Personally processed data)

High erosion rates during this period reflect the significant kinetic energy of raindrops, which is capable of triggering the detachment of soil particles and increasing surface runoff rates (Uniqbu et al., 2021). Heavy rainfall occurring over a short duration generates greater kinetic energy, thereby potentially accelerating soil erosion processes, particularly on open land or land with low vegetation cover (Fajeriana & Risal, 2023). The greater the rainfall intensity and the more frequent the rainfall events, the more significantly the potential for erosion increases, as the soil structure becomes more easily dispersed and carried away by surface runoff (Majewski et al., 2023).

Soil erodibility is a parameter that reflects the degree to which soil is susceptible to erosion. The higher the erodibility value, the greater the potential for the soil to be eroded. This value is influenced by several physical properties of the soil, particularly its texture, structure and permeability (Maulana et al., 2024). Soil characteristics based on laboratory analysis results indicate that the soil texture at all sampling points is dominated by sandy loam and loam, with a relatively high sand content at some locations tabel. According to Injiliana et al., (2021), coarse-textured soil, particularly on sloping land, is prone to erosion if not covered by adequate vegetation. The soil texture found at the study site is predominantly medium to coarse-grained. According to Ayuningtyas et al., (2018), soil of this nature absorbs water readily and drains well. Yang et al., (2024) add that the resistance of soil texture to erosion is influenced by its type.

Soil permeability values at the study site range from moderate to high, with the highest values generally found in forested areas. The relatively high permeability in forested areas indicates that the soil is looser, rich in organic matter and has good soil biological activity. Kalaati et al., (2019) emphasise that low soil permeability is one of the main factors contributing to erosion, particularly on sloping land, due to the increased volume and velocity of surface runoff. Low permeability directly increases soil erodibility due to the soil's limited ability to allow water to pass through. Kurniawan & Sari (2017) add that soils with low permeability tend to experience greater surface runoff because rainwater cannot infiltrate optimally and flows over the soil surface, thereby potentially carrying soil particles. Furthermore, Ayuningtyas et al., (2018) explain that soils with a high clay content experience a reduction in infiltration rates, which leads to increased runoff and accelerates water saturation.

Soil organic matter is a component found both within and on the surface of the soil, originating from the remains of organisms such as plants and animals, as well as human activities. Analysis results show that the organic matter content in forest land and mixed-use gardens is relatively high, whereas in dryland fields it generally falls into the low to moderate category. Organic matter content in forest land is higher than in other types of land due to the dense vegetation, minimal cultivation, and the abundance of litter. This is consistent with the findings of Sabaruddin et al., (2019), who noted that forest land has a high capacity for carbon sequestration due to the accumulation of biomass and the ongoing process of natural succession.

Table 3. Soil Erodibility Analysis Results

Code	%dust	%clay	% fine sand	% organic matter (a)	structural class (b)	Permeability class	M	K
K1TG	26.4	10.7	11.3	1.19	3	3	3368	0.35
K2TG	30.0	21.0	8.9	2.51	2	4	3070	0.28
K3TG	40.4	15.3	8.0	2.76	2	3	4096	0.33
K4TG	27.2	21.9	9.2	2.32	3	4	2842	0.30
K1KB	37.2	18.8	7.9	3.52	2	3	3660	0.27
K2KB	31.9	14.6	9.6	5.16	3	3	3542	0.25
K3KB	21.4	13.5	11.7	4.63	3	3	2862	0.22
K4KB	22.0	22.2	10.0	4.38	2	4	2496	0.19
K1SB	19.5	11.3	12.5	2.79	3	3	2835	0.26
K2SB	20.2	12.7	12.1	2.02	3	3	2815	0.27
K3SB	24.1	8.2	12.2	2.74	3	3	3333	0.30
K4SB	25.2	8.5	11.9	3.78	3	2	3394	0.25
K1HT	18.5	8.1	13.2	4.47	3	2	2920	0.19
K2HT	16.1	8.2	13.6	5.96	3	2	2729	0.14
K3HT	16.7	5.7	14.0	3.90	3	1	2891	0.17
K4HT	18.5	8.0	13.2	4.89	3	2	2913	0.18

Notes: K1 = 0-8%; K2 = 8-15%; K3 = 15-25%; K4 = 25-40%; TG = Farmland; KB=Plantation; SB = Scrubland; HT = Forest

The results of the erodibility analysis in Table 3 show that the erodibility values at the study site fall within the Low-Moderate category. Highest erosion susceptibility was found in tegalan land, with a K value of 0.35. This high erodibility value may be due to the fact that tegalan land has a much higher percentage of very fine silt and sand compared to the percentage of clay, coupled with a lower organic matter content than other land types, as well as a high soil texture class and permeability value. Pahlevi et al., (2019) noted that a high erodibility value indicates a high level of soil susceptibility to rain-induced erosion. A low erodibility value indicates that the soil is less susceptible to erosion, whereas a higher erodibility value indicates a greater degree of soil vulnerability. According to Liu et al., (2019) and Li et al., (2024), soil erodibility is the result of a complex interaction between soil physical properties, and its value increases in soils with unstable aggregates and low organic matter content, as found in dryland fields in Ngantang Sub-district.

Table 4. C and P Value at the Study Site

Code	Land Use	C	Conservation	P
K1TG	Unspecified Field	0.7	bench terrace in poor condition	0.4
K2TG	Unspecified Field	0.7	bench terrace in poor condition	0.4
K3TG	Unspecified Field	0.7	bench terrace in poor condition	0.4
K4TG	Unspecified Field	0.7	bench terrace in poor condition	0.4
K1KB	KC, medium density	0.2	bench terrace in fair condition	0.15
K2KB	KC, medium density	0.2	bench terrace in fair condition	0.15
K3KB	KC, medium density	0.1	bench terrace in fair condition	0.15
K4KB	KC, medium density	0.1	bench terrace in fair condition	0.4
K1SB	Scrub	0.3	CC 0-8%	0.5
K2SB	Scrub	0.3	CC 8-15%	0.6
K3SB	Scrub	0.3	CC 15-25%	0.8
K4SB	Scrub	0.3	CC >25%	0.9
K1HT	Natural forest	0.001	CC 0-8%	0.5
K2HT	Natural forest	0.001	CC 8-15%	0.6
K3HT	Natural forest	0.001	CC 15-25%	0.8
K4HT	Natural forest	0.001	CC >25%	0.9

Notes : K1 = 0-8%; K2 = 8-15%; K3 = 15-25%; K4 = 25-40%; TG = Farmland; KB = Plantation SB = Scrub; HT = Forest; KC = Mixed garden; CC = *Contur Cropping*

Based on field observations, measurements and data analysis, varying LS values were obtained, in line with differences in slope length at the study site. The longer a slope, the greater the surface runoff velocity, resulting in increased soil erosion intensity. High water flow velocity is generally influenced by continuous slope gradient, slope length, and flow concentration in narrow channels, which have the potential to trigger rill erosion or gully erosion (Wang et al., 2024). Nevertheless, steep slopes do not always result in high erosion rates, as vegetation and land management practices also play a role in determining the extent of erosion, either by suppressing or increasing the erosion rate (Sun & Li, 2025). Furthermore, an increase in slope gradient also increases the number of soil particles splashed downwards due to the impact energy of raindrops (Beczek et al., 2022).

Forests have the lowest C value, at 0.001, due to their dense vegetation, strong and large roots, and canopy diversity, which significantly reduce the kinetic energy of rainfall. The lowest conservation effect is found in garden land use, with a value of 0.15, due to its bench-terrace configuration under moderate conditions. This terraced land condition will slow the rate of surface runoff, thereby reducing the rate of erosion. According to Sutrisno et al., (2011), bench terraces are used as cultivation areas on sloping land and aim to absorb surface runoff and control erosion. Sianipar et al., (2023) add that land on steep slopes where no conservation measures are implemented will have a negative impact on soil quality, as the rate of erosion will exceed the rate of soil formation, leading to soil degradation.

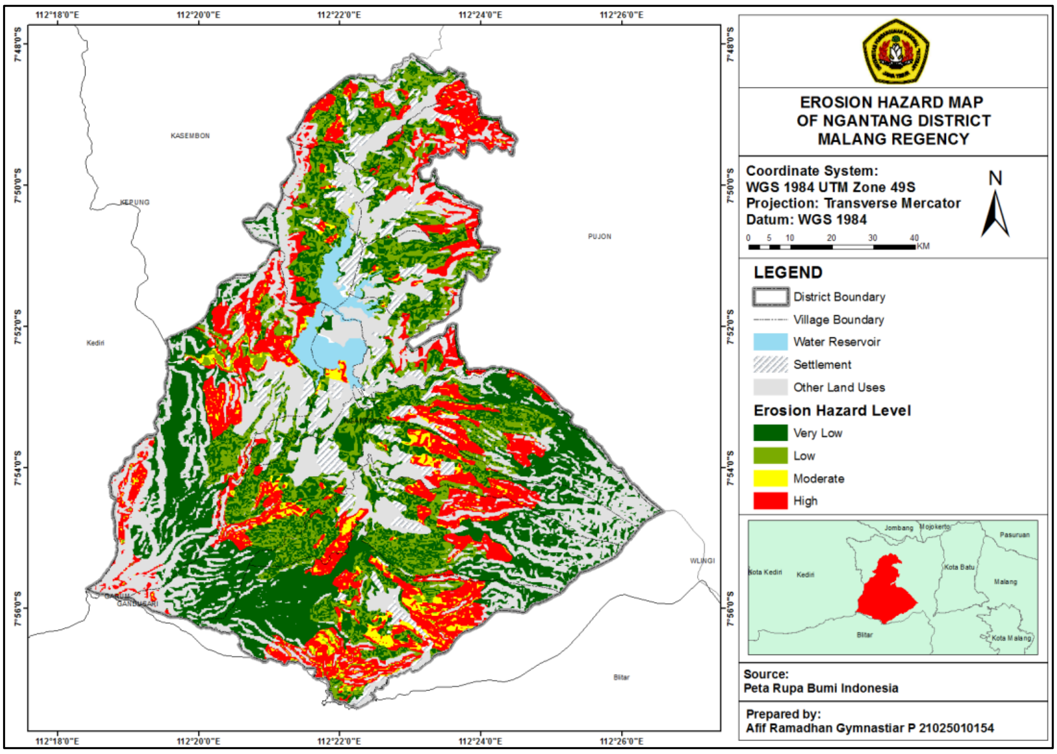

Figure 3. Erosion Hazard Map

Estimation of Actual Erosion and Erosion Hazard Level

Erosion values were calculated using the USLE method with the R.K.LS.C.P equation developed by Wischmeier & Smith (1978), and the erosion hazard levels are presented in Table *5*. Actual erosion values at the study site varied across different land uses. Actual erosion values show extreme differences between land uses. The highest values were found on K4TG dryland (377.32 tons/ha/year) and K4SB scrubland (353.01 tons/ha/year), which are classified as having a severe to very severe erosion hazard. Conversely, the lowest values were found on forested land (0.29–0.97 tons/ha/year). This difference indicates that factor C is the primary determinant of actual erosion. Forest vegetation is capable of reducing erosion by more than 99% compared to open land, even on steep slopes. This finding is consistent with the results of a study by Biddoccu et al., (2020), which showed that permanent vegetation cover is the most effective factor in erosion control.

Actual erosion values (A) were highest on scrubland and fallow land, particularly at observation points located on steep slopes. The high erosion rate on scrubland is influenced by sparse and uneven vegetation cover, which means the soil surface is not optimally protected from the kinetic energy of raindrops, thereby increasing the intensity of soil particle detachment. This condition is reflected in the high land cover factor (C) value and the lack of conservation measures on the land, resulting in a high P value. Steep slopes increase the velocity and volume of surface runoff, thereby enhancing the flow's capacity to transport soil particles. This finding is consistent with the results of Sheng et al., (2025), who stated that slope gradient and vegetation distribution are the primary determinants of erosion rates at the slope scale.

Table 5. Measured Actual Erosion Values (A)

No	Code	R	K	LS	C	P	A	Solum	EHL
1	K1TG	1490.588	0.35	1.00	0.7	0.4	145.96	92	S
2	K2TG	1490.588	0.28	1.76	0.7	0.4	202.15	115	B
3	K3TG	1490.588	0.33	2.28	0.7	0.4	313.11	110	B
4	K4TG	1490.588	0.30	3.22	0.7	0.4	405.16	120	B
5	K1KB	1490.588	0.27	1.01	0.2	0.15	11.98	120	SR
6	K2KB	1490.588	0.25	1.70	0.2	0.15	21.02	120	R
7	K3KB	1490.588	0.22	2.26	0.1	0.15	10.90	120	SR
8	K4KB	1490.588	0.19	3.14	0.1	0.4	34.92	120	R
9	K1SB	1490.588	0.26	1.07	0.3	0.50	61.63	106	S
10	K2SB	1490.588	0.27	1.83	0.3	0.60	134.45	77	B
11	K3SB	1490.588	0.30	2.21	0.3	0.80	238.57	120	B
12	K4SB	1490.588	0.25	3.83	0.3	0.90	379.05	120	B
13	K1HT	1490.588	0.19	1.09	0.001	0.50	0.16	120	SR
14	K2HT	1490.588	0.14	1.77	0.001	0.60	0.23	120	SR
15	K3HT	1490.588	0.17	2.63	0.001	0.80	0.54	120	SR
16	K4HT	1490.588	0.18	3.86	0.001	0.90	0.94	114	SR

Notes: SR=Very Low; R=Low; S=Moderate; B=Severe; SB=Very Severe
(Source: Analytical Data,2025)

Elevated erosion rates on dryland fields in Ngantang Sub-district are caused by ground cover vegetation consisting of annual crops and poorly maintained terraces, resulting in high runoff levels. Paimin (2017) explains that a plant's ability to suppress erosion and surface runoff is influenced by several factors, such as plant height, canopy continuity, vegetation density, and root systems. Deep, well-developed roots play a role in increasing water absorption whilst holding the soil in place against erosion. Furthermore, a dense canopy with closely spaced branches and leaves is able to dampen the impact energy of rainfall and direct water to flow down the stems into the soil, where it is absorbed by the roots. These conditions result in reduced surface runoff, thereby significantly mitigating erosion rates. A relatively high P factor value indicates poor soil conservation practices. Furthermore, high soil erodibility indicates that the soil is relatively prone to dispersion when subjected to rainfall energy. This situation is exacerbated by steep slopes, which increase the velocity and volume of surface runoff. These findings reinforce the results of the study by Parenja et al., (2025), which states that the effectiveness of terracing and vegetation cover are key factors in controlling erosion on sloping agricultural land. Panagos et al., (2017) further stated that the combination of steep slopes, high runoff, and soil that is prone to erosion are the main drivers of severe erosion in agricultural landscapes and open land.

Actual erosion rates were lowest on forested land, ranging from just 0.16 to 0.94 tons/ha/year. These low erosion rates on forested land demonstrate the exceptional effectiveness of natural vegetation in protecting the soil surface from the kinetic energy of rainfall. The forest canopy, a thick layer of litter, and a dense root system serve to dissipate rainfall energy, enhance infiltration, and strengthen soil aggregates. The high organic matter content in forest soils also results in a more stable soil structure and better permeability, thereby reducing surface runoff. This aligns with the findings of Dunggio & Ichsan (2022), who state that forests are an effective form of land cover for controlling erosion even on steep slopes. Plantation land exhibits actual erosion values in the very low to low categories, ranging from 11.98 to 34.92, which are significantly influenced by the quality of terracing and the density of vegetation cover. Relatively dense vegetation also reduces the C factor value, thereby enhancing soil surface protection.

Correlation Between Causal Factors and Erosion (A)

Multiple linear regression analysis was used to determine the influence of the factors causing erosion, as included in the Universal Soil Loss Equation (USLE) model, on the actual erosion rate (A) at the study site. The independent variables tested included soil erodibility (K), slope length and steepness (LS), land cover (C), and land management practices (P). The rainfall erosivity value (R) was not included in the regression model because all sample points were located in the same rainfall zone, meaning that the value of R was constant and did not provide variation in the statistical analysis.

The analysis results indicate that the regression model performs very well in explaining the variation in actual erosion (Appendix). A correlation coefficient (R) of 0.903 indicates a very strong relationship between the variables in the model and actual erosion. The coefficient of determination (R^2) of 0.816 indicates that 81.6% of the variation in actual erosion can be explained by the variables K, LS, C, and P, whilst the remainder is influenced by other factors outside the model. The test results show an F-value of 12.161 with a significance level of 0.001 ($p < 0.05$), meaning that the variables K, LS, C, and P simultaneously have a significant effect on actual erosion.

Variables slope length and slope gradient (LS) are the most statistically significant factors, with a coefficient of 57.946, a T-value of 3.043, and a significance level of 0.011. This indicates that a one-unit increase in the LS value will increase actual erosion by 57.946 units, assuming all other variables remain constant. This confirms that topography has a consistent and significant influence on the erosion process in the study area. Variable vegetation cover (C) has the highest standard coefficient (beta) of 0.618, indicating the greatest relative contribution to the variation in actual erosion, although its significance is borderline (0.053). This confirms the important role of vegetation cover in controlling erosion rates. The soil erodibility (K) and land management practices (P) variables showed positive coefficients but were not statistically significant (p>0.05), with significance values of 0.233 and 0.095, respectively. This indicates that both variables act as supporting factors in the model, the influence of which may be overshadowed by the dominance of topography and land cover factors or influenced by the homogeneity of land conditions at the study site.

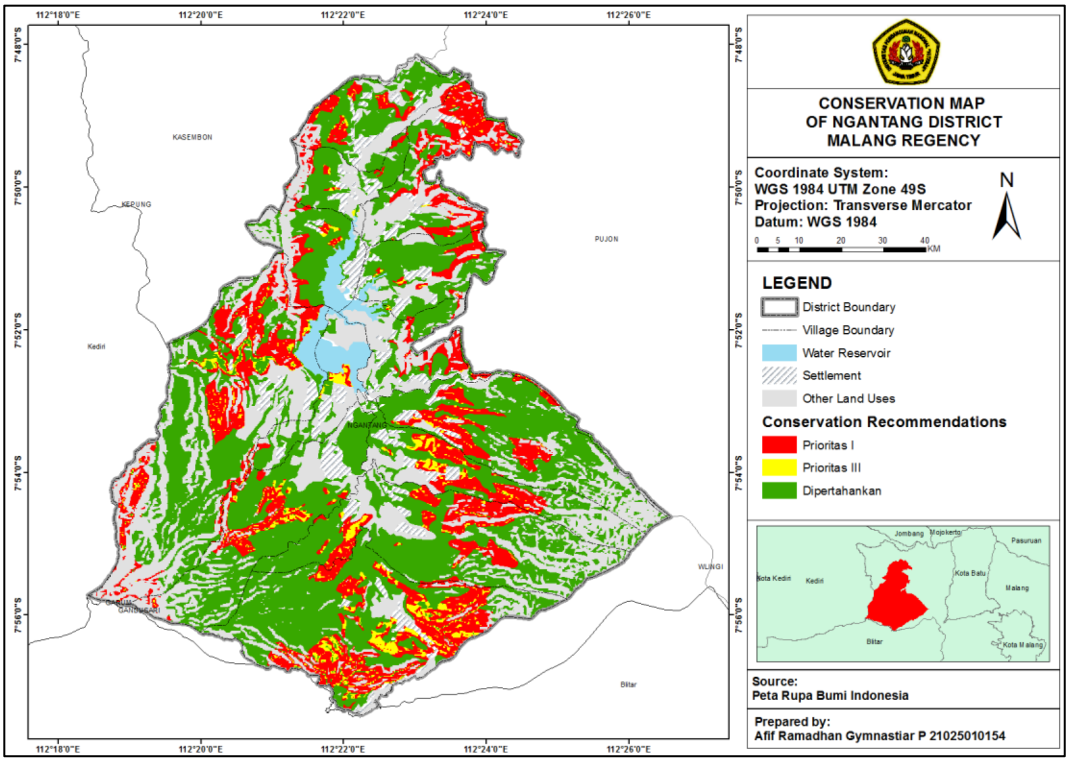

Figure 4. Conservation Priority Map

Conservation Guidelines

Conservation measures that can be implemented at the study site involve combining scrubland with the planting of permanent grass strips. The grass strips are planted transversely, closely following the contours of the slope, so as to slow down surface runoff. The recommended grass species are local grasses resistant to water flow pressure, such as vetiver (*Vetiveria zizanioides*) or mini elephant grass. The combination of grass strips and shrubs forms a mutually supportive conservation system, where the grass acts as a sediment filter, while the shrubs help stabilize the soil and prevent the spread of erosion. This is consistent with Nurmani et al., (2016), who explain that vegetation plays a vital role in absorbing the kinetic energy of rainfall, slowing surface runoff, enhancing infiltration, reducing erosion intensity, and supporting soil biota activity that contributes to soil improvement.

Conservation measures on Tegalan land can be implemented by converting land use to plantations with crops suited to the socio-economic conditions of the Ngantang sub-district community, which is generally dominated by coffee cultivation.

Furthermore, improvements need to be made to poorly maintained bench terraces. These efforts aim to reduce the effective slope length, lower surface runoff velocity, and enhance the soil's water absorption capacity. Terraces act as barriers to water flow, thereby reducing flow energy and increasing the soil's stability in retaining particles. Herlina et al., (2023) state that terracing is an effective conservation technique on land with moderate to steep slopes as it can control runoff without significantly altering the land-use system. A study by Nsabiyumva et al., (2025) also shows that altering slope topography through terracing can significantly reduce soil loss by decreasing flow energy and prolonging the residence time of water on the surface. Thus, the application of bench terraces on dryland fields at the study site is consistent with the principles of sustainable soil conservation.

CONCLUSION

The actual erosion rate in Ngantang Sub-district is highly variable and significantly determined by specific land utilization, with the most severe rates occurring on dryland (up to 405.16 tons/ha/year) and scrubland (up to 379.05 tons/ha/year) situated on steep slopes, resulting in a Very Severe Erosion Hazard Level (EHL). Conversely, natural forest and well-managed plantations exhibit exceptionally low erosion rates (as low as 0.16 tons/ha/year). Multiple linear regression confirmed that vegetation cover (C factor) is the most dominant factor influencing erosion ($\beta = 0.618$), highlighting a critical novelty that local vegetation density completely supersedes topographical constraints in mitigating soil loss within this specific volcanic landscape. To mitigate this hazard, prioritizing the conversion of dryland to multi-strata agroforestry and installing permanent grass strips on scrublands is highly recommended to suppress actual erosion rates below the tolerable limits. These targeted conservation strategies provide a quantifiable spatial framework for local stakeholders to achieve sustainable land management and prevent further severe land degradation.

ACKNOWLEDGEMENTS

We would like to thank the Ngantang Sub-district Administration for its support of this researchand all those involved.

REFERENCES

Asdak, C. (2023). *Hydrology and Watershed Management*. (First edition). UGM Press. **[*In Indonesian language*]**

ASTM. (2022). ASTM D2434-22: Standard Test Method for Permeability of Granular Soils (Constant Head). ASTM International.

ASTM. (2019). ASTM D2216-19: Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. ASTM International.

Auliyani, D., & Wijaya, W. W. (2017). Comparison of sediment yield predictions using the Universal Soil Loss Equation model approach with direct measurements. *Jurnal Penelitian Pengelolaan Daerah Aliran Sungai (Journal of Watershed Management Research)*, *1*(1), 61–71. **[*In Indonesian language*]**

Ayuningtyas, E. A., Ilma, A. F. N., & Yudha, R. B. (2018). Mapping of Soil Erodibility and Its Correlation with Soil Characteristics in the Serang Watershed, Kulonprogo. *Jurnal Nasional Teknologi Terapan (JNTT)*, *2*(1), 37–46. **[*In Indonesian language*]**

Beczek, M., Ryżak, M., Mazur, R., Sochan, A., Polakowski, C., & Bieganowski, A. (2022). Influence of slope incline on the ejection of two-phase soil splashed material. *PLoS ONE*, *17*. https://doi.org/10.1371/journal.pone.0262203

Biddoccu, M., Guzmán, G., Capello, G., Thielke, T., Strauss, P., Winter, S., Zaller, J., Nicolai, A., Cluzeau, D., Popescu, D., Bunea, C., Hoble, A., Cavallo, E., & Gómez, J. (2020). Evaluation of soil erosion risk and identification of soil cover and management factor (C) for RUSLE in European vineyards with different soil management. *International Soil and Water Conservation Research*, *8*, 337–353. https://doi.org/10.1016/j.iswcr.2020.07.003

Dunggio, I., & Ichsan, A. C. (2022). The Effectiveness of Vegetative Planting in Mitigating Erosion and Sedimentation (A Case Study in the Limboto River Basin, Gorontalo Province). *Jurnal Belantara*, *5*(1), 45–58. **[*In Indonesian language*]**

Fajeriana, N., & Risal, D. (2023). Improving Understanding of Erosion Potential: Erosivity and Erodibility Through Rainfall Simulations on Different Topographies and Land Covers. *Abdimas: Papua Journal of Community Service*, *5*(1), 64–74. **[*In Indonesian language*]**

Gee, G. W., & Bauder, J. W. (1986). *Particle-size Analysis*. In A. Klute (Ed.), Methods of Soil Analysis Part 1: Physical and Mineralogical Methods (2nd ed., pp. 383–411). American Society of Agronomy.

Guimarães, M. H., Martins, M., Vieira, D., Brito, I., Kelly, C., Guiomar, N., Stathopoulos, N., Zoka, M., Nóvoa, T., Cerdà, A., Faria, B., Madeira, J., Fidalgo, L., Panagos, P., Zdruli, P., Keesstra, S., Prats, S., Giuseppe, P. D., & Dobos, E. (2024). Preliminary assessment of the knowledge gaps to prevent soil erosion. *Soils for Europe.*, *1*. https://doi.org/10.3897/soils4europe.e118669

Herlina, E., Hayati, H., & Muktasam, M. (2023). Analysis of Land Use Direction based on Land Capability Class in the Kelep Watershed, Lombok. *Jurnal Sains Teknologi & Lingkungan*, *9*(3), 502–515. **[*In Indonesian language*]**

Holisah, E. U. N., & Prijono, S. (2022). The Effect of Different Shade Trees on Soil Water-Holding Capacity in the Sumbermanjing Wetan Smallholder Coffee Plantation. *Jurnal Tanah Dan Sumberdaya Lahan*, *9*(2), 375–383. **[*In Indonesian language*]**

Injiliana, L., Widiastuti, T., & Riyono, J. N. (2021). Soil Erodibility (K) Under Various Land Covers in Baru Village, Silat Hilir Subdistrict, Kapuas Hulu Regency.

Jurnal Hutan Lestari, *8*(4), 773–781. **[*In Indonesian language*]**

Kalaati, I., Ramlan, R., & Rahman, A. (2019). Soil Erodibility Levels on Landslopes of Various Gradients in Labuan Toposo Village, Labuan Subdistrict, Donggala Regency. *Agrotekbis: Jurnal Ilmu Pertanian (e-Journal)*, *7*(2), 172–178. **[*In Indonesian language*]**

Kurniawan, R., & Sari, R. (2017). The Effect of Permeability on Infiltration Rate. *Jurnal Deformasi*, *2*(1), 50–60. **[*In Indonesian language*]**

Li, M., Wang, K., Ma, X., Fan, M., & Song, Y. (2024). Effects of land use change on soil aggregate stability and erodibility in the karst region of Southwest China. *Agronomy*, *14*(7), 1534.

Liu, M., Han, G., & Zhang, Q. (2019). Effects of soil aggregate stability on soil organic carbon and nitrogen under land use change in an erodible region in Southwest China. *International Journal of Environmental Research and Public Health*, *16*(20), 3809.

Maulana, H., Hermita, N., Fatmawaty, A. A., & Firnia, D. (2024). Analysis of Soil Erodibility for Sustainable Beneng Taro Cultivation Based on Elevation. *Jurnal Ilmiah Membangun Desa Dan Pertanian*, *9*(6), 533–546. **[*In Indonesian language*]**

Majewski, M., Czuchaj, A., & Marciniak, M. (2023). Impact of rainfall intensity on soil erosion based on experimental research. *Landform Analysis, 42*, 25-36. *10.12657/Landfana-042-002].*

Malík, A., Naharuddin, N., Massiri, S. D., Misrah, M., & Sustri. (2025). Integrative Application of USLE and GIS for Modeling Soil Erosion Dynamics and Conservation Prioritization in the Poboya Watershed, Indonesia. *International Journal of Life Science and Agriculture Research*, *4*(11). https://doi.org/10.55677/ijlsar/v04i11y2025-09

Nsabiyumva, J. M. V., Apollonio, C., Castelli, G., Bresci, E., Petroselli, A., Sabir, M., Hicintuka, C., & Preti, F. (2025). Impact of Slow-Forming Terraces on Erosion Control and Landscape Restoration in Central Africa's Steep Slopes. *Land, 14*(7), 1419. https://doi.org/10.3390/land14071419

Nurmani, U., Monde, A., & Rahman, A. (2016). Erosion Hazard Index (EHI) for Various Land-Use Types in Malei Village, Balaesang Tanjung Subdistrict, Donggala Regency. *Agrotekbis*, *4*(2), 186–194. **[*In Indonesian language*]**

Pahlevi, R. S., Hasan, H., & Devy, S. D. (2019). A Study of Soil Erodibility in Pit 3000, Block 3, PT Bharinto Ekatama, West Kutai Regency, East Kalimantan Province. *Jurnal Teknologi Mineral FT UNMUL*, *6*(1), 17-20. http://dx.doi.org/10.30872/jtm.v6i1.1386 **[*In Indonesian language*]**

Paimin, P. (2017). The effectiveness of mahogany (Swietenia macrophylla) plantation forest on controlling erosion and runoff. *Forum Geografi*, *19*(1), 88–102.

Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Jae Lim, K., Yang, J. E., Ni, J., Miao, C., & Chattopadhyay, N. (2017). Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Scientific Reports*, *7*(1), 4175.

Parenja, J. A., Salsabila, M. A., & Parasnalurita, D. (2025). Terracing as a Solution to Erosion on Critical Land. *Jurnal Pendidikan Sosial Dan Humaniora*, *4*(3), 4775–4787. **[*In Indonesian language*]**

Pawar, R., Sharma, R. K., Kumar, A., & Sepehya, S. (2020). Impact of land use change on soil erosion, sedimentation and soil microbiome. *International Journal of Chemical Studies*, *8*(2), 881–886. https://doi.org/10.22271/chemi.2020.v8.i2m.8877

Rianto, D. J., & Marwadi, A. (2023). The Relationship Between Soil Erodibility and Erosion on Former Coal Mining Sites. *Jurnal Sains Teknologi & Lingkungan*, *9*(2), 379–390. **[*In Indonesian language*]**

Sabaruddin, S., Fitri, S. N. A., & Lestari, L. (2019). The Relationship Between Soil Organic Matter Content and the Post-Harvest Period of *Acacia mangium* Willd. Plantations. *Journal of Tropical Soils*, *14*(2), 105–110. **[*In Indonesian language*]**

Saputra, R. T., Utami, S. R., & Agustina, C. (2022). The relationship between slope angle and percentage of surface rock and landslides, based on simulation results. *Jurnal Tanah Dan Sumberdaya Lahan*, *9*(2), 339–346. **[*In Indonesian language*]**

Seran, S. S. L. M. F. (2022). Analysis of Erosion in the Noelmina Watershed Using the USLE Method. *Eternitas: Jurnal Teknik Sipil*, *2*(1), 33–39. **[*In Indonesian language*]**

Sheng, Y., Zhang, S., Li, L., Cao, Z., & Zhang, Y. (2025). Simulation of slope soil erosion intensity with different vegetation patterns based on cellular automata model. *Frontiers in Environmental Science, 12,* 1512973. https://doi.org/10.3389/fenvs.2024.1512973

Shoumik, B. A. A., Khan, Md. Z., & Islam, Md. S. (2023). Soil erosion estimation by RUSLE model using GIS and remote sensing techniques: A case study of the tertiary hilly regions in Bangladesh from 2017 to 2021. *Environmental Monitoring and Assessment*, *195*(9), 1096–1096. https://doi.org/10.1007/s10661-023-11699-4

Sianipar, K. O., Sumiyati, S., & Yulianti, N. (2023). Erosion Prediction Using the RUSLE Method on Farmland in Candikuning Village, Baturiti Subdistrict, Tabanan Regency. *Jurnal BETA (Biosistem Dan Teknik Pertanian), 12*(1)*,* 80-90. https://doi.org/10.24843/jbeta.2024.v12.i01.p09 **[*In Indonesian language*]**

Srivastava, S., Basche, A., Traylor, E., & Roy, T. (2023). The efficacy of conservation practices in reducing floods and improving water quality. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/fenvs.2023.1136989

Sun, Y., & Li, Y. (2025). Overview of Different Land Use Practices and Impact on Soil Erosion. *Scientific Journal of Technology*. https://doi.org/10.54691/4h8kj389

Suprayogi, S., Purnama, L. S., & Darmanto, D. (2024). *Watershed Management* (First edition). UGM Press. **[*In Indonesian language*]**

Sutrisno, J., Sanim, B., Saefuddin, A., & Sitorus, S. R. P. (2011). Policy Guidelines for Erosion and Sedimentation Control in the Keduang Sub-Watershed, Wonogiri Regency. *Sains Tanah-Journal of Soil Science and Agroclimatology*, *8*(2), 105–118. **[*In Indonesian language*]**

Taslim, R. K., Mandala, M., & Indarto, I. (2019). Erosion Predictions in East Java: Application of USLE and GIS. *Jurnal Ilmu Lingkungan*, *17*(2), 323–332. **[*In Indonesian language*]**

Thomas, J., Joseph, S., & Thrivikramji, K. P. (2018). Estimation of soil erosion in a rain shadow river basin in the southern Western Ghats, India using RUSLE and transport limited sediment delivery function. *International Soil and Water Conservation Research*, *6*(2), 111–122.

Uniqbu, A., Sangadji, M. F., & Abdullah, A. (2021). Surface Runoff Rates and Erosion in Relation to Land Use in Batuboy Village, Buru Regency. *Agritrop*, *19*(1), 59–66. **[*In Indonesian language*]**

Walkley, A., & Black, I. A. (1934). An Examination of the Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. Soil Science, 37(1), 29–38.

Wang, Z., Zeng, R., & Ma, P. (2024). Determining of gully erosion susceptibility based on UAV and machine learning in Loess Plateau. *Geomatics Natural Hazards and Risk*, *15*(1), 2421382. https://doi.org/10.1080/19475705.2024.2421382

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning.* The USDA Agricultural Handbook No. 537. Department of Agriculture, Science and Education Administration.

Yang, T., Zhang, Z., Yu, P., Yin, Z., Li, A., Zhou, X., Qi, Z., & Wang, B. (2024). Soil aggregates and water infiltration performance of different water and soil conservation measures on phaeozems sloping farmland in northeast China. *Agronomy*, *14*(10), 2410.

Zhang, X., Zhu, Q., Sang, J., & Ding, X. (2022). Effects of rainfall and the slope gradient on the soil and water loss in a purple soil area. *Soil and Water Research*, *17*(4), 232–242. https://doi.org/10.17221/45/2022-swr

How To Cite This Article, with *APA style* :
Gymnastiar, A. R., Purwadi, P., & Sasongko, P. E. (2026). Land-Use Driven Soil Erosion and Conservation Priorities in Tropical Highlands: *A USLE-Based Analysis from Ngantang, Indonesia*. *Jurnal Pembelajaran dan Biologi Nukleus*, *12*(2), 620-637. https://doi.org/10.36987/jpbn.v12i2.9262

Conflict of interest : The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions : All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was submited by [**Afif Ramadhan Gymnastiar**]. All authors contributed on previous version and revisions process of the manuscript. All authors read and approved the final manuscript.