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Prediction of Erosion Hazard Level in Tripe Jaya District Using the Universal Soil Loss Equation (USLE) Method

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Abstract: The Tripe Jaya Subdistrict in Gayo Lues Regency features a highly vulnerable landscape where steep slopes, intense rainfall, and limited vegetation cover collectively contribute to severe erosion risk. Erosion in this region threatens soil fertility, agricultural productivity, slope stability, transportation infrastructure, and riverbank integrity. This study aims to predict and map erosion hazard levels using the Universal Soil Loss Equation (USLE) integrated with Geographic Information System (GIS) analysis, based on rainfall, soil type, slope, and land cover data. The results classify the study area into five erosion hazard categories: very light (2,909.09 ha), light (20,669.38 ha), moderate (10,880.66 ha), heavy (432.99 ha), and very heavy (6,922.76 ha), with the most critical zones concentrated in steep and intensively utilized areas. These findings emphasize the substantial erosion risk in Tripe Jaya and provide an essential reference for mitigation planning, land-use regulation, and infrastructure protection, particularly for road segments adjacent to riverbanks.

Keywords : USLE, Erosion Rate, Erosion Hazard Level, Geographic Information System

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Introduction

Erosion is the process of soil displacement and removal from one location to another by water flow, wind, or gravity. Excessive erosion can lead to reduced soil fertility and diminished water infiltration and storage capacity (Pratiwi et al., 2024). Naturally, erosion is influenced by factors such as rainfall intensity, soil texture, slope gradient, and vegetation cover. High rainfall on sandy or sedimentary soils combined with steep slopes significantly increases erosion potential (Sri Santi L M F Seran, 2022).

Rainfall plays a major role in particle detachment, where raindrop impact dislodges soil grains. On bare land, raindrop splash causes soil particles to be ejected upward and outward. On flat terrain, particles are dispersed evenly, whereas on sloped land they move downward following gravity-driven runoff. Human activities, including deforestation, agricultural expansion, mining, and plantation development, further intensify erosion by removing surface vegetation and exposing the soil layer (Sri Santi L M F Seran, 2022).

Gayo Lues Regency is characterized by mountainous terrain with slopes exceeding 40% (Ullyana et al., 2021). Tripe Jaya Subdistrict, as one of its administrative regions, contains very steep slopes with gradients of around 50% across much of its area and receives more than 2,500 mm of annual rainfall over the majority of the subdistrict (Murdawati et al., 2024). Erosion in Tripe Jaya is strongly influenced by river processes, particularly in areas where the river runs directly alongside road segments. Riverbank erosion and lateral scouring gradually weaken the soil supporting road foundations, agricultural land (including paddy fields), bridge structures, and in some cases nearby residential buildings. This process results in cracking, ground subsidence, and partial structural failure of affected road sections.

The interaction among steep slopes, high rainfall, and active riverbank erosion significantly increases erosion vulnerability in Tripe Jaya, making river-induced erosion a critical factor for infrastructure stability and land-management planning. The severity of these conditions indicates that Tripe Jaya Subdistrict faces a substantial erosion hazard. To better understand and quantify erosion risk, the USLE method is applied to predict erosion levels across the area. The resulting erosion hazard maps provide essential reference data for mitigation planning and government decision-making in minimizing erosion impacts. The analysis incorporates rainfall intensity, soil type, slope, and land cover as key parameters.

Methodology

Study Area

Tripe Jaya Subdistrict is located within Gayo Lues Regency, Aceh Province, and is bordered by Pantan Cuaca Subdistrict to the north, Terangun Subdistrict to the south, Nagan Raya Regency to the west, and Blang Jerango Subdistrict to the east. The geographic extent of the study area is illustrated in Figure 1.

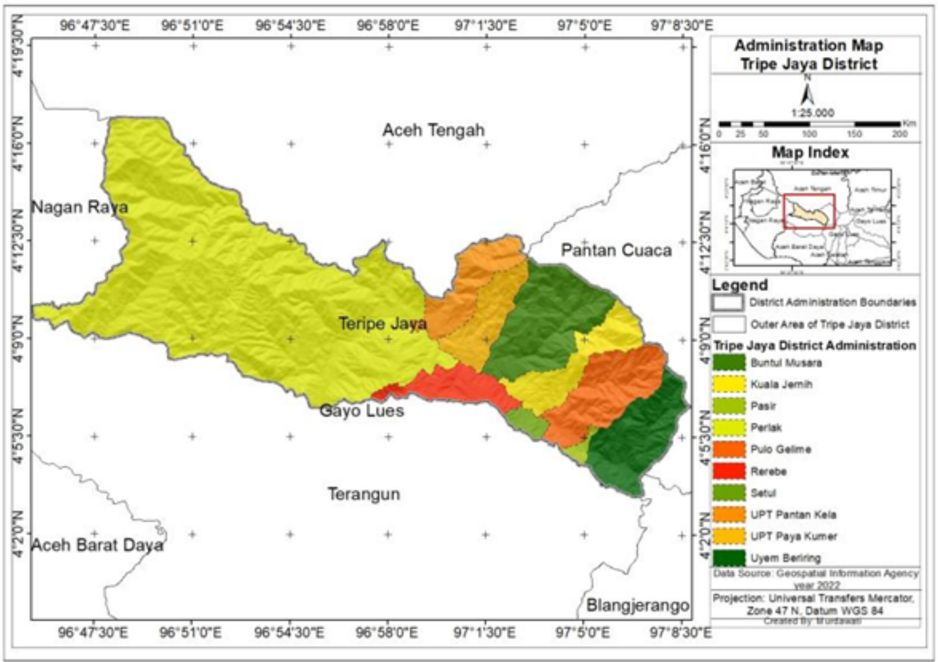

Figure 1. The Administration Map Tripe Jaya District (Murdawati et al., 2024)

Data

This study utilized both secondary data obtained from open-source platforms and relevant governmental institutions, as well as primary data collected through direct field observation. A systematic workflow was applied during data processing, while primary data were used for ground validation using GPS, a camera, and field observation notes. The dataset includes multiple sources spanning different time periods, depending on data availability for the study area. Details of the datasets are presented in Table 1.

Table 1. Data

Data Type	Year	Source
Administrative Data	2022	Geospatial Information Agency (BIG)
Land Use Data	2021	Ministry of Environment and Forestry (MoEF)
Soil Type Data	2007	Food and Agriculture Organization of the United Nations (FAO)
Demographic and National Data	2018	Geospatial Information Agency (BIG)
Rainfall Data	2013-2022	Climate Hazards Group InfraRed Precipitation with Station (CHIRPS)
River and Road Shapefiles	2022	Geospatial Information Agency (BIG)
Satellite Imagery (SAS Planet)	2023	SAS Planet

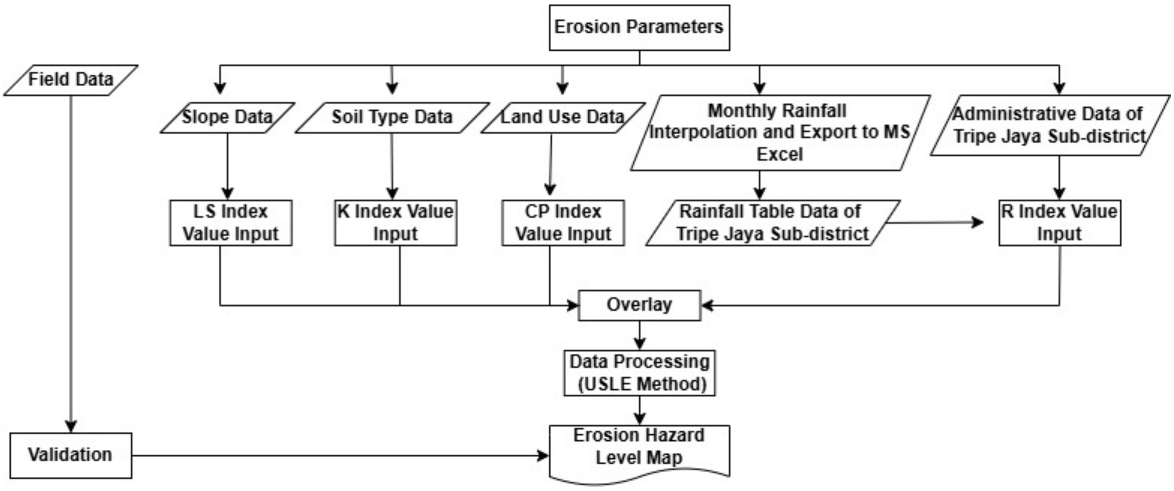

Figure 2. Flow Diagram of Erosion Hazard Mapping Process

The Universal Soil Loss Equation (USLE) is an empirical model used to estimate long-term average annual soil loss by integrating rainfall erosivity, soil erodibility, slope length and steepness, and land cover/management practices as controlling factors (Wischmeier & Smith, 1978). The USLE framework is based on the principle that erosion is not governed by a single variable, but by the interaction among climatic drivers, soil characteristics, topographic configuration, and land-surface conditions. In this model, rainfall provides the primary erosive force (R), soil properties determine susceptibility to detachment (K), slope influences runoff velocity and sediment-carrying capacity (LS), and land cover and management practices determine the level of ground surface protection (CP). By integrating these parameters in a GIS environment, USLE allows spatially explicit estimation of erosion risk across the study area.

$$A = R \; x \; K \; x \; LS \; x \; CP \quad (1)$$

where :
A = annual soil loss (tons/ha/year)
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
CP = cover-management factor

The resulting soil-loss estimates were then classified into erosion hazard levels. This categorization enables meaningful interpretation of erosion intensity across land units, as shown in Table 2 (Sarminah et al., 2018):

Table 2. Erosion Hazard Level Classification (EHL)

Erosion Rate (A) (ton/ha/year)	Tingkat Bahaya Erosi	
	Erosion Hazard Class	Category
<15	I	very light
15-60	II	light
60-180	III	moderate
180-480	IV	heavy
>480	V	very heavy

The rainfall erosivity factor (R) was calculated using monthly rainfall data because rainfall intensity strongly influences soil particle detachment and runoff formation (Styawan et al., 2015).

$$\mathrm{R} = 2.21 . P^{1.36} \quad (2)$$

where:
R = erosivity index,

P = monthly rainfall.
Areas with higher rainfall intensity yield larger R values, indicating stronger erosive energy.

The soil erodibility factor (K) expresses the susceptibility of the soil to erosion. K values were assigned based on soil classification derived from FAO soil data. For example, Andosol and Brown Forest soils, which dominate the study area, were assigned K = 0.28 due to their moderate structural resistance to particle detachment (Andriyani et al., 2020). The slope factor (LS) quantifies the influence of slope gradient and slope length on erosion potential. LS values were derived from DEM-generated slope data and flow-accumulation analysis. Steeper terrain results in faster runoff and higher sediment transport capacity (Kumendong et al., 2015). The cover-management factor (CP) reflects the ability of vegetation and land-use practices to protect the soil surface. Dense vegetation such as forest and shrubland were assigned low CP values (0.001), whereas plantations and settlement areas received higher values due to reduced surface protection (Nurkholis et al., 2023) (Agus et al., 2014).

Spatial analysis in this study was primarily performed using vector-based (shapefile) processing. Although some datasets (such as DEM-derived slope and interpolated rainfall) were initially in raster format, they were converted into polygon shapefiles prior to integration. The K and CP layers were already available in vector format, while LS values were converted from DEM-derived slope rasters into vector classes. All layers were spatially joined and overlaid in a GIS environment to compute USLE-based erosion estimates. The index values used in the analysis were separated into three dedicated tables for clarity (Tables 3–5).

Table 3. K Index Values

Description K	K Index Values
Alluvial and Glei	0,29
Andosol	0,28
Non calcic brown	0,28
Latosol	0,26
Litosol	0,13

Table 4. LS Index Values

Description LS	LS Index Values
0-8%	0,40
8-15%	1,40
15-25%	3,10
25-40%	6,80
>40%	9,50

Table 5. CP Index Values

Description CP	CP Index Values
Settlement, Vacant Land	0,01
Rice Field	0,004
Shrub	0,001
Forest	0,001
Plantation	0,15

These index values served as the input parameters for the USLE-based erosion computation.

Results and Discussion

LS Index Values

Table 6. LS Values

Village	Area of LS Index Value (Ha)					Total Area
	0,40	1,40	3,10	6,80	9,50	
Buntul Musara	108,95	120,85	236,57	1231,86	2234,76	3932,99

Village	Area of LS Index Value (Ha)					Total Area
	0,40	1,40	3,10	6,80	9,50	
Kuala Jernih	37,51	72,23	198,50	721,17	1116,68	2146,10
Pasir	16,62	15,61	24,36	97,43	68,20	222,23
Perlak	304,16	742,48	2102,37	9611,38	11143,03	23903,41
Pulo Gelime	69,86	74,17	159,99	680,58	1960,86	2945,46
Rerebe	36,09	94,94	299,45	822,66	271,70	1524,84
Setul	11,03	20,17	53,14	220,91	76,08	381,33
UPT Pantan Kela	56,30	114,69	147,31	469,01	1225,15	2012,46
UPT Paya Kumer	44,27	98,07	234,42	582,94	801,60	1761,31
Uyem Beriring	17,74	849,91	173,55	51,90	1785,18	2878,29
Total	**702,53**	**2203,13**	**3629,65**	**14489,84**	**20683,25**	**41708,41**
Persentase	**2%**	**5%**	**9%**	**35%**	**50%**	**100%**

The distribution of LS values shows that areas with gentle slopes (<8%) constitute only around 2% of the total area, implying relatively weak erosive force due to slow surface runoff. Slopes of 8-15% cover approximately 5% of the land and represent slightly elevated erosion potential. Areas with slopes between 15-25% and 25-40% account for 9% and 35% of the total area, respectively, which significantly increases runoff velocity and sediment transport. The most critical slope category is >45%, representing 50% of the Tripe Jaya area. This category is associated with the highest LS index value of 9.50 indicating extremely strong erosion susceptibility. Steep terrain combined with direct proximity to river channels and road infrastructure intensifies soil detachment and facilitates lateral erosion, thereby strongly contributing to the overall erosion hazard in the region.

CP Index Values

Table 7. CP Values

Village	Area of CP Index Value (Ha)				Total Area
	0,001	0,004	0,01	0,15	
Buntul Musara	3348,55	43,39	30,36	526,58	3948,88
Kuala Jernih	1567,39	36,60	7,51	541,70	2153,21
Pasir	113,27	14,57	20,38	78,24	226,46
Perlak	21260,72	81,62	79,31	2488,47	23910,13
Pulo Gelime	2657,01	90,98	9,08	195,78	2952,85
Rerebe	377,09	26,04	2,93	1120,51	1526,57
Setul	37,13	0,49	6,19	343,62	387,43
UPT Pantan Kela	1522,42	68,75	62,22	384,91	2038,31
UPT Paya Kumer	1040,31	30,83	75,23	640,71	1787,07
Uyem Beriring	1750,46	0,00	35,37	1103,09	2888,92
Total	**33674,36**	**393,28**	**328,59**	**7423,61**	**41819,84**
Persentase	**81%**	**0,94%**	**1%**	**18%**	**100%**

The CP value of 0.001 covers 33,674.36 Ha (81%), representing dense vegetation cover dominated by forest and shrubs, which effectively protect soil from erosion. A CP value of 0.004 (393.28 Ha; 0.94%) corresponds to rice fields, while a value of 0.01 (328.59 Ha; 1%) reflects residential areas and vacant land. The highest erosion-inducing CP value, 0.15, covers 7,423.61 Ha (18%) and is associated with plantation areas, where reduced ground cover and soil disturbance increase erosion susceptibility. These results confirm that land management practices, particularly deforestation and agricultural land expansion, have a measurable impact on erosion risk.

K and R Index Values Index

The K index analysis indicates that the study area is predominantly composed of Andosol and Brown Forest soils, both exhibiting a K value of 0.28. These soils possess moderate erodibility due to their granular structure, which makes them relatively resistant to particle detachment under normal conditions but vulnerable under intense rainfall and slope exposure.

Table 8. R Index Value

Village	R Index Value	Persentase
Buntul Musara	8537	10%
Kuala Jernih	7683	9%
Pasir	2753	3%
Perlak	24448	29%
Pulo Gelime	8032	9%
Rerebe	5703	7%
Setul	3030	4%
UPT Pantan Kela	10005	12%
UPT Paya Kumer	9169	11%
Uyem Beriring	6239	7%
Total	85599	100%

Styawan et al. (2015) state that an erosivity index (R) value of 2,280 ha/cm is classified as high. In Tripe Jaya Subdistrict, the R index values far exceed this threshold across all villages, confirming high rainfall-induced erosive energy throughout the region. Perlak Village recorded the highest R value at 24,448 (29%), followed by UPT Pantan Kela (10,005; 12%) and UPT Paya Kumer (9,169; 11%). These elevated R values indicate that rainfall plays a primary role in driving soil detachment and transport, particularly in steep and poorly vegetated areas.

The visualization results of maps illustrating erosion parameters in Tripe Jaya Subdistrict, Gayo Lues Regency, Aceh are presented as follows.

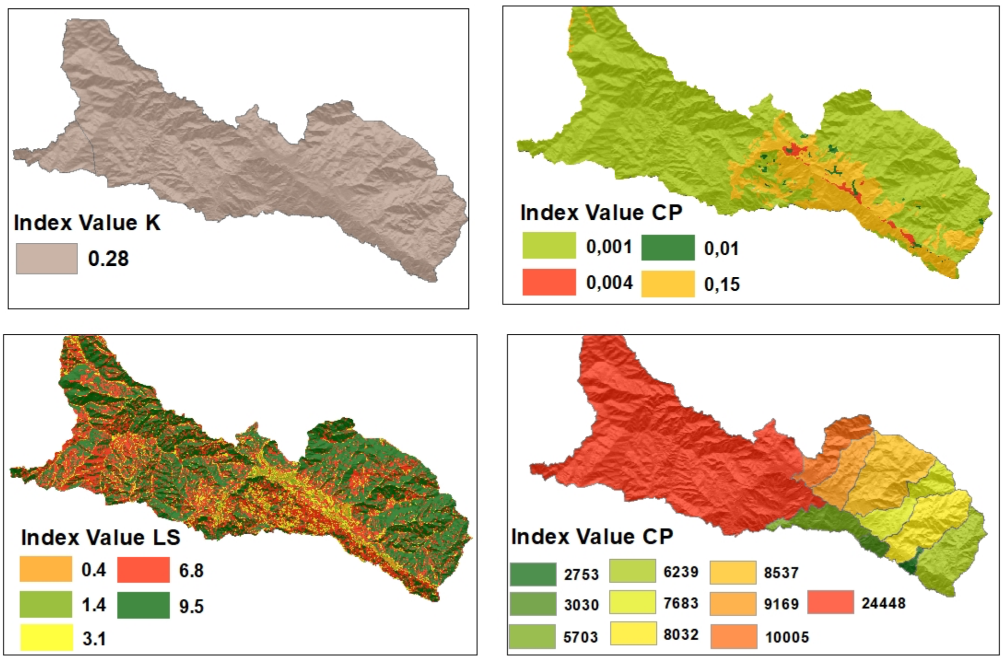

Figure 3. The Erosion Parameters

Erosion Hazard Level

Table 9. Results and Analysis of Erosion Hazard Level

Village	Very Light	Light	Moderate	Heavy	Very Heavy	Total Area
Buntul Musara	249,80	3161,53	71,94	0,00	460,66	3943,92
Kuala Jernih	590,15	1017,80	17,72	38,93	488,62	2153,21
Pasir	136,67	9,24	4,60	5,94	70,01	226,46
Perlak	615,36	10142,37	10589,71	188,03	2374,66	23910,13
Pulo Gelime	242,06	2500,09	22,33	16,55	171,81	2952,85
Rerebe	285,50	118,99	19,13	64,18	1038,77	1526,57
Setul	40,54	9,54	12,48	40,98	283,88	387,43

Village	Very Light	Light	Moderate	Heavy	Very Heavy	Total Area
UPT Pantan Kela	102,33	1502,06	38,51	42,20	353,20	2038,31
UPT Paya Kumer	78,02	1017,71	68,53	12,13	610,69	1787,07
Uyem Beriring	568,65	1190,06	35,71	24,04	1070,46	2888,92
Total	**2909,09**	**20669,38**	**10880,66**	**432,99**	**6922,76**	**41814,88**
Persentase	**7%**	**49%**	**26%**	**1%**	**17%**	**100%**

The erosion hazard in Tripe Jaya Subdistrict is distributed across five classes, with nearly half of the area classified as light erosion and around one-quarter as moderate. This indicates that although much of the region remains moderately stable, a substantial portion 17% of the area faces very heavy erosion risk. The most severely affected villages are Perlak, Uyem Beriring, and Rerebe, where a combination of steep slopes, high rainfall, and close river proximity intensifies erosion processes. These areas exhibit accelerated soil loss and visible physical impacts such as riverbank undercutting and infrastructure damage. Meanwhile, the heavy erosion class is present in nearly all villages, reinforcing that erosion risk is not localized but spatially widespread across the subdistrict. The resulting erosion hazard maps illustrate these spatial variations and provide a visual reference for identifying priority areas for erosion mitigation.

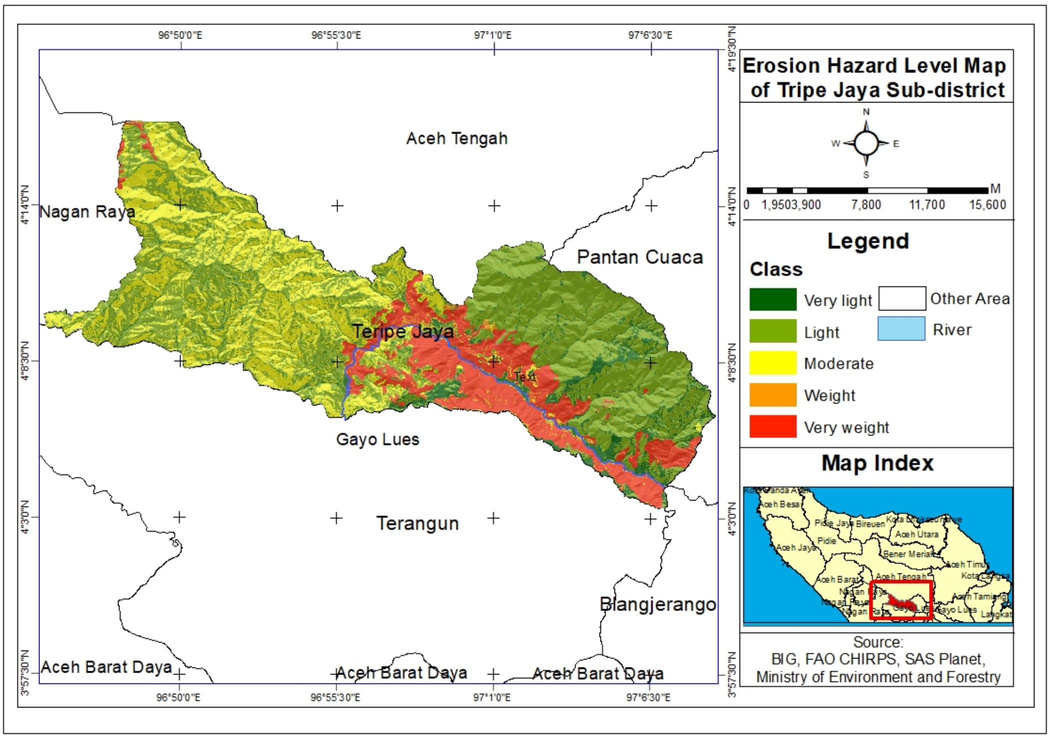

Figure 4. Erosion Hazard Map

Field observations confirm that the dominant erosion mechanism in the study area is riverbank erosion. In several river-adjacent road segments, lateral scouring and bank undercutting were observed to destabilize the soil supporting the road structure.

Figure 5. Field observations in Tripe Jaya Sub-district

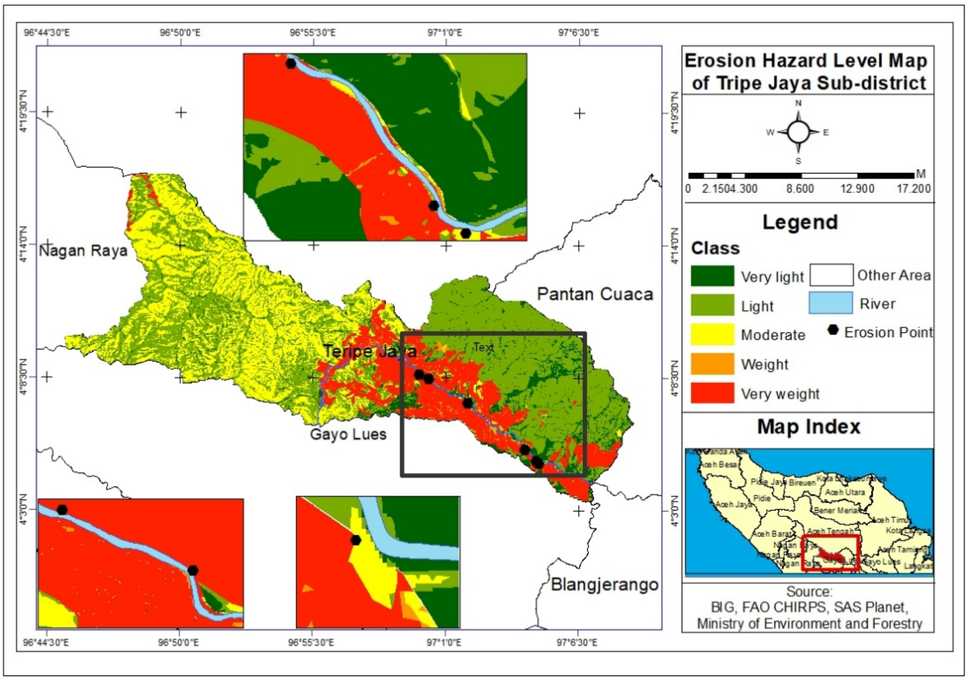

Figure 6. Validation Points from Field Observations

Conclusions

This study assessed and mapped erosion hazards in Tripe Jaya Subdistrict using the USLE model integrated with spatial analysis. The results show clear spatial variation, dominated by light (49%) and moderate (26%) hazard classes, while 17% of the area exhibits very high erosion risk. Although severe erosion is concentrated in specific locations such as Perlak, Uyem Beriring, Rerebe, and Pulo Gelimen, the presence of heavy erosion classes in nearly all villages indicates that erosion is a widespread environmental challenge rather than a localized phenomenon. The dominant erosion mechanism is riverbank undercutting, which has contributed to road failure and degradation of agricultural land in areas directly adjacent to river channels.

These findings highlight the urgent need for targeted erosion mitigation measures, including riverbank protection, reforestation, slope stabilization, and the regulation of land clearance activities in highly susceptible zones. The spatial distribution of erosion risk produced in this study provides valuable guidance for infrastructure planning, disaster risk reduction, and sustainable land-use management by local authorities.

This research is constrained by the temporal variability of datasets and the reliance on literature-derived USLE coefficients. Future studies should incorporate high-resolution topographic data, real-time rainfall monitoring, and field-based soil property measurements to further enhance model precision and predictive reliability.

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