Vol. 17 No. 1 (2026) 63-72

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage: https://www.jrtppi.id

Kementerian Perindustrian
REPUBLIK INDONESIA

Calculation of Erosion Rate and Conservation Efforts in the Lut Tawar Sub-Watershed

Hiwana Alfadhila*, Hairul Basri, Purwana Satriyo, Devianti, Syakur

Universitas Syiah Kuala

ARTICLE INFO

Article history:
Received February 05, 2026
Received in revised form March 05, 2026
Accepted April 05, 2026
Available online May 05, 2026

Keywords:
Erosion Hazard Level, Conservation Efforts, Geographic Information System, Lut Tawar Sub-Watershed.

ABSTRACT

This study aims to analyze the level of erosion hazard (TBE) and formulate alternative soil and water conservation efforts that are appropriate to the conditions of the Lut Tawar Sub-watershed. The approach used is the integration of Geographic Information Systems (GIS) with the Universal Soil Loss Equation (USLE) method. Analysis of the magnitude of erosion (A) is carried out by calculating the rainfall erosivity factor (R), soil erodibility (K), slope length and gradient (LS), as well as plant management and conservation action factors (CP) in each land map unit (SPL). The results of the study show that the analysis of the erosion hazard level (TBE)—the potential for water erosion—indicates that the TBE value of 0.02 is included in the very light category. The TBE value in the range of 1.07–1.33 is classified as light, while the TBE value of 2.39 is included in the moderate category. Furthermore, the TBE value in the range of 3.95–6.51 indicates a severe level of erosion hazard, and the TBE value is very severe, namely 8.04 to 346.23. Overall, the TBE pattern at the site is classified as high, indicating that some SSTs are vulnerable to soil damage due to erosion. This is primarily influenced by a combination of very high actual erosion rates and relatively low Etol values in several soil types. Soil conservation efforts consist of mechanical conservation and vegetative conservation. Mechanical conservation includes the application of terracing and contour land management. Meanwhile, vegetative conservation is carried out through the planting of ground cover plants and the development of agroforestry systems on sloping land. This research can support sustainable management planning for the Lut Tawar Subwatershed and be used as a consideration in the formulation of soil and water conservation policies.

1. INTRODUCTION

A watershed (Daerah Aliran Sungai, DAS) is a land area bounded by ridges where rainfall flows into a main river and eventually empties into the sea. In Indonesia, watersheds play a strategic role in sustaining ecosystems, communities, and economic activities (O'Higgins & O'Dwyer, 2019) (Skjølsvik & Kaloudis, 2023) (Maltby et al, 2023). As an interconnected ecological system, disturbances in one component produce cascading impacts across the watershed. Watershed management therefore regulates the interaction between natural resources and human activities to ensure sustainability (Aryani et al, 2020).

The Krueng Peusangan Watershed is categorized as a top-priority degraded watershed in Aceh. In 2019, very critical land covered 8,107.68 hectares (3.17%), while critical land reached 83,186.59 hectares (32.52%). This condition disrupts hydrological stability and intensifies erosion. In 2021, more than 50% of the watershed experienced severe to very severe *erosion hazard* (Ananda & Iqbal, 2021), driven by high rainfall, steep slopes, erodible soils, limited vegetation cover, and improper land management (Wischmeier & Smith, 1978).

The Lut Tawar Sub-watershed, a strategic upstream unit within the 255,810.67-hectare Krueng Peusangan Watershed (consisting of 12 sub-watersheds), strongly influences downstream hydrological processes and

*Correspondence author.
E-mail: hiwanaalfadhila.692@gmail.com (Hiwana Alfadhila)

doi: https://doi.org/10.21771/jrtppi.2026.v17.no1.p63-72

Accreditation number: (Ristekdikti) 158/E/KPT/2021

sediment transport. However, rapid and uncontrolled development, land-use change, forest encroachment, plantation expansion, mining, and hydropower activities have accelerated its degradation (Salviya et al, 2023). Critical land is concentrated in upstream areas of Lut Tawar, Krueng Ceulala, and Timang Gajah, including built-up land, open agriculture, and livestock areas. Economic expansion further increases pressure on natural resources (Ekawaty et al, 2018) (Missleini, 2023) (Ridwan & Sarjito, 2024), while deforestation in upper and middle reaches intensifies downstream sedimentation (Arifin et al, 2022). This process reduces river capacity, heightens flood risk (Sholihah et al, 2020) (Merten et al, 2021) (Ariyani et al, 2023) (Bennett et al, 2023), and contributes to landslides influenced by slope, soil depth, soil type, and land use (Van Tho, 2020).

Although previous studies identified high *erosion hazard* in the broader Krueng Peusangan Watershed (Ananda & Iqbal, 2021), detailed spatial analysis focusing specifically on the Lut Tawar Sub-watershed remains limited. Prior research has not comprehensively integrated *Geographic Information Systems* (GIS) with the *Universal Soil Loss Equation* (USLE) at the sub-watershed scale, nor translated quantitative erosion assessments into context-specific soil and water conservation strategies.

This study therefore evaluates the *erosion hazard* level in the Lut Tawar Sub-watershed using the *USLE* method integrated with *GIS*, quantifies erosion magnitude (A), identifies dominant contributing factors (R, K, LS, and CP), classifies *erosion hazard* levels, and formulates targeted mechanical and vegetative conservation measures. The results provide a scientific basis for sustainable upstream watershed management and evidence-based conservation policy in the Krueng Peusangan region.

2. METHODS

The research was conducted in the Lut Tawar Sub-watershed, Krueng Peusangan Watershed, Central Aceh Regency, from August 2025 to December 2025. The tools used in this study included a laptop, *Global Positioning System* (GPS), ArcGIS 10.8, SPSS, a camera, a soil drill, sample ring, plastic, rubber, and stationery. The materials consisted of an administrative map of Central Aceh, a boundary map of the Lut Tawar Sub-watershed, a slope map, a soil type map, a rainfall map, a land use map, and chemicals for laboratory soil analysis.

This study employed a quantitative descriptive approach to explain existing field conditions through systematic data recording and analysis (Martín Duque et al, 2015) (Wang et al, 2019) (Biswas et al, 2021). The data consisted of primary and secondary data. Primary data were obtained from field observations and soil sampling conducted directly in the Lut Tawar Sub-watershed, while laboratory analysis was carried out to determine soil characteristics. Secondary data were obtained from literature studies and relevant agencies.

The research was conducted in four stages: (1) preparation and data collection) ((2) field surveys and soil sampling in the Lut Tawar Sub-watershed) ((3) laboratory analysis and spatial data processing using *ArcGIS*) (and (4) data analysis and presentation of results.

To analyze the research problem, direct observation and soil analysis were conducted at the research location. Erosion values were calculated using the *Universal Soil Loss Equation* (*USLE*) method (Bera, 2017) (Pham et al, 2018) (Benavidez et al, 2018).

Universal Soil Loss Equation (USLE).

$$A = R \times K \times LS \times C \times P \quad \text{...(1)}$$

Description:

A: Soil erosion rate (tons/ha/year)

R: Rainfall erosivity index (Kj/ha)

K: Soil erodibility index (tons/Kj)

L: Slope length index

S: Slope gradient index

C: Vegetation cover index

P: Land management/soil conservation measures index

To determine appropriate conservation measures in areas with high erosion rates, the calculated erosion value (A) was compared with the allowable soil loss (*eTol*).

If A > eTol, then $CP = \frac{Etol}{RKLS}$ ……………………………… (2)

The results of this calculation were used as the basis for formulating soil and water conservation measures to prevent land degradation and maintain sustainable soil productivity.

3. RESULT AND DISCUSSION

Erosion Rate Calculation (A)

The erosion rate for each land unit (SPL) was calculated using the USLE equation, considering the factors R, K, LS, C, and P. The results of the erosion rate calculations are presented in Table 1 below, showing the extent of soil loss at each SPL.

Table 1.
Erosion Rate Calculation

No	Code	R	K	LS	C	P	A (Ton/Ha/Year)
1	SPL 1	1636.25	0.20	3.1	0.2	0.1	19.79
2	SPL 2	1636.25	0.21	0.4	0.2	0.5	13.92
3	SPL 3	1636.25	0.88	0.4	0.29	0.04	6.70
4	SPL 4	1636.25	0.20	0.4	0.2	0.5	12.92
5	SPL 5	1434.55	0.07	0.4	1	1	41.98
6	SPL 6	1434.55	0.43	0.4	0.56	1	137.35
7	SPL 7	1434.55	0.05	6.8	0.05	0.04	0.91
8	SPL 8	1434.55	0.03	6.8	0.2	0.4	21.71
9	SPL 9	1434.55	0.35	1.4	0.2	0.5	71.16
10	SPL 10	1434.55	0.69	3.1	0.001	1	3.08
11	SPL 11	1636.25	0.34	1.4	0.7	1	542.05
12	SPL 12	1636.25	0.84	6.8	0.2	0.5	934.83
13	SPL 13	1434.55	0.97	0.4	0.29	0.04	6.46
14	SPL 14	1434.55	0.61	0.4	0.2	0.5	35.15
15	SPL 15	1434.55	0.43	0.4	1	1	246.35
16	SPL 16	1434.55	0.11	0.4	0.01	0.25	0.16
17	SPL 17	1636.25	0.79	1.4	0.2	0.5	180.84

Source: Analysis Results (2025)

Based on calculations using the USLE method, erosion rates varied significantly from 0.16 tons/ha/year to 934.83 tons/ha/year. This variation reflects the combined influence of rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover (C), and conservation practices (P). Most land units exhibited moderate to very high erosion rates, indicating considerable susceptibility to soil degradation.

Low erosion rates (<10 tons/ha/year) were recorded in SPL 7, SPL 10, SPL 13, SPL 3, and SPL 16. These locations were characterized by low C and P values, indicating good vegetation cover and effective conservation measures, as well as relatively lower LS influence, which reduced runoff energy despite high rainfall erosivity.

Very high erosion rates were observed in SPL 5, SPL 6, SPL 11, SPL 12, SPL 15, and SPL 17, with some exceeding 500 tons/ha/year. These values were primarily associated with high LS, C, and P factors, reflecting steep slopes, limited vegetation cover, and insufficient conservation measures. SPL 12 recorded the highest erosion rate (934.83 tons/ha/year), influenced by a high LS value (6.8), high soil erodibility, and suboptimal land cover conditions.

Moderate to high erosion in several land cover units was influenced by moderate LS values combined with land cover that was not fully capable of controlling runoff. This indicates that vegetation quality and conservation effectiveness remain key determinants of erosion intensity.

Overall, the analysis confirms that land cover (C) and conservation practices (P) strongly influence erosion rates. Areas with dense vegetation consistently show lower erosion, whereas open or poorly managed land experiences substantial soil loss. Conservation measures such as vegetative cover improvement, terracing, and slope management are therefore essential to reduce erosion risk (Xiong et al, 2018) (Desta et al, 2021) (Chen et al, 2021) (Liu et al, 2021).

Subsequent analysis examined the relationship between actual erosion and influencing factors using Pearson correlation (r) in SPSS to assess the strength and direction of relationships between erosion and R, K, LS, C, and P (Maha et al, 2023).

Table 2.
Pearson Correlation Test

Variable	Actual Erosion	R Factor	K Factor	LS Factor	C Factor	P Factor
Actual Erosion	1.000	0.332	0.209	0.352	0.345	0.353
Sig. (2-tailed)	—	0.193	0.420	0.166	0.175	0.165
R Factor	0.332	1.000	0.202	−0.013	−0.110	−0.174
Sig. (2-tailed)	0.193	—	0.437	0.959	0.674	0.505
K Factor	0.209	0.202	1.000	−0.160	−0.013	−0.149
Sig. (2-tailed)	0.420	0.437	—	0.540	0.961	0.569
LS Factor	0.352	−0.013	−0.160	1.000	−0.366	−0.240
Sig. (2-tailed)	0.166	0.959	0.540	—	0.148	0.353
C Factor	0.345	−0.110	−0.013	−0.366	1.000	**0.626**
Sig. (2-tailed)	0.175	0.674	0.961	0.148	—	**0.007**
P Factor	0.353	−0.174	−0.149	−0.240	**0.626**	1.000
Sig. (2-tailed)	0.165	0.505	0.569	0.353	**0.007**	—

Source: Analysis Results (2025)

Table 3.
Factors in Determining Erosion

No	Factor	r (Pearson)
1	R	0.33
2	K	0.20
3	LS	0.35
4	C	0.34
5	P	0.35

Source: Analysis Results (2025)

Pearson correlation results indicate that LS and P factors show the strongest relationship with erosion (r = 0.35), followed by C (r = 0.34) and R (r = 0.33), while K shows the weakest correlation (r = 0.20). Although all variables demonstrate positive relationships, the relatively low correlation coefficients suggest that erosion is influenced by the interaction of multiple factors rather than a single dominant variable. These findings reinforce the need for integrated land management strategies in erosion control.

Determining the eTol Value

Tolerable erosion (ETol) indicates the maximum amount of soil loss that is acceptable without causing long-term decline in land function and productivity (Mandal et al, 2021) (Kahirun et al, 2023) (Madenoğlu et al, 2024) (Abebe et al, 2025). In this study, the ETol value was determined based on effective soil depth using the formula proposed by Hammer (1981) as explained by Arsyad (2010), considering soil depth and land use age. The ETol value was then compared with actual erosion rates to determine erosion risk levels for each land unit (Sahido et al, 2025). The ETol values are presented in Table 4.

Table 4.
eToll Value Analysis

Code	Depth (cm)	Depth (mm)	Depth Factor	Useful Life (Year)	T	T (Ton/Ha/Year)
SPL 1	20 cm	200	0.9	500	0.36	3.6
SPL 2	72 cm	720	0.9	500	1.296	12.96
SPL 3	20 cm	200	0.9	500	0.36	3.6

Code	Depth (cm)	Depth (mm)	Depth Factor	Useful Life (Year)	T	T (Ton/Ha/Year)
SPL 4	54 cm	540	0.9	500	0.972	9.72
SPL 5	59 cm	590	0.9	500	1.062	10.62
SPL 6	50 cm	500	0.9	500	0.9	9
SPL 7	25 cm	250	0.9	500	0.45	4.5
SPL 8	15 cm	150	0.9	500	0.27	2.7
SPL 9	29 cm	290	0.9	500	0.522	5.22
SPL 10	20 cm	200	0.9	500	0.36	3.6
SPL 11	30 cm	300	0.9	500	0.54	5.4
SPL 12	15 cm	150	0.9	500	0.27	2.7
SPL 13	15 cm	150	0.9	500	0.27	2.7
SPL 14	30 cm	300	0.9	500	0.54	5.4
SPL 15	25 cm	250	0.9	500	0.45	4.5
SPL 16	40 cm	400	0.9	500	0.72	7.2
SPL 17	20 cm	200	0.9	500	0.36	3.6

Source: Analysis Results (2025)

Determining Erosion Hazard Class (EBH)

The Erosion Hazard Class (EBH) was calculated by comparing actual erosion (A) with tolerable erosion (ETol) (Zhang et al, 2021). EBH is classified into five categories: very light, light, moderate, heavy, and very heavy. The results are presented in Table 5.

Table 5.
Erosion Hazard Class Analysis

No	Code	A (Ton/Ha/Year)	ETol	TBE	Category
1	SPL 1	19.79	3.6	5.50	Heavy
2	SPL 2	13.92	12.96	1.07	Light
3	SPL 3	6.70	3.6	1.86	Light
4	SPL 4	12.92	9.72	1.33	Light
5	SPL 5	41.98	10.62	3.95	Heavy
6	SPL 6	137.35	9	15.26	Very Heavy
7	SPL 7	0.91	4.5	0.20	Very Light
8	SPL 8	21.71	2.7	8.04	Very Heavy
9	SPL 9	71.16	5.22	13.63	Very Heavy
10	SPL 10	3.08	3.6	0.85	Very Light
11	SPL 11	542.05	5.4	100.38	Very Heavy
12	SPL 12	934.83	2.7	346.23	Very Heavy
13	SPL 13	6.46	2.7	2.39	Moderate
14	SPL 14	35.15	5.4	6.51	Heavy
15	SPL 15	246.35	4.5	54.74	Very Heavy

16	SPL 16	0.16	7.2	0.02	Very Light
17	SPL 17	180.84	3.6	50.23	Very Heavy

Source: Analysis Results (2025)

The EBH results indicate substantial variation in erosion hazard levels across SPLs, ranging from very light to very heavy. Very light categories were identified in SPL 7, SPL 10, and SPL 16, where TBE values were below 1, indicating actual erosion remains far below tolerable limits. These conditions reflect effective vegetation cover and conservation practices.

Light to moderate categories were found in SPL 2, SPL 3, SPL 4, and SPL 13 (TBE 2.39). Heavy categories occurred in SPL 1 and SPL 14, where TBE values exceeded 5, indicating erosion rates have surpassed tolerable limits and require improved management.

The very heavy category dominates, including SPL 5, SPL 6, SPL 8, SPL 9, SPL 11, SPL 12, SPL 15, and SPL 17. TBE values in these units range from 8 to above 300, demonstrating severe soil loss far beyond natural recovery capacity. These areas require urgent conservation interventions.

Overall, the high TBE pattern reflects the interaction between high actual erosion and relatively low ETol values in several soil units. Strengthening conservation practices is therefore essential to reduce erosion rates and sustain land productivity. The erosion hazard distribution is illustrated in Figure 1.

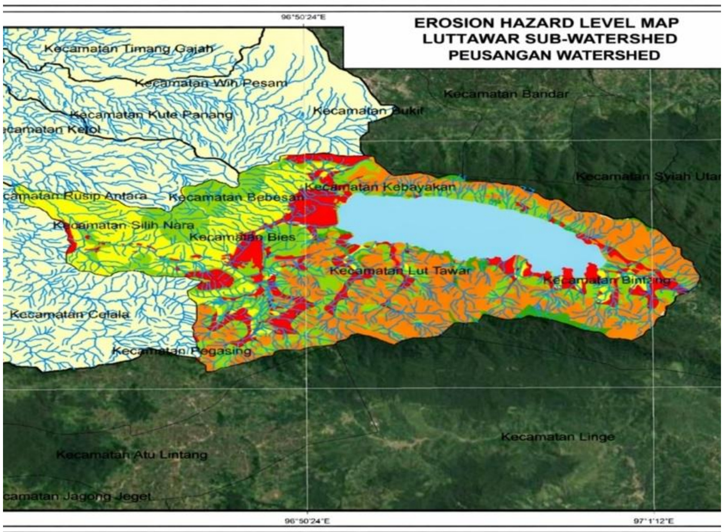

Figure 1. Erosion Danger Level Map of Lut Tawar Sub-watershed

Soil and Water Conservation Efforts

Soil conservation efforts in the Lut Tawar Sub-watershed were implemented in response to findings that several land units had erosion levels exceeding their tolerance limits. This indicates that without intervention, the land is at risk of further degradation affecting soil stability, productivity, and environmental quality. Conservation measures were therefore applied to reduce erosion through improved land cover and management techniques adapted to the characteristics of each land unit (Ismayani & Febrianto, 2020). The analysis results are presented in Table 6.

Table 6. Conservation Efforts

No	Code	A (Actual Erosion)	eTol	TBE	Status	Conservation Efforts to Reduce Erosion					After carrying out conservation efforts		
						RKLS	C	Mark	P	Mark	A (Actual Erosion)	TBE	Category
1	SPL 1	19.79	3.60	5.50	A > eTol	989.35	Undisturbed Bushes	0.01	Tight Ground Cover	0.1	0.99	0.27	Very light
2	SPL 2	13.92	12.96	1.07	A < eTol	139.19							
3	SPL 3	6.70	3.60	1.86	A < eTol	577.59							
4	SPL 4	12.92	9.72	1.33	A < eTol	129.22							
5	SPL 5	41.98	10.62	3.95	A < eTol	41.98							
6	SPL 6	137.35	9.00	15.26	A > eTol	245.27	Wetland Rice Plants	0.01	Traditional Terrace	0.4	0.98	0.11	Very light
7	SPL 7	0.91	4.50	0.20	A < eTol	456.56							
8	SPL 8	21.71	2.70	8.04	A > eTol	271.41	Undisturbed Bushes	0.01	Tight Ground Cover	0.1	0.27	0.10	Very light
9	SPL 9	71.16	5.22	13.63	A > eTol	711.60	Permanent reeds	0.02	Tight Ground Cover	0.1	1.42	0.27	Very light
10	SPL 10	3.08	3.60	0.85	A < eTol	3.077.24							
11	SPL 11	542.05	5.40	100.38	A > eTol	774.36	Grass Plants	0.29	Grassland (Good)	0.04	8.98	1.66	Light
12	SPL 12	934.83	2.70	346.23	A > eTol	9.348.29	Undisturbed Bushes	0.01	Tight Ground Cover	0.01	0.93	0.35	Very light
13	SPL 13	6.46	2.70	2.39	A < eTol	556.67							
14	SPL 14	35.15	5.40	6.51	A > eTol	351.49	Permanent reeds	0.02	Plants in the Path	0.05	0.35	0.07	Very light
15	SPL 15	246.34	4.50	54.74	A > eTol	246.34	Undisturbed Bushes	0.01	Grassland (Good)	0.04	0.10	0.02	Very light
16	SPL 16	0.16	7.20	0.02	A < eTol	63.13							
17	SPL 17	180.84	3.60	50.23	A > eTol	1.808.39	Undisturbed Bushes	0.01	Tight Ground Cover	0.1	1.81	0.50	Very light

Source: Analysis Results (2025)

The reduction in Erosion Hazard Level (EHRR) occurs through decreases in plant management (C) and conservation practice (P) factors. The implementation of dense ground cover, permanent vegetation, terracing, and contour management lowers C and P values, which directly reduces actual erosion (A) in the USLE equation. Since ETol remains constant, a reduction in A decreases the A/ETol ratio, leading to lower EHRR values across most SPLs.

The results show that SPLs with A > ETol experienced significant reductions in erosion after conservation measures were applied. Most units shifted to very light categories, indicating that vegetation improvement and mechanical conservation effectively reduce surface runoff and protect soil from rainfall impact.

Although several SPLs still show relatively higher TBE values due to large RKLS factors and slope characteristics, erosion levels have decreased compared to initial conditions. This confirms that conservation interventions effectively mitigate land degradation risk and improve erosion control performance.

Table 7.
Erosion Danger Level of Conservation Efforts

No	Code	A (Actual Erosion)	TBE	Category
1	SPL 1	19.79	0.27	Very Light
2	SPL 2	13.92	1.07	Light
3	SPL 3	6.70	1.86	Light
4	SPL 4	12.92	1.33	Light
5	SPL 5	41.98	3.95	Medium
6	SPL 6	137.35	0.11	Very Light
7	SPL 7	0.91	0.20	Very Light
8	SPL 8	21.71	0.10	Very Light
9	SPL 9	71.16	0.27	Very Light
10	SPL 10	3.08	0.85	Very Light
11	SPL 11	542.05	1.66	Very Light
12	SPL 12	934.83	0.35	Light
13	SPL 13	6.46	2.39	Very Light
14	SPL 14	35.15	0.07	Medium
15	SPL 15	246.34	0.02	Very Light
16	SPL 16	0.16	2.39	Very Light
17	SPL 17	180.84	0.50	Medium

Source: Analysis Results (2025)

The post-conservation Erosion Hazard Level (EHA) evaluation shows that most Land Map Units fall into the very light category (EHA < 1). This indicates that conservation measures through vegetation improvement and soil conservation techniques effectively reduced erosion rates below tolerable limits. Figure 2 illustrates the spatial distribution of erosion hazard levels after conservation implementation.

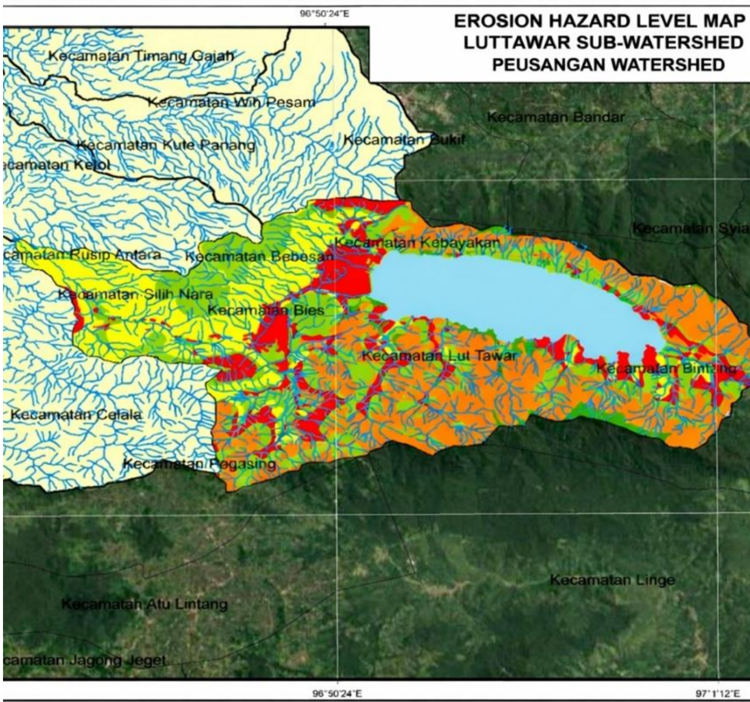

Figure 2. Conservation Effort Map

Overall, conservation efforts significantly reduced erosion hazard levels at the study site, as reflected by the predominance of the very light category. These findings confirm that soil conservation practices effectively maintain land stability and support sustainable land use.

4. CONCLUSION

Based on the analysis results, the Erosion Hazard Level (EBH) in the Lut Tawar Sub-watershed ranges from mild to very severe. Areas categorized as high to very severe are generally located on land units characterized by steep slopes, inadequate land cover, and minimal soil conservation practices. These conditions increase surface runoff intensity and soil detachment, accelerating land degradation. This pattern confirms that the Lut Tawar Sub-watershed has relatively high erosion potential and requires systematic, sustainable, and site-specific land management interventions.

The analysis using the USLE method shows that slope length and slope gradient (LS) and soil conservation practices (P) are the most dominant factors influencing erosion rates. Land cover and management (C) and rainfall erosivity (R) also contribute to erosion variability, while soil erodibility (K) has the lowest influence. These findings indicate that erosion in the study area results from the interaction between topographic characteristics and land management practices rather than a single controlling factor.

The comparison between actual erosion (A) and tolerable erosion (ETol) reveals that several land units exceed acceptable soil loss limits, highlighting the urgency of effective conservation measures. The implementation of vegetative and mechanical conservation strategies has demonstrated the capacity to reduce erosion hazard levels, particularly through improvements in ground cover and conservation management practices.

Recommended soil and water conservation efforts include conservation measures tailored to slope conditions and erosion intensity, integrating mechanical techniques such as terracing, contour planting, and conservation structures with vegetative approaches such as dense ground cover and agroforestry systems. Priority should be given to land units with high LS values and inadequate conservation practices. Future research should apply more comprehensive analytical approaches, such as multiple regression analysis or spatial-based modeling, and incorporate additional supporting variables to improve the accuracy of erosion prediction and support evidence-based land management strategies.

REFERENCE

Abebe, T. G., Lemma, T. M., Meshesha, T. W., Lemma, E., & Tesfay, F. (2025). Determination of tolerable soil loss limit using quantitative biophysical model: a case study in Andit Tid watershed, central highland of Ethiopia. Environmental Monitoring and Assessment, 197(5), 506. https://doi.org/10.1007/s10661-025-13938-2

Ananda, K. R., & Iqbal, D. (2021). Analisis Pengelolaan Das Peusangan Berkelanjutan, Provinsi Aceh. Agrienvi: Jurnal Ilmu Pertanian, 15(2), 66-76. https://e-journal.upr.ac.id/index.php/aev/article/view/3905/2944

Arifin, E. T. N., Susandi, A., Budi, B. I., Rahesanita, D., Satryo, I. F., Ali, M. F., Rahmah, N. N., & Khahfi, Y. M. (2022). Pemanfaatan Sistem Informasi Geografis dalam Pemetaan Laju Erosi Menggunakan Metode USLE di Sub DAS Cirasea. JPIG (Jurnal Pendidikan Dan Ilmu Geografi), 7(1), 62-78. https://doi.org/10.21067/jpig.v7i1.6649

Ariyani, D., Perdinan, Purwanto, M. Y. J., Sunarti, E., Juniati, A. T., & Ibrahim, M. (2023). Contributed Indicators to Fluvial Flood Along River Basin in Urban Area of Indonesia. GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY, 15(4), 102-114. https://doi.org/10.24057/2071-9388-2022-084

Arsyad, S. (2010). Konservasi tanah dan Air (2nd ed.). IPB Press.

Aryani, N., Ariyanti, D. O., & Ramadhan, M. (2020). Pengaturan Ideal tentang Pengelolaan Daerah Aliran Sungai di Indonesia (Studi di Sungai Serang Kabupaten Kulon Progo). Jurnal

Hukum Ius Quia Iustum, 27(3). https://doi.org/10.20885/iustum.vol27.iss3.art8

Benavidez, R., Jackson, B., Maxwell, D., & Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. Hydrology and Earth System Sciences, 22(11), 6059-6086. https://doi.org/10.5194/hess-22-6059-2018

Bennett, W. G., Karunarathna, H., Xuan, Y., Kusuma, M. S. B., Farid, M., Kuntoro, A. A., Rahayu, H. P., Kombaitan, B., Septiadi, D., Kesuma, T. N. A., Haigh, R., & Amaratunga, D. (2023). Modelling compound flooding: a case study from Jakarta, Indonesia. Natural Hazards, 118(1), 277-305. https://doi.org/10.1007/s11069-023-06001-1

Bera, A. (2017). Assessment of soil loss by universal soil loss equation (USLE) model using GIS techniques: a case study of Gumti River Basin, Tripura, India. Modeling Earth Systems and Environment, 3(1), 29. https://doi.org/10.1007/s40808-017-0289-9

Biswas, M., Paul, A., & Jamal, M. (2021). Tectonics and Channel Morpho-Hydrology-A Quantitative Discussion Based on Secondary Data and Field Investigation (pp. 461-494). https://doi.org/10.1007/978-3-030-60143-0_16

Chen, J., Li, Z., Xiao, H., Ning, K., & Tang, C. (2021). Effects of land use and land cover on soil erosion control in southern China: Implications from a systematic quantitative review. Journal of Environmental Management, 282, 111924. https://doi.org/10.1016/j.jenvman.2020.111924

Desta, G., Tamene, L., Abera, W., Amede, T., & Whitbread, A. (2021). Effects of land management practices and land cover types on soil loss and crop productivity in Ethiopia: A review. International Soil and Water Conservation Research, 9(4), 544-554. https://doi.org/10.1016/j.iswcr.2021.04.008

Ekawaty, R., Yonariza, Y., Ekaputra, E. G., & Arbain, A. (2018). Telaahan Daya Dukung dan Daya Tampung Lingkungan Dalam Pengelolaan Kawasan Daerah Aliran Sungai di Indonesia. Journal of Applied Agricultural Science and Technology, 2(2), 30-40. https://doi.org/10.32530/jaast.v2i2.42

Ismayani, N., & Febrianto, H. (2020). Pencegahan Longsor Melalui Konservasi Lahan Di Kecamatan Simpang Empat Kabupaten Karo. Jurnal Azimut, 3(SMAR), 9-14. https://doi.org/10.31317/jaz.v3iSMAR.628

Kahirun, Hamzah, N., Rahman, A. A., Yusria, W. O., Hajar, N., & Putra, E. N. (2023). Performance of Wanggu Watershed Management Based on Land Indicators. Indonesian Journal of Environmental Management and Sustainability, 7(3), 116-127. https://doi.org/10.26554/ijems.2023.7.3.116-127

Liu, R., Thomas, B. W., Shi, X., Zhang, X., Wang, Z., & Zhang, Y. (2021). Effects of ground cover management on improving water and soil conservation in tree crop systems: A meta-analysis. CATENA, 199, 105085. https://doi.org/10.1016/j.catena.2020.105085

Madenoğlu, S., Pınar, M. Ö., Şahin, S., & Erpul, G. (2024). Sustainable Land Management for Mitigating Soil Erosion at the Catchment Scale. Türkiye Tarımsal Araştırmalar Dergisi, 11(2), 176-190. https://doi.org/10.19159/tutad.1434369

Maha, R. R., Wicaksono, A. P., Nugroho, N. E., Lukito, H., & Suharwanto, S. (2023). Pengaruh Kemiringan Lereng terhadap Nilai Laju Erosi di PT Darma Henwa Bengalon Coal Project. Prosiding Seminar Nasional Teknik Lingkungan Kebumian SATU BUMI, 4(1). https://doi.org/10.31315/psb.v4i1.8832

Maltby, K. M., Kerin, S., & Mills, K. E. (2023). Barriers and enablers of climate adaptation in fisheries: Insights from Northeast US fishing communities. Marine Policy, 147, 105331. https://doi.org/10.1016/j.marpol.2022.105331

Mandal, D., Chandrakala, M., Alam, N. M., Roy, T., & Mandal, U. (2021). Assessment of soil quality and productivity in different phases of soil erosion with the focus on land degradation neutrality in tropical humid region of India. CATENA, 204, 105440. https://doi.org/10.1016/j.catena.2021.105440

Martín Duque, J. F., Zapico, I., Oyarzun, R., López García, J. A., & Cubas, P. (2015). A descriptive and quantitative approach regarding erosion and development of landforms on abandoned mine tailings: New insights and environmental implications from SE Spain. Geomorphology, 239, 1-16. https://doi.org/10.1016/j.geomorph.2015.02.035

Merten, J., Nielsen, J. Ø., Rosyani, Soetarto, E., & Faust, H. (2021). From rising water to floods: Disentangling the production of flooding as a hazard in Sumatra, Indonesia. Geoforum, 118, 56-65. https://doi.org/10.1016/j.geoforum.2020.11.005

Missleini. (2023). Kerusakan Lingkungan Dan Jasa Ekosistem Akibat Perilaku Tekanan Manusia. ALADALAH: Jurnal Politik, Sosial, Hukum Dan Humaniora, 1(3), 256-268. https://doi.org/10.59246/aladalah.v1i3.418

O'Higgins, T. G., & O'Dwyer, B. (2019). A vulnerability framework to protect coastal social ecological systems. Anthropocene Coasts, 2(1), 279-292. https://doi.org/10.1139/anc-2018-0023

Pham, T. G., Degener, J., & Kappas, M. (2018). Integrated universal soil loss equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in A Sap basin: Central Vietnam. International Soil and Water Conservation Research, 6(2), 99-110. https://doi.org/10.1016/j.iswcr.2018.01.001

Ridwan, M., & Sarjito, J. (2024). Studi Kajian Dampak Perubahan Tutupan Lahan terhadap Kejadian Banjir di Daerah Aliran Sungai. ENVIRO: Journal of Tropical Environmental Research, 26(1), 38-45. https://doi.org/10.20961/enviro.v26i1.93145

Sahido, W. P. M., Rahim, Y., Dude, S., & Rahman, R. (2025). Prediksi Erosi Menggunakan Metode Usle (Universal Soil Loss Equation) Dan Sistem Informasi Geografis (Sig) Di Kecamatan Bolaang Uki Kabupaten Bolaang Mongondow Selatan. AGROTEK: Jurnal Ilmiah Ilmu Pertanian, 9(1), 92-103. https://doi.org/10.33096/agrotek.v9i1.715

Salviya, L. L., Taryana, D., Masruroh, H., & Aristin, N. F. (2023). Pendugaan erosi menggunakan metode Modified Universal Soil Loss Equation (MUSLE) di Sub DAS Bale. Jurnal Integrasi Dan Harmoni Inovatif Ilmu-Ilmu Sosial, 3(10), 1139-1159. https://doi.org/10.17977/um063v3i10p1139-1159

Sholihah, Q., Kuncoro, W., Wahyuni, S., Puni Suwandi, S., & Dwi Feditasari, E. (2020). The analysis of the causes of flood disasters and their impacts in the perspective of environmental law. IOP Conference Series: Earth and Environmental Science, 437(1), 012056. https://doi.org/10.1088/1755-1315/437/1/012056

Skjølsvik, K. O., & Kaloudis, A. (2023). Innovating the Innovation System Thinking: a Systemism Model. Journal of the Knowledge Economy, 15(3), 11912-11931. https://doi.org/10.1007/s13132-023-01561-w

Van Tho, N. (2020). Coastal erosion, river bank erosion and landslides in the Mekong Delta: Causes, effects and solutions (pp. 957-962). https://doi.org/10.1007/978-981-15-2184-3_125

Wang, H., Gao, J., & Hou, W. (2019). Quantitative attribution analysis of soil erosion in different geomorphological types in karst areas: Based on the geodetector method. Journal of Geographical Sciences, 29(2), 271-286. https://doi.org/10.1007/s11442-019-1596-z

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: A guide to conservation planning (Agriculture Handbook No. 537).

Xiong, M., Sun, R., & Chen, L. (2018). Effects of soil conservation techniques on water erosion control: A global analysis. Science of The Total Environment, 645, 753-760. https://doi.org/10.1016/j.scitotenv.2018.07.124

Zhang, T., Wilson, G. V., Hao, Y., & Han, X. (2021). Erosion hazard evaluation for soil conservation planning that sustains life expectancy of the A-horizon: The black soil region of China. Land Degradation & Development, 32(8), 2629-2641. https://doi.org/10.1002/ldr.3931