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Development of an Automated Workflow for Spatial Modeling of Erosion Rates in the Upstream Cisanggarung Watershed Using Model Builder-Based USLE–GIS Integration

Tri Wahyudin Ahmad[1,✉], Muhammad Syahril Badri Kusuma[2], Faizal Immaduddin Wira Rohmat[2], Arief Yudho Wicaksono[1], Vika Febriyani[1]

[1] Magister Water Resource Management, Civil and Environmental Engineering Faculty, Bandung Institute of Technology, INDONESIA.
[2] Water Resource Management, Civil and Environmental Engineering Faculty, Bandung Institute of Technology, INDONESIA.

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Corresponding Author:
✉ triwahyudinahmad@gmail.com
(Tri Wahyudin Ahmad)

ABSTRACT

Soil erosion is one of the major environmental degradation processes that directly contribute to land quality deterioration, increased river sedimentation, and disruption of hydrological functions within a watershed. This study aims to spatially model erosion rates in the Upstream Cisanggarung Watershed using the Universal Soil Loss Equation (USLE) integrated with a GIS-based Model Builder to develop an automated, efficient, and reproducible workflow. The analysis was conducted by incorporating all USLE components (R, K, LS, and CP). Rainfall data, soil type maps, 30 m resolution FABDEM, and land cover maps were employed as the main inputs in the modeling process. The results indicate that erosion rates range from 20.66 to 67.60 ton/ha/years, with a Sediment Delivery Ratio (SDR) of 6.58%. Consequently, the sediment yield reaching the watershed outlet was estimated to range from 60.517,5 to 198.034,6 ton/years. Spatially, erosion hotspots were identified in areas with steep slopes dominated by dryland agriculture and plantation land use. The integration of Model Builder improve data processing consistency, reduce manual errors, and enable rapid data updates for subsequent analyses. These findings underscore the need for implementing conservation strategies such as terracing, contour farming, and vegetative rehabilitation to reduce erosion rates and support sustainable watershed management.

1. INTRODUCTION

The Cisanggarung Watershed has its headwaters located in Kuningan Regency and its downstream area in Cirebon Regency, with a catchment area of approximately 1.003,99 km², accounting for about 12.91% of the total area of the Cimanuk–Cisanggarung river basin (Kementerian PUPR, 2017). The Cisanggarung River flows from the southern to the northern part of Java Island, and one of the main issues in the Cisanggarung Watershed is land erosion. Erosion is a process or phenomenon involving the loss of topsoil, caused by the action of water or wind (Suripin, 2002). The erosion process occurs sequentially, consisting of detachment, transportation, and deposition (Asdak, 1995). Raindrop impact is the primary mechanism for soil particle detachment in water induced erosion. When raindrops strike an exposed soil surface, soil particles are dislodged and thrown into the air, due to gravitational forces, these particles subsequently fall back to the ground. On undulating to steep slopes, detached soil particles are transported downslope through rolling and rotational motion toward downstream areas (Isma & Tarigan, 2018). The detachment of soil particles leads to soil pore clogging and surface sealing, resulting in the formation of a soil crust at the surface layer (Pakpahan *et al*., 2025). Soil erosion is a serious environmental issue associated with agricultural intensification, land degradation, and anthropogenic activities (Melinda *et al*., 2021). To maintain land productivity, policy interventions are primarily focused on the implementation of soil and water conservation practices (Farikha *et al*., 2023; Aouissi *et al*., 2025), However, unsustainable agricultural practices remain the main drivers of soil erosion (Gericke *et al*., 2019), partly due to sediment deposition in riverbeds during low flow conditions as a consequence of increased erosion rates. The Upper Cisanggarung Watershed plays a crucial role in providing water for agricultural, domestic, and ecological needs in downstream areas (Ministry of Public Works of the Republic of Indonesia, 2010). However, the conversion of forest land into agricultural and residential areas over recent decades has increased the risk of soil erosion. This phenomenon is reflected in increasing sedimentation in the downstream reaches of the river, which may reduce channel capacity and exacerbate flood hazards (Kusuma *et al*., 2020; Kementerian PUPR, 2022; Ahmad *et al*., 2025).

Efforts to understand soil erosion rates require quantitative methods that can provide clear and measurable results (Kardhana *et al*., 2024). One of the most widely used approaches is the Universal Soil Loss Equation (USLE) (Corral-Pazos-de-Provens *et al*., 2023; Wawer *et al*., 2005; Pyne *et al*., 2025). This method estimates soil erosion based on several key factors, including rainfall erosivity, soil erodibility, slope length and steepness, land cover and vegetation, crop management, and applied conservation practices (He *et al*., 2024). Conventionally, the USLE method has several limitations because the processing of rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice (P) factors is conducted manually and separately, resulting in analyses that are less efficient, time consuming, and prone to error (Hidayat & Andajani, 2018). In addition, the conventional USLE approach is unable to adequately represent spatial variability and does not provide automation for data updating. The integration of Model Builder within a Geographic Information System (GIS) enables automated modeling processes, workflow consistency, and improved spatial accuracy. Model Builder facilitates analysis replication, significantly reduces processing time, and allows rapid data updates through a structured workflow (Nugroho, 2016). Consequently, soil erosion rate estimates become more efficient, reproducible, and well suited to the requirements of modern spatial analysis (Pyne *et al*., 2025).

This study aims to analyze soil erosion rates in the Cisanggarung Watershed using the Universal Soil Loss Equation (USLE) integrated with Model Builder within a GIS to obtain more efficient and accurate erosion mapping, capable of representing spatial variability in detail through the automation of all calculation factors (Gebremichael *et al*., 2025). In addition to producing erosion distribution maps and identifying priority areas for soil conservation, this study is expected to provide comprehensive scientific information to support sustainable watershed management, sedimentation control, and the development of targeted conservation strategies. The integration of Model Builder also offers a documented, consistent, and easily replicable workflow, enabling its reuse for data updating and future soil erosion analyses.

2. RESEARCH METHODOLOGY

This study was conducted in the Upper Cisanggarung Watershed, which is part of the Cimanuk Cisanggarung River Basin. The Cisanggarung River is the main river within the watershed, with its headwaters originating from Darma Reservoir, Kuningan Regency, West Java Province. The river length within Upper Cisanggarung Watershed is 177,711 m and consists of 21 tributaries, as shown in Figure 1. In general, the administrative boundaries of the Upper Cisanggarung Watershed encompass five regencies, namely Majalengka Regency, Ciamis Regency, Brebes Regency, Kuningan Regency, and Cirebon Regency. Topographically, the Upper Cisanggarung Watershed is situated at elevations ranging from 62 to 2,000 m above sea level. The rainfall data used in this study were obtained from three ground based rainfall stations, namely Gunung Sirah Rainfall Station, Darma Rainfall Station, and Cikeusik Rainfall Station, as shown in Figures 2, 3 and 4, with a data record spanning from 2005 to 2024. This study focuses solely on predicting soil erosion rates for the year 2024 in the Upper Cisanggarung Watershed.

2.1. Materials And Methods

A laptop equipped with GIS software was used to determine rainfall erosivity values, with spatial mapping conducted based on data from three rainfall stations. Soil erodibility analysis was performed using soil type data obtained from the Harmonized World Soil Database (HWSD). The Digital Elevation Model (DEM) used in this study has a spatial resolution of 30 × 30 m and was derived from the Forest and Buildings Removed Copernicus DEM (Hawker *et al*., 2022). To determine the slope length and steepness factor (LS) and to define the cover management factor (C), which ranges from 0 to 1, where a value of 0 indicates 100% protection of the land against erosion hazards. The support practice factor (P) also ranges from 0 to 1, where a value of 1 represents conditions without erosion control measures, while values less than 1 indicate the implementation of mechanical soil conservation practices. Soil erosion rates were calculated using the USLE method, considering the R, K, LS, and CP factors (Baral & Bhurtyal, 2025; Andriyani & Fadila, 2024; Kardhana *et al*., 2024).

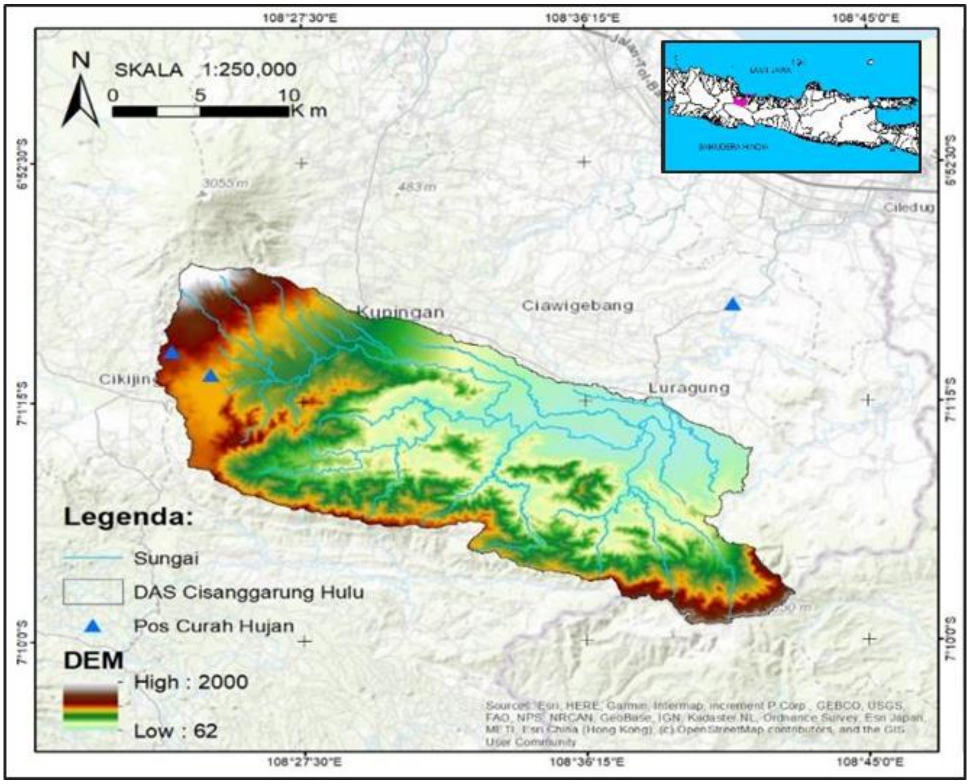


Figure 1. Map of the Upper Cisanggarung Watershed

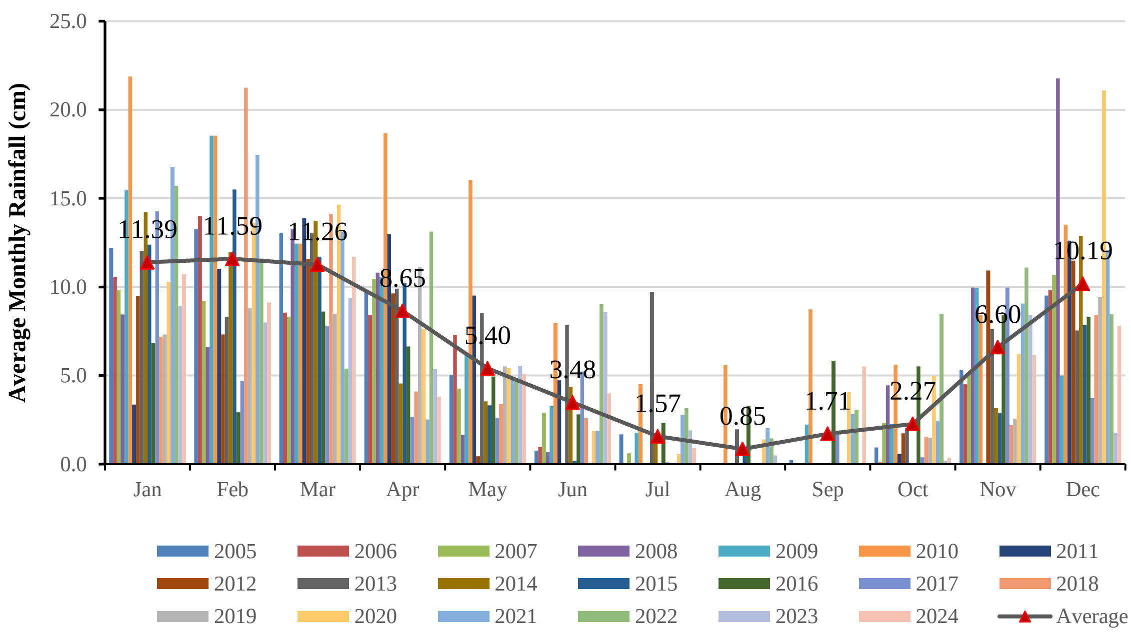


Figure 2. Monthly average rainfall data at Cikeusik station

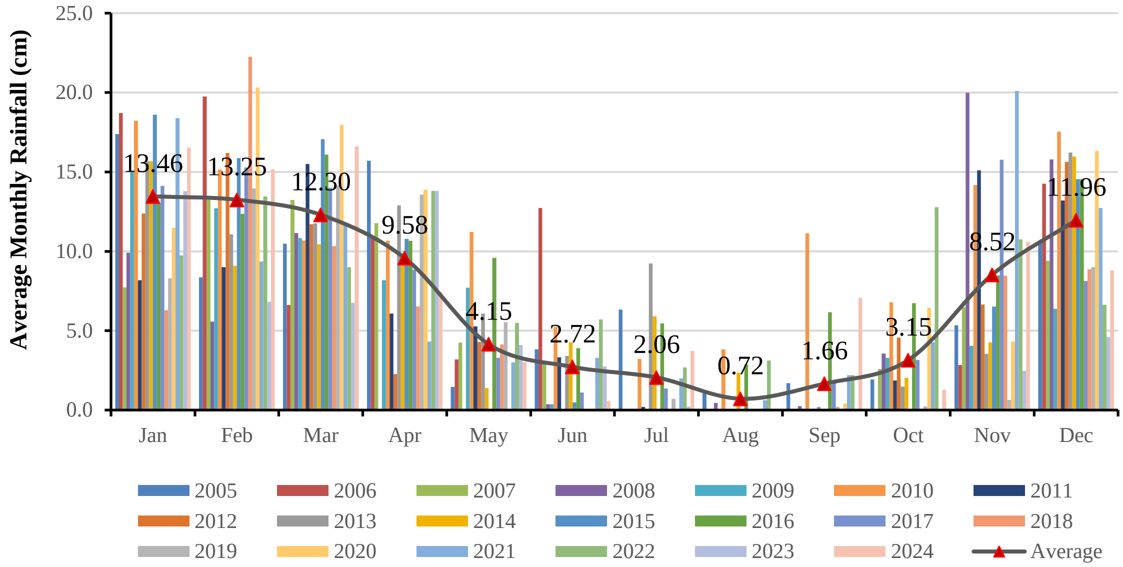


Figure 3. Monthly average rainfall data at Darma station

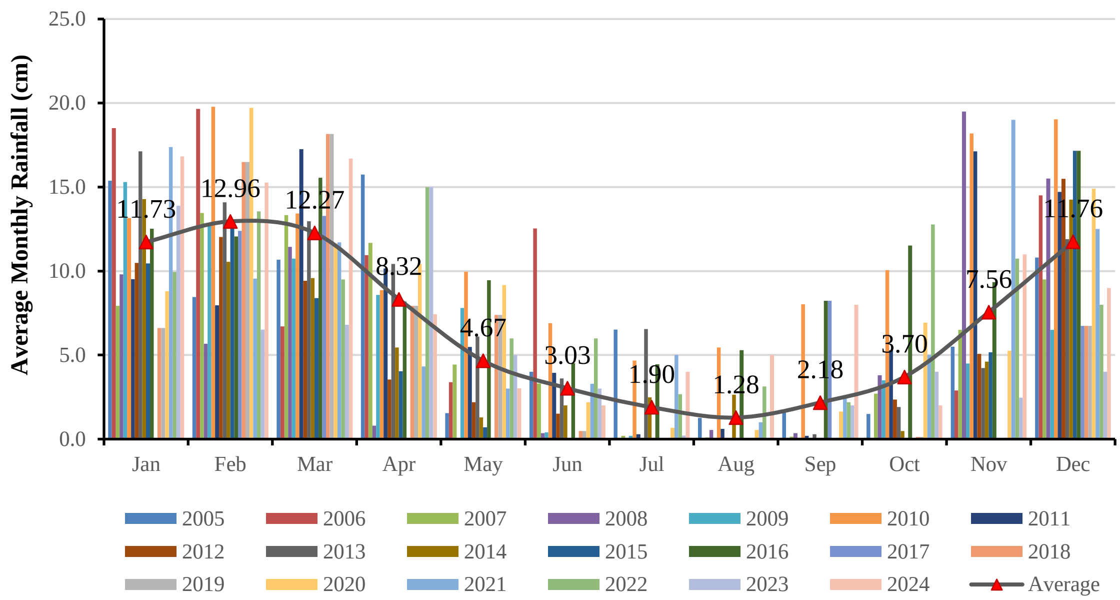


Figure 4. Monthly average rainfall data at Gunung Sirah station

2.2. Research Procedure

The research methodology began with a literature review to identify the concepts, parameters, and quantitative approaches used in USLE based soil erosion assessment. The subsequent stage involved data collection, including rainfall data, soil characteristics, slope gradient, land use, and conservation practices relevant to the conditions of the Upper Cisanggarung Watershed. All datasets were then processed using Geographic Information System (GIS) techniques to calculate each USLE factor, namely rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), and cover and conservation practices (CP). The results of each factor calculation were subsequently integrated to develop a spatial soil erosion rate model using the equation $A = R \times K \times LS \times CP$, which was implemented automatically through the GIS Model Builder framework.

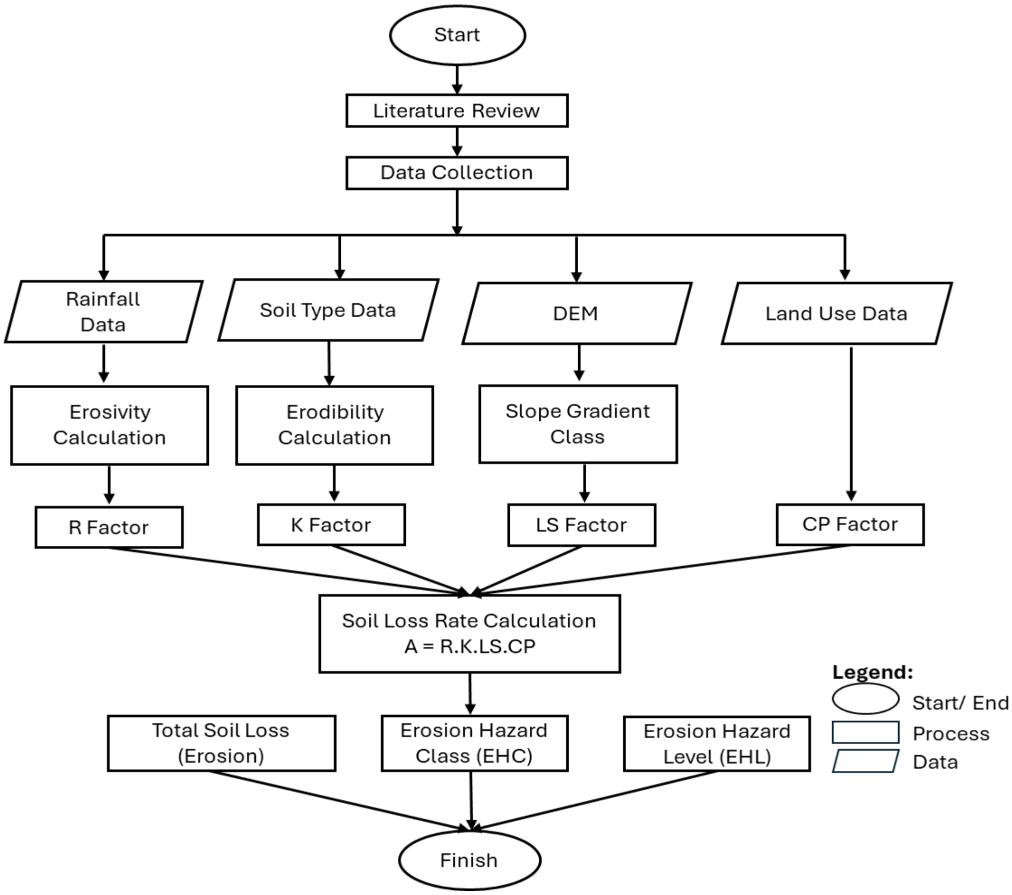


Figure 5. Steps in developing an automated workflow for spatial modeling of erosion rates

The main outputs include the Erosion Hazard Classes (EHC) and the Erosion Hazard Levels (EHL), which are generated through the spatial integration of all parameters, as illustrated in Figure 5. The Model Builder workflow is applied throughout the processing of all USLE factors, from factor computation to soil erosion rate estimation, as well as the automatic classification of results within the GIS environment. This workflow enables systematic and reproducible erosion analysis, meeting the requirements of geospatial watershed scale modeling.

2.3. Data Interpretation

2.3.1. Rainfall Erosivity Factor (R)

Various rainfall erosivity equations have been developed based on the characteristics of study locations across different regions of the world (Kardhana H *et al*., 2024). The Bols erosivity equation is widely used and is based on empirical studies conducted on Java Island (Suripin, 2002). Rainfall erosivity data used for the period 2020 to 2024, as shown in Figures 6, were employed to calculate the monthly average erosivity index using Equation (1).

$$EI30 = 6.119 \; x \; Pb^{1.211} \; x \; N^{-0.474} \; \text{x} \; Pmax^{0.526} \quad (1)$$

where *EI30* is monthly average erosivity index, *Pb* is total monthly rainfall (cm), *N* is number of rainy days per month, and *Pmax* is the maximum daily rainfall within a month (cm).

2.4. Soil Erodibility Factor (*K*)

The soil erodibility parameter (*K*) is used to represent the susceptibility of soil to erosion, which is influenced by rainfall characteristics and surface conditions, and is associated with the sediment transport capacity, runoff volume, and flow

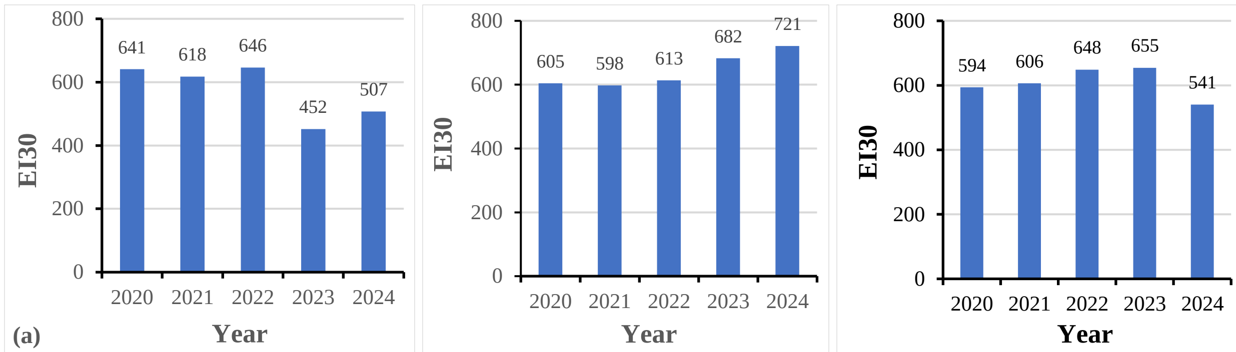


Figure 6. Rainfall erosivity based on rainfall date from 3 stations: (a) Cikeusik station, (b) Darma Station, (c) Gunung Sirah Station

velocity (Julien, 2010; Nugroho *et al*., 2025). Soil erodibility values were determined based on the soil type map by identifying the soil types within the Upper Cisanggarung Watershed. As shown in Table 1, each soil type was assigned a corresponding K value, which was subsequently analyzed using GIS in raster format.

Table 1. Soil erodibility values in the Upper Cisanggarung Watershed

Soil Type	K Value	Area (Km^2)
Complex of Reddish Brown Mediterranean Soils and Lithosols	0.188	3.517
Brown Latosol	0.175	1.298
Association of Grayish Brown Alluvial and Brown Alluvial Soils	0.193	2.607
Reddish Brown Latosol	0.121	50.787
Association of Brown Andosol and Brown Regosol	0.271	14.044
Brown Latosol	0.175	16.807
Complex of Brown Mediterranean Soils and Lithosols	0.323	14.715
Association of Brown Latosol and Gray Regosol	0.186	13.967
Complex of Grumusol, Regosol, and Mediterranean Soils	0.201	22.372
Association of Yellow Podzolic and Regosol Soils	0.158	36.694
Complex of Yellowish Red Podzolic Soils	0.175	188.824
Dark Reddish Brown Latosol	0.058	43.991
Complex of Yellowish Red Latosol and Brown Latosol	0.116	26.052
Association of Yellow Podzolic and Regosol Soils	0.158	0.498
Association of Grayish Brown Alluvial and Brown Alluvial Soils	0.193	9.089

Sources: Puslitbang Pengairan Bogor. (1985)

2.5. Slope Length and Steepness Factor (LS)

The LS factor values were calculated using GIS based on FABDEM data, which represent digital surface elevation (Fekir *et al*., 2025). The equation developed by (Wood & Dent, 1983) was used to calculate the slope factor (*LS*).

$$LS = 34,7046 \left(\frac{L}{22.1}\right)^{m} x \ (\cos\alpha)^{1.503} \text{ x } \left(\frac{(\sin\alpha)^{1.249}}{2} + (\sin\alpha)^{2.249}\right) \quad (2)$$

where L is slope length (m), m is 0.5 for slopes > 5%, 0.4 for slopes between 3-5%, and 0.3 for slopes < 3%, and α is slope angle (deg or rad). Table 2 was used to determine the slope classes in the Upper Cisanggarung Watershed.

Table 2. Slope classes of Upper Cisanggarung Watershed (Asdak, 1995)

Class	Slope	Classsification	Area (Km^2)	%
1	0 - 2 %	Flat	31.573	7.090
2	2 - 15 %	Gentle	150.408	33.780
3	15 - 40 %	Steep	168.808	37.910
4	> 40 %	Very Steep	94.472	21.220

2.6. Land Cover and Conservation Practice Factor (*CP*)

Land management measures are classified into the land cover vegetation factor (*C*) and the soil conservation practice factor (*P*) (Bekele & Gemi, 2021). Table 3 details Land cover types of the Upper Cisanggarung Watershed. Land use types related to factor (*C*) are obtained from the land cover map (KLHK, 2022), and the land cover data are then converted using the codes defined in the BTA-155 study (Dirjen SDA, 2014; 2015). The land cover factor represents the combined effects of vegetation cover and plant residues on erosion, as well as the ratio of erosion from land with a particular cropping pattern to that from land with different crop types (Liu *et al*., 2017). This factor ranges from 0 to 1, where a value of 0 indicates 100% protection of the land from erosion hazards. Conservation practices included in factor (*C*) consist of tillage, crop rotation, and residue management, while the land conservation factor represents the ratio of erosion from land with management practices to erosion from land without management (Kironoto *et al*., 2021). This factor ranges from 0 to 1, where a value of 1 represents conditions without erosion control measures, and values less than 1 indicate conditions with mechanical land treatment. Conservation practices commonly included in factor (*P*) are contouring, contour strip cropping, terracing, and mulched surfaces.

Table 3. Land cover types of the Upper Cisanggarung Watershed

Land Cover Type	Area (Km^2)	%
Secondary Dryland Forest	47.4	10.64
Plantation Forest	168.04	37.74
Shrubland	1.21	0.27
Plantation	5.5	1.23
Settlement	33.94	7.62
Water Body	4.18	0.94
Dryland Agriculture	78.51	17.63
Dryland Agriculture Mixed with Shrubs	48.17	10.82
Paddy Field	58.31	13.1

Sources: KLHK (2022).

Table 4. BTA code classification

BTA Code	Land Cover Type
1	Settlement
2	Paddy Field
3	Non-irrigated agriculture
4	Estates and plantations
5	Mixed gardens
6	Natural forest
7	Production forest
8	Shrub
9	Grassland
10	Swamps/ ponds/ Water Body
11	Unproductive land
0	Clouds
12	Rocks

Sources: Dirjen SDA (2015).

In the GIS Model Builder schematic shown in Figure 9, the vegetation factor and land conservation practice factor are combined into a single integrated *CP* factor, as both factors are closely interrelated. In general, the *CP* factor depends on slope gradient. The integrated *CP* factor has been developed as a function of land use, slope gradient, and land management level. Therefore, the cross matrix in Table 5 is used as a lookup table input within the GIS. Furthermore, with the aid of Model Builder and parameter data according to Table 5, the resulting land cover and soil conservation factor can be obtained.

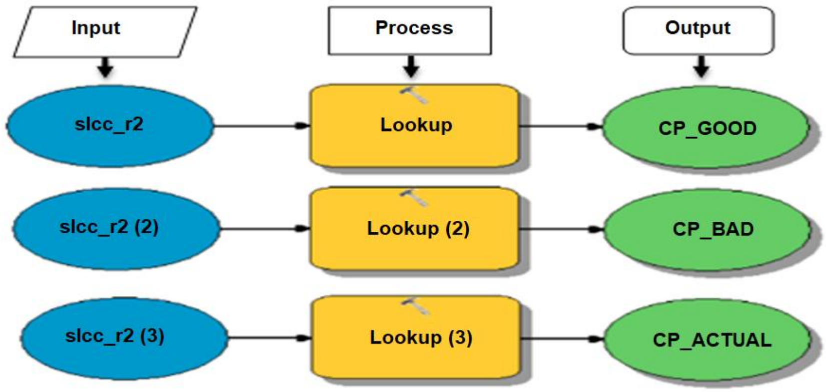


Figure 9. Schematic of *CP* value calculation

Table 5. Cross matrix *CP* value

BTA Code	Landcover	Slope Code	Slope (%)	Slope *LC*	*CP* Good	*CP* Bad	*CP* Actual
1	Settlement Area	1	0 - 2	101	0.050	0.050	0.050
1	Settlement Area	2	2 - 15	201	0.050	0.050	0.050
1	Settlement Area	3	15 - 40	301	0.050	0.050	0.050
1	Settlement Area	4	> 40	401	0.050	0.050	0.050
2	Paddy Field	1	0 - 2	102	0.010	0.010	0.010
2	Paddy Field	2	2 - 15	202	0.010	0.010	0.010
2	Paddy Field	3	15 - 40	302	0.010	0.010	0.010
2	Paddy Field	4	> 40	402	0.010	0.010	0.010
3	Dryland Agriculture	1	0 - 2	103	0.045	0.310	0.110
3	Dryland Agriculture	2	2 - 15	203	0.063	0.330	0.145
3	Dryland Agriculture	3	15 - 40	303	0.096	0.360	0.230
3	Dryland Agriculture	4	> 40	403	0.137	0.440	0.320
4	Plantation	1	0 - 2	104	0.005	0.225	0.047
4	Plantation	2	2 - 15	204	0.010	0.254	0.066
4	Plantation	3	15 - 40	304	0.020	0.286	0.086
4	Plantation	4	> 40	404	0.034	0.320	0.117
5	Dryland Agriculture Mixed with Shrubs	1	0 - 2	105	0.022	0.155	0.055
5	Dryland Agriculture Mixed with Shrubs	2	2 - 15	205	0.031	0.165	0.076
5	Dryland Agriculture Mixed with Shrubs	3	15 - 40	305	0.048	0.198	0.115
5	Dryland Agriculture Mixed with Shrubs	4	> 40	405	0.068	0.220	0.155
6	Secondary Dryland Forest	1	0 - 2	106	0.000	0.001	0.000
6	Secondary Dryland Forest	2	2 - 15	206	0.001	0.001	0.001
6	Secondary Dryland Forest	3	15 - 40	306	0.001	0.002	0.001
6	Secondary Dryland Forest	4	> 40	406	0.001	0.002	0.001
7	Forest Plantation	1	0 - 2	107	0.001	0.001	0.001
7	Forest Plantation	2	2 - 15	207	0.001	0.002	0.002
7	Forest Plantation	3	15 - 40	307	0.002	0.003	0.003
7	Forest Plantation	4	> 40	407	0.002	0.003	0.003
8	Shrubland	1	0 - 2	108	0.001	0.001	0.001
8	Shrubland	2	2 - 15	208	0.002	0.002	0.002
8	Shrubland	3	15 - 40	308	0.002	0.002	0.002
8	Shrubland	4	> 40	408	0.002	0.002	0.002
10	Water Body	1	0 - 2	110	0.000	0.000	0.000
10	Water Body	2	2 - 15	210	0.000	0.000	0.000
10	Water Body	3	15 - 40	310	0.000	0.000	0.000
10	Water Body	4	> 40	410	0.000	0.000	0.000

2.7. Erosion Hazard Level

According to the (Kardhana *et al*., 2024), the classification of erosion hazard levels is determined based on the rate of soil loss expressed in tons/ha/year, as presented in Table 6. This classification indicates whether the level of erosion occurring in a watershed has reached a critical or hazardous stage, and therefore can be used as a reference for watershed management and conservation planning.

Table 6. Classification and description of erosion hazard level

Class Erosion Hazard	Erosion Level (tons/ha/year)	Description
I	< 15	Very Slight
II	15 – 60	Slight
III	60 – 180	Moderate
IV	180 – 480	Severe
V	> 480	Very Severe

Sources: Suripin (2002)

2.7.1. Sediment Delivery Ratio (*SDR*) and Sediment Yield (*Y*)

The Boyce method was used to estimate the Sediment Delivery Ratio (*SDR*) based on an empirical relationship between watershed area and the efficiency of sediment transport from source areas to the outlet. The Boyce formulation is based on the principle that the larger the watershed area, the smaller the proportion of sediment that successfully reaches the outlet due to deposition processes occurring along the flow paths (Isma *et al*., 2018; Asdak, 1995).

$$SDR = 0.41\ AW^{-0.3} \tag{3}$$

where AW is watershed area (km²)

Sediment yield (Y) represents the actual sediment output that is successfully transported from erosion source areas to the watershed outlet, and is influenced by rainfall erosivity, soil erodibility, land use, slope gradient, and sediment transport efficiency (Chaidar *et al*., 2017).

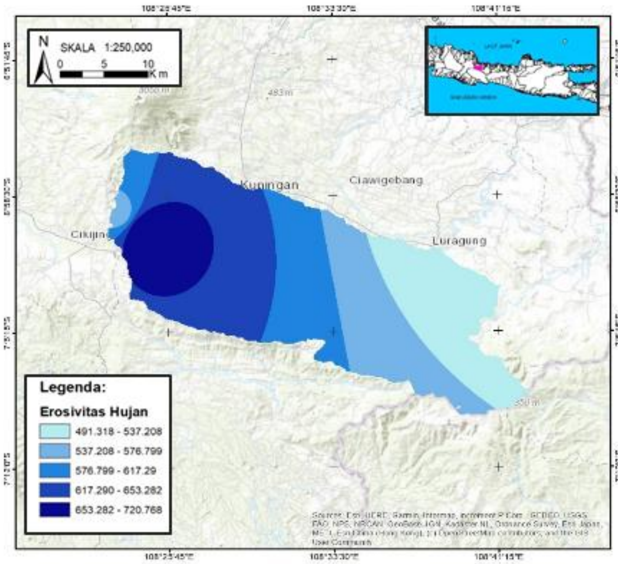
$$Y = SDR \times A \tag{4}$$

where A is annual specific erosion (ton·ha^{-1}·year^{-1})

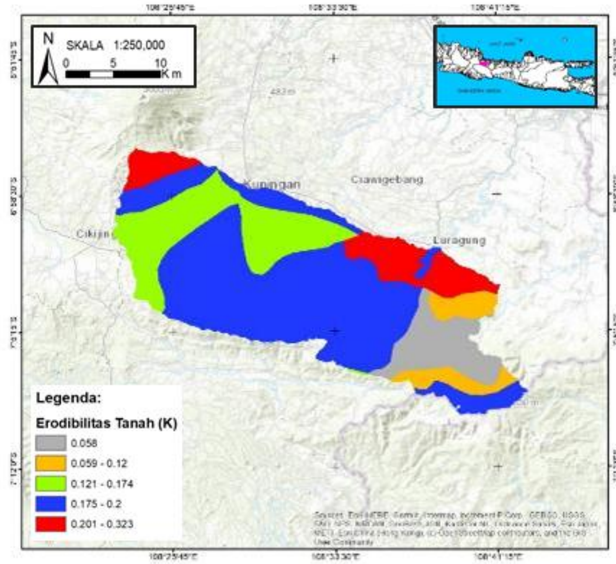
3. RESULTS AND DISCUSSION

The erosivity values in the Upper Cisanggarung Watershed indicate that the average rainfall erosivity ranges from 491.318 to 720.768 cm/year across three rainfall stations, as shown in Figure 10(a). High rainfall intensity can damage soil aggregates (Liu *et al*., 2017). The calculation of soil erodibility aims to determine the level of soil susceptibility to detachment and transport by water. This value represents the sensitivity of soil physical properties, including texture, structure, permeability, and organic matter content, and thus becomes a key parameter in estimating erosion rates to identify areas that are most vulnerable and require conservation measures, as illustrated in Figure 10(b). Topographic conditions, including slope angle, slope length, and slope shape, play an important role in determining the magnitude of surface runoff. Steep slopes increase the kinetic energy of flow, which ultimately enhances the capacity of runoff to transport soil particles (Farikha *et al*., 2023).

The calculation of the *K* factor was obtained from the Water Resources Research and Development Center (Puslitbang Pengairan, 1985), as presented in Table 1. The *K* factor is determined by soil physical properties that change very slowly over time scales of decades, such as soil texture, structure, permeability, and organic matter content. These parameters are inherent in nature and do not undergo significant changes without major disturbances to the landscape. In the Upper Cisanggarung Watershed, K values range from 0.058 to 0.323. The dominant soil type is the complex of red yellow podzolic soils with a K value of 0.175, covering an area of 188.824 km² or 42% of the total area of the Upper Cisanggarung Watershed. Soils with higher K values tend to experience higher erosion rates compared to soils with lower K values under the same rainfall intensity (Wischmeier & Smith, 1978; Asdak, 1995).



(a)



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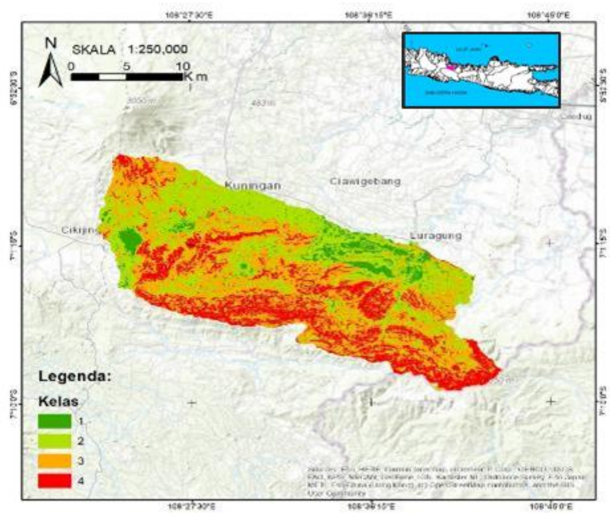

(c)

Figure 10. Erosion factors for the Upper Cisanggarung Watershed: (a) Erosivity (*R*), (b) Erodibility (*K*), (c) Slope Gradient (*LS*)

Based on Table 2, the Upper Cisanggarung Watershed is dominated by steep slope classifications at 37.91%, followed by gentle slopes at 33.8%, very steep slopes at 21.22%, and flat areas at 7.09%. High LS factor values contribute to increased surface runoff velocity, intensify soil particle detachment processes, and enhance the transport energy of runoff (Kardhana *et al*., 2024). However, the estimation of the *LS* factor in soil erosion modeling using the USLE at a regional landscape scale still faces various challenges. To address this issue, the calculation of the *LS* factor is typically based on raster resolution and the spatial extent of the DEM, allowing erosion prediction models to be adjusted to variations in relief conditions (Bekele & Gemi, 2021; Aouissi *et al*., 2025).

Based on Figure 11, the classification of the land cover and soil conservation factor (*CP*) shows that areas with poor conservation and erosion control practices have CP values ranging from 0 to 0.44, areas with actual (moderate) conservation and erosion control practices range from 0 to 0.319, and areas with good conservation and erosion control practices range from 0 to 0.14, where conservation measures such as residue management and erosion control are implemented mechanically. The magnitude and spatial distribution of actual soil erosion can be determined by overlaying the four raster layers, namely the *R* factor, *K* factor, *LS* factor, and *CP* factor.

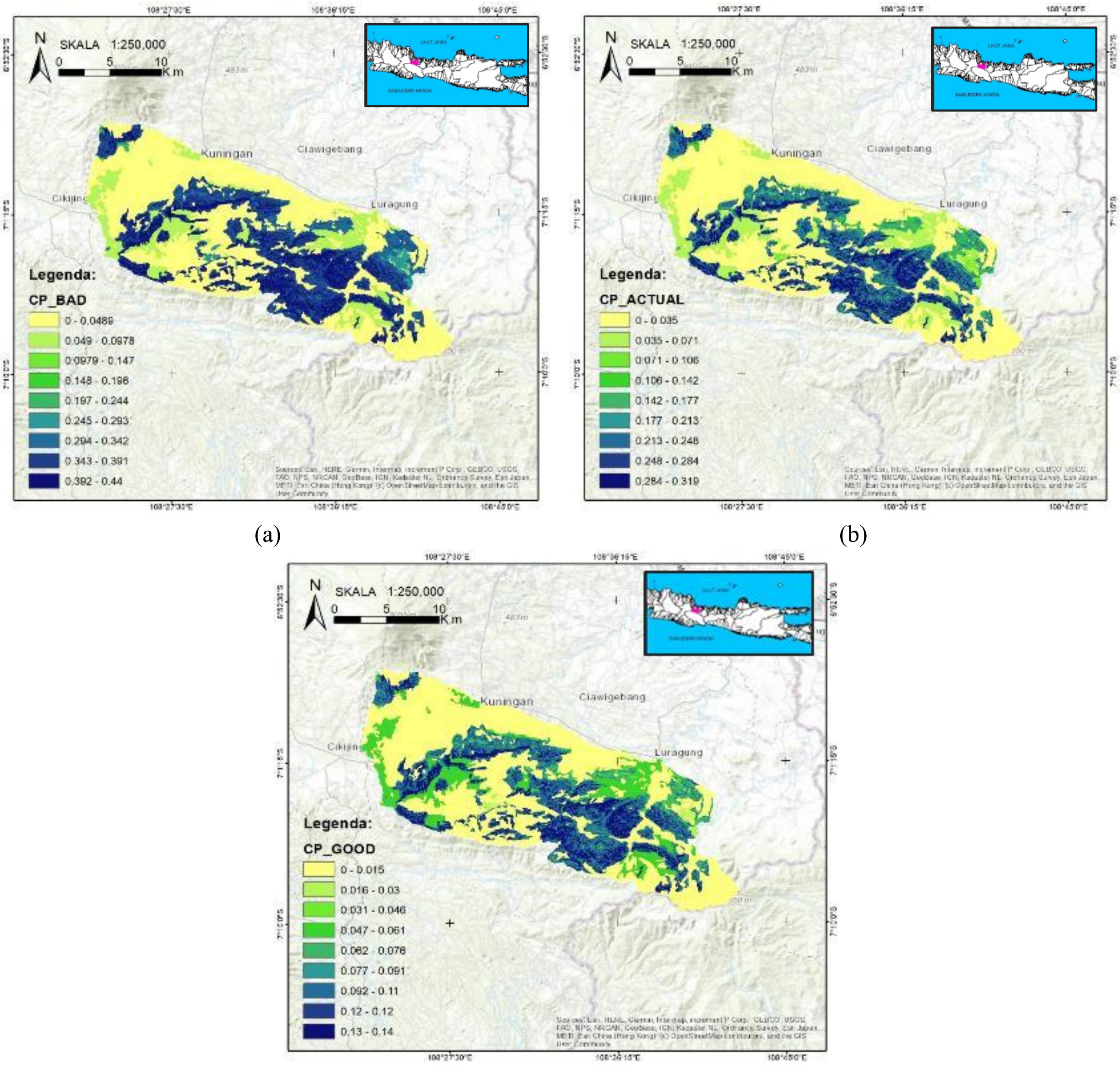

Figure 11. Land cover and conservation practice (CP) factor for the Upper Cisanggarung Watershed: (a) Bad, (b) Actual, (c) Good

The analysis results, as shown in Table 7, indicate that the total erosion at the study area under good land management conditions has an erosion rate of 20.66 tons/ha/year, under actual land management conditions the erosion rate is 47.30 tons/ha/year, and under poor land management conditions the erosion rate is 67.60 tons/ha/year. An *SDR* value of 6.58% according to Boyce indicates that the amount of sediment reaching the river system is estimated in the range between

Table 7. Results of soil erosion rate calculation

Soil Bulk Density	Total Erosion			SDR	Sediment Yield	
	(ton/year)	(m^3/year)	($ton \cdot ha^{-1} \cdot year^{-1}$)		(m^3/year)	(ton/year)
1.80 g/cm^3	919.773,86	510.985,48	20.66	6.58%	33.620.8	60.517,5
	2.106.169,48	1.170.094,16	47.30		76.987,6	138.577,6
	3.009.824,92	1.672.124,95	67.60		110.019,2	198.034,6

60.517,5 and 198.034,6 tons/year. These results suggest that the area has a slight to moderate erosion hazard level; therefore, the implementation of soil and water conservation measures is required to reduce sediment yield and maintain the sustainability of watershed hydrological functions.

The integration of Model Builder within GIS makes a significant contribution to the efficiency and consistency of erosion modeling processes. The automation of all stages in calculating the (*R*, *K*, *LS*, and *CP*) factors produces a standardized workflow, reduces the potential for manual errors, and allows the analysis to be replicated across various land use scenarios. Furthermore, GIS capabilities in handling high-resolution spatial data enable more accurate detection of erosion distribution patterns compared to non-spatial approaches. Model Builder also facilitates updating input parameters and conducting model sensitivity analyses, thereby improving the reliability of erosion rate estimates at the watershed scale.

Spatial analysis shows that erosion hotspots are concentrated in areas with a combination of steep slopes, soils with high erodibility values, and unstable land cover. Areas with rugged topography in the upper part of the Cisanggarung Watershed tend to generate higher erosion values, as shown in Figure 12 (a, b, c), particularly in areas where forest has been converted into dryland agriculture. The identification of these hotspots is important for determining priority zones for soil conservation and vegetation rehabilitation.

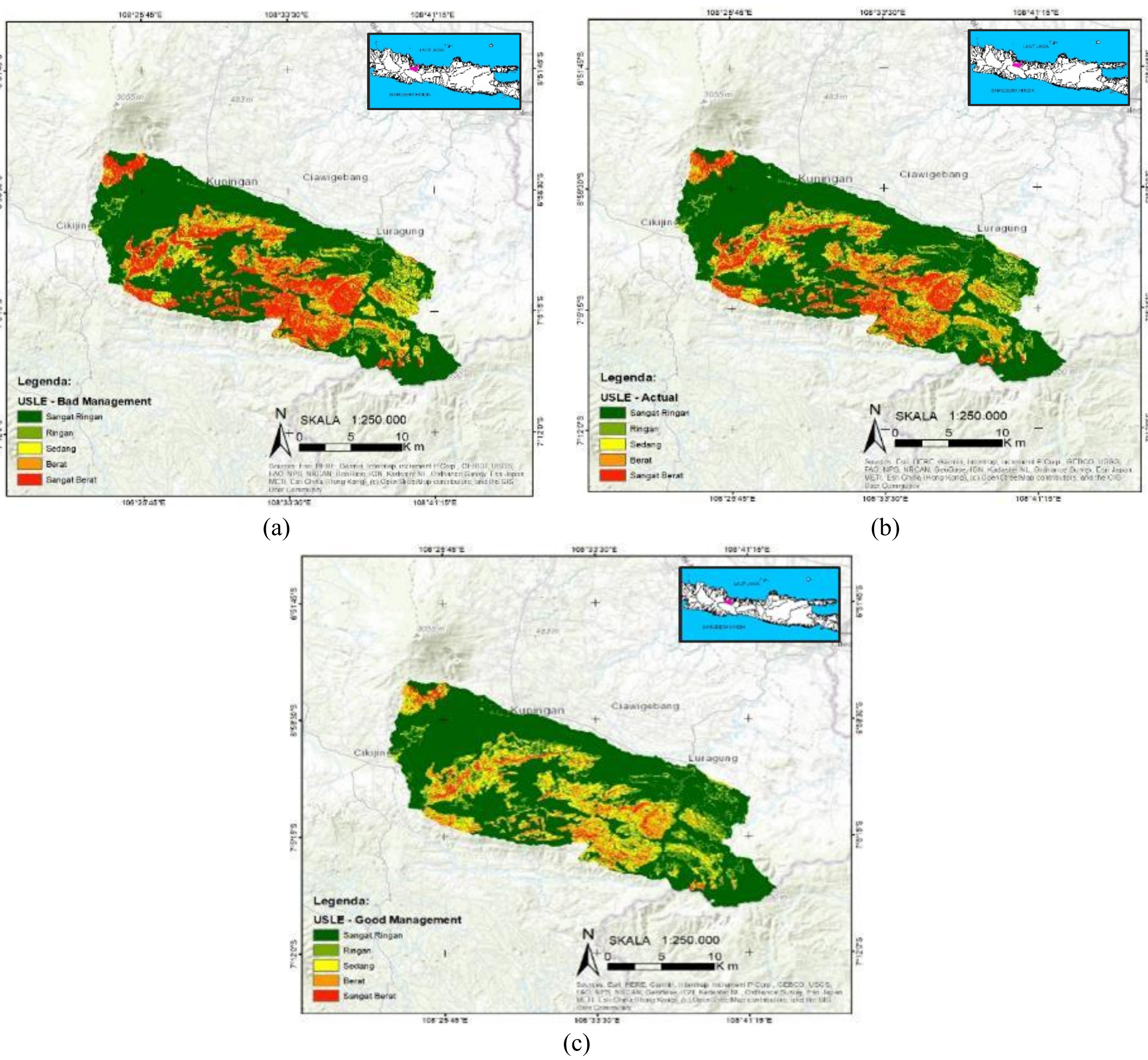

Figure 12. Soil erosion classification in the Cisanggarung Upper Watershed (a) USLE Bad, (b) USLE Actual, (c) USLE Good

The land types most vulnerable to erosion are represented by dryland agriculture, upland fields, and open land, which have high CP factor values and minimal vegetation cover. The use of K-factor datasets may introduce uncertainty if local soil properties change due to anthropogenic activities. Spatial uncertainty also arises from DEM resolution, which affects the accuracy of the LS factor. Nevertheless, the integration of Model Builder reduces procedural uncertainty through the automation of the modeling workflow and consistent process documentation.

The results of this study are consistent with findings from the Upper Citarum Watershed, where high erosion rates primarily occur on steep slopes dominated by dryland agriculture (Kardhana *et al*., 2024). The erosion rate values in the Cisanggarung Watershed show a similar distribution pattern, with the highest intensities occurring in the upstream zones that have steeper slopes. This comparison indicates that anthropogenic pressure and land use change are dominant factors differentiating erosion levels among watersheds in West Java Province.

4. CONCLUSIONS AND RECOMMENDATIONS

The application of Model Builder integrated with GIS has proven effective in calculating and mapping erosion rates in the Upper Cisanggarung Watershed. The erosion rates range from 20.66 to 67.60 tons/ha/year, with sediment yields between 60.517,5 and 198.034,6 tons/year. These results indicate that the study area is classified as having a slight to moderate erosion hazard level based on the classification criteria. An SDR value of 6.58% indicates that only a small portion of the eroded material reaches the main river network, while the remainder is deposited on hillslopes and in minor channels. The main factors influencing erosion are steep slope gradients, high rainfall intensity, and the limited implementation of land conservation practices. Therefore, soil and water conservation strategies such as contour farming, ground cover vegetation, and terracing are required to reduce soil loss and maintain watershed hydrological stability. The integration of Model Builder within GIS is expected to be further developed to improve the accuracy and effectiveness of sustainable watershed management. Conservation efforts can be directed toward the application of mechanical and vegetative techniques, such as terracing, agroforestry, and tree planting. It is recommended that dryland agricultural areas on steep slopes (>40%) be gradually converted into plantation forests to reduce erosion rates and enhance infiltration and slope stability. To improve model accuracy, further studies are required in the form of field validation, particularly through measurements of actual erosion and sediment yield at the watershed outlet, to strengthen parameters and calibrate the model.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
TWA	✓	✓	✓			✓		✓		✓				✓
MSBK		✓	✓	✓			✓		✓	✓		✓		
FIWR	✓			✓					✓		✓	✓		
AYW		✓			✓	✓	✓	✓						
VF					✓	✓					✓		✓	

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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