Erosion and Sedimentation Analysis of the Sario Sub-Watershed, Manado City, North Sulawesi: A USLE-GIS Approach

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ABSTRACT

The Sario Sub-Watershed is a densely populated urban catchment in Manado City, North Sulawesi, that drains directly into Manado Bay and is prone to recurring floods and riverbed siltation. This study analyzed the rate of soil erosion and the amount of sediment reaching the Sario River in the downstream part of the sub-watershed, an area not yet specifically assessed by earlier studies covering the whole Sario watershed. Erosion was estimated using the Universal Soil Loss Equation (USLE) integrated with a Geographic Information System (GIS), combining rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover (C), and conservation practice (P) factors derived from ten years (2015-2024) of rainfall data, soil and land-cover maps, and a Digital Elevation Model. The resulting sediment yield delivered to the river was then estimated using the Sediment Delivery Ratio (SDR) of Auerswald (1992) and the Boyce method. Results show a total annual erosion of 715,436.74 tons across 1,207.10 ha, or an area-weighted average of 592.69 tons/ha/year, placing the sub-watershed in Erosion Hazard Class V (very severe) under Indonesian Ministry of Forestry Regulation No. 32/2009. Class V areas cover 596.96 ha (49.45%), concentrated on steep, densely settled terrain dominated by Eutric Cambisol soil. The estimated SDR of 0.291 yields a sediment load of 208,191.90 tons/year reaching the Sario River. These findings indicate that erosion and sedimentation in the sub-watershed are driven mainly by steep topography combined with low-conservation-value settlement land, underlining the need for forestry-based watershed interventions such as land rehabilitation, urban green open space development, riparian buffer strips, and agroforestry to reduce erosion, sedimentation, and recurrent flooding.

Keywords: *soil erosion, sedimentation, USLE, GIS, sub-watershed management*

INTRODUCTION

A watershed is a land area bounded by ridgelines and valleys that functions to store and channel rainwater and sediment through its river network toward an outlet such as a lake or the sea (Haikal et al., 2023; Nurrohman & Adlin, 2018; Supatno & Asih, 2016). A well-functioning watershed supports ecosystem balance and supplies water for agricultural, residential, and industrial needs (Sudiartono et al., 2022). However, its condition is strongly influenced by biophysical factors such as topography, soil type, vegetation cover, and land use, and poor management of these factors gives rise to environmental problems, particularly erosion and sedimentation (Gusma et al., 2023).

The Sario Sub-Watershed forms part of the larger Sario Watershed in Manado City, North Sulawesi, and plays an important role because its channel passes through densely populated settlement and urban areas. Conversion of forest and shrubland into settlement, infrastructure, and economic activity has reduced the land's capacity to absorb rainwater, potentially accelerating erosion and sedimentation along the Sario River, which is frequently associated with flooding and channel siltation. A previous study by Turangan et al. (2019) assessed erosion across the entire Sario Watershed using the USLE method and reported an average erosion rate of 53.89 tons/ha/year, but did not focus specifically on the downstream sub-watershed or incorporate a sedimentation analysis. The present study therefore focuses on the downstream part of the sub-watershed, an area of dense activity that is particularly vulnerable to sedimentation from land-cover change and increased surface runoff. Suadnya et al. (2017) further reported that flood discharge in the Sario River recurs almost every rainy season, with overflow already occurring in the Citraland area at a 10-year return period, indicating that erosion, sedimentation, and flooding in the Sario Sub-Watershed are closely interrelated issues requiring comprehensive assessment. A similar pattern of flood vulnerability driven by the interaction of slope, land cover, and rainfall intensity has also been reported elsewhere in North Sulawesi, where GIS-based flood-hazard mapping in the Binerean Landscape, South Bolaang Mongondow Regency, found that flat to gently sloping terrain combined with high monthly rainfall largely determined the recurrence of flooding, underlining the broader relevance of integrating land-cover and topographic analysis into flood and sedimentation studies in the region (Ragentu et al., 2025).

One widely used method for quantifying erosion is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), which estimates erosion based on climatic, soil, slope, land-cover, and conservation-practice factors. Erosion values obtained from USLE can further be linked to the amount of sediment reaching a river channel through the Sediment Delivery Ratio (SDR) approach of Auerswald (1992) (Moha et al., 2020). The integration of USLE with a Geographic Information System (GIS) allows spatial data such as rainfall, soil type, topography, and land use to be combined within a single system, so that erosion and sedimentation can be mapped spatially rather than expressed only as aggregate figures, providing a stronger basis for watershed management planning (Puno et al., 2021).

This study aims to (1) analyze the level of erosion in the Sario Sub-Watershed based on variation in land cover and slope steepness using the USLE method with a GIS approach, and classify erosion hazard classes according to Indonesian Ministry of Forestry Regulation No. 32/2009; and (2) predict the amount of sediment delivered to the Sario River using the Sediment Delivery Ratio (SDR) approach of Auerswald (1992) and the Boyce method, and analyze its implications for sub-watershed management in the forestry sector. The results are expected to provide updated quantitative data to support integrated watershed management by relevant agencies, particularly the Tondano Watershed Management Agency (BPDAS Tondano), and to inform the prioritization of Forest and Land Rehabilitation (RHL-DAS) activities in the Sario Sub-Watershed.

METHODOLOGY

Time and Place of Research

This research was conducted from December 2025 to January 2026 in the Sario Sub-Watershed, Manado City, North Sulawesi, geographically located at 1°27'29.4" N and 124°50'31.6" E. Administratively, the sub-watershed covers several urban wards within the districts of Sario, Wenang, Wanea, and Tikala, and drains directly into Manado Bay, making it a downstream area highly vulnerable to erosion and sedimentation originating from upstream regions.

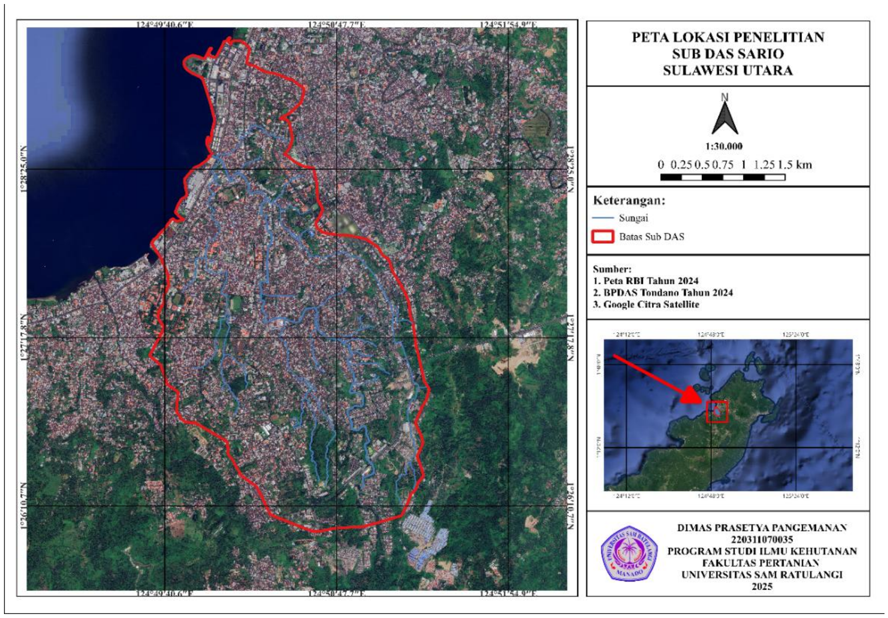

Figure 1. Map of the Research Location

Tools and Materials

The tools used in this study included a laptop with Quantum GIS (QGIS) version 3.42.1 for spatial data processing, Google Earth Pro for satellite imagery verification, and Microsoft Excel for tabular data processing and calculation of USLE factors. Secondary data used included ten years (2015-2024) of monthly rainfall data from the North Sulawesi Climatology Station of the Meteorology, Climatology, and Geophysics Agency (BMKG); soil-type and 2024 land-cover maps from the Tondano Watershed Management Agency (BPDAS Tondano); and Digital Elevation Model (DEM) data obtained from the Indonesian Geoportal (Ina-Geoportal).

Research Method

This study applied a descriptive quantitative method with a spatial analysis approach. Spatial processing was carried out in QGIS and included masking of the sub-watershed boundary, data editing, and overlay of thematic layers. All data analyzed were secondary data - rainfall records, soil-type and land-cover maps, and DEM data - obtained from relevant agencies and official online sources. Calculation results were summarized in tables using pivot tables in Microsoft Excel and mapped spatially to visualize the distribution of erosion levels across the sub-watershed.

Data Analysis Procedure

The sub-watershed boundary was delineated manually from DEM and river-network data in QGIS by tracing ridgelines separating flow toward the Sario River from flow toward adjacent catchments, and validated against the 2024 BPDAS Tondano sub-watershed boundary map. All spatial layers were projected to a uniform coordinate system (WGS 84 / UTM Zone 51N) prior to further analysis.

The rainfall erosivity factor (R) was calculated from ten years of monthly rainfall data using the Lenvain (1975) equation as described in Pamungkas (2020), $R = 2.21P^{1.36}$, where P is the average monthly rainfall in centimeters. Monthly R values were summed to obtain the annual rainfall erosivity index, which is homogeneous across the study area since it is derived from a single representative rainfall station.

The soil erodibility factor (K) was assigned to each soil-map unit based on the BPDAS Tondano soil-type map and relevant literature. The slope length and steepness factor (LS) was derived from Ina-Geoportal DEM data reprojected to WGS 84 / UTM Zone 51N, with slope percentage calculated using the Slope function in QGIS and classified into five classes following Salma et al. (2024), as summarized in Table 1.

Table 1. Slope Length and Steepness (LS) Classification

Class	Slope (%)	Description	LS Value
I	0-8	Flat	0.4
II	>8-15	Gently sloping	1.4
III	>15-25	Moderately steep	3.1
IV	>25-40	Steep	6.8
V	>40-100	Very steep	9.5

Source: Salma et al. (2024)

Land cover for 2024 was obtained from BPDAS Tondano and verified through visual interpretation of Google Earth Pro satellite imagery. Six land-cover classes were identified: mixed gardens, settlement, dryland agriculture mixed with shrubs, swamp, open space, and shrubland. Each class was assigned a land-cover management factor (C) value following Raco et al. (2022) and Pratama et al. (2024), as shown in Table 2. Because none of the land-cover classes in the sub-watershed - including dense settlement areas - apply soil-conservation practices such as terracing or contour planting, the conservation-practice factor (P) was set equal to 1 for all classes, following Harliando et al. (2023) and Seto and Pandey (2019).

Table 2. Land Cover Management (C) Factor Values by Land-Cover Class

Land Cover	C Value
Mixed garden	0.20
Settlement	0.50
Dryland agriculture mixed with shrubs	0.28
Swamp	0.01
Shrubland	0.26
Open space	0.30

Source: Raco et al. (2022) and Pratama et al. (2024)

Annual soil loss (A, in tons/ha/year) was then computed using the USLE equation of Wischmeier and Smith (1978): $A = R \times K \times LS \times C \times P$, by overlaying all five factor layers in QGIS. The resulting erosion values were classified into five erosion hazard classes following Indonesian Ministry of Forestry Regulation No. 32/2009 (Table 3), and summarized by land-cover class and slope class using pivot tables in Microsoft Excel.

Table 3. Erosion Hazard Classification

Erosion Hazard Class	Erosion Rate (tons/ha/year)	Description
I	<15	Very low
II	15-60	Low
III	60-180	Moderate
IV	180-480	Heavy
V	>480	Very heavy

Source: Ministry of Forestry Regulation No. 32/2009

The amount of sediment actually delivered to the Sario River was then estimated in two stages. First, the Sediment Delivery Ratio (SDR) was calculated using the Auerswald (1992) equation, $SDR = -0.02 + 0.358A^{-0.02}$, where A is the sub-watershed area in hectares. Second, the resulting SDR was used to compute the total annual sediment yield (Y, in tons/year) using the Boyce method as applied by Purwadi et al. (2016): $Y = \bar{X} \times SDR \times A$, where $\bar{X}$ is the area-weighted average erosion rate (tons/ha/year), obtained by dividing total annual erosion by the total sub-watershed area.

Finally, thematic maps showing the spatial distribution of erosion hazard classes were produced in QGIS following standard cartographic conventions (title, legend, scale, north arrow, and coordinate system), and the results were analyzed descriptively with respect to the distribution of erosion by land cover and slope class, the interaction among USLE factors, and the implications of the estimated sedimentation for the condition of the Sario River and sub-watershed management from a forestry perspective.

RESULTS AND DISCUSSION

Rainfall Erosivity Factor (R)

The rainfall erosivity index (R) was calculated from ten years (2015-2024) of monthly rainfall data using the Lenvain method. Average monthly rainfall and the corresponding R values are presented in Table 4.

Table 4. Average Monthly Rainfall and Rainfall Erosivity Index (R) of the Sario Sub-Watershed, 2015-2024

Month	Rainfall (mm)	Rainfall (cm)	R
January	513.14	51.31	468.08
February	302.05	30.21	227.67
March	300.14	30.01	225.71
April	192.58	19.26	123.44
May	151.85	15.19	89.35
June	234.59	23.46	161.44
July	170.74	17.07	104.80
August	111.33	11.13	58.58
September	187.50	18.75	119.04
October	201.53	20.15	131.31
November	206.44	20.64	135.68
December	403.52	40.35	337.57
Total (∑R)			**2,182.68**

Source: secondary data processing

The highest monthly rainfall erosivity occurred in January (468.08) and the lowest in August (58.58), consistent with the annual rainfall pattern, in which rainfall is concentrated in January and December (wet season) and lowest in August (dry season). The resulting annual rainfall erosivity value for the Sario Sub-Watershed is 2,182.68, and this value is homogeneous across the entire sub-watershed since it is derived from data representing the whole study area. The high R values during the wet months indicate substantial kinetic energy of rainfall capable of detaching soil particles, potentially triggering erosion and higher surface runoff compared with drier months, consistent with Nazuhan et al. (2018), who noted that rainfall concentrated within short periods increases erosion risk relative to rainfall distributed evenly throughout the year.

Soil Erodibility Factor (K)

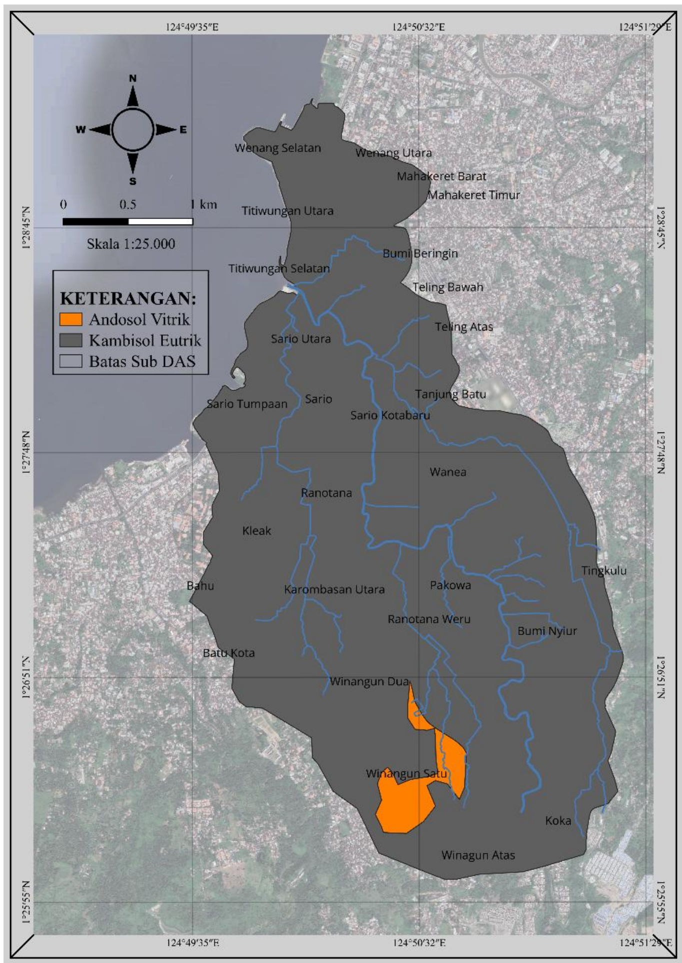

Figure 2. Soil Type Map of the Sario Sub-Watershed

The Sario Sub-Watershed is dominated by two soil types: Eutric Cambisol (K = 0.334) and Vitric Andosol (K = 0.28). Eutric Cambisol dominates most of the sub-watershed, particularly its northern, central, and eastern parts, while Vitric Andosol is found only in the southern part, in the Winangun Satu and Winangun Dua wards. Based on standard erodibility classification, the K value of Eutric Cambisol falls in the moderately high class, while that of Vitric Andosol falls in the moderate class. The higher K value of Eutric Cambisol indicates a greater susceptibility to erosion, consistent with Andriyani and Fadila (2024), who noted that higher K values correspond to greater potential soil loss. Given the dominance of Eutric Cambisol across most of the sub-watershed, the area is generally classified as having moderate to moderately high susceptibility to erosion. This soil-mediated variation in erodibility is consistent with findings from the Mount Masarang Protected Forest, North Sulawesi, where measured K values also differed markedly among land-cover types - lowest under grass/reed cover and highest on agricultural land with reduced organic matter and higher silt content - confirming that soil physical and chemical properties interact with land management to shape erosion susceptibility (Djufri et al., 2021).

Slope Length and Steepness Factor (LS)

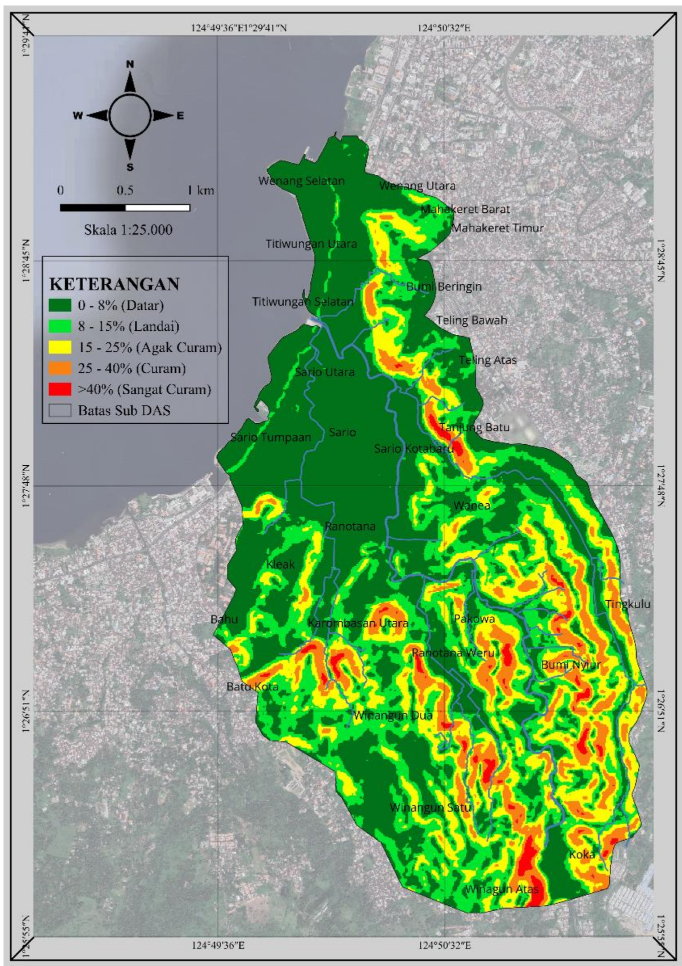

Figure 3. Slope Class Map of the Sario Sub-Watershed

The upstream and central parts of the sub-watershed (around Wenang Selatan, Sario, and Sario Kotabaru) are generally flat to gently sloping (0-15%), whereas the eastern and southern parts (Tanjung Batu, Bumi Nyiur, Winangun, and Koka) exhibit more varied topography with substantial areas of moderately steep to very steep terrain (15->40%). Steep and very steep classes tend to follow the pattern of tributary streams, indicating narrow valleys with sharp slopes along river courses. This is consistent with Kusumo and Nursari (2016), who noted that steep-slope areas have higher LS values and therefore greater erosion potential. This significant topographic variation is one of the main factors underlying the high spatial variation in erosion rates across the sub-watershed, as discussed further below.

Land Cover (C) and Conservation Practice (P) Factors

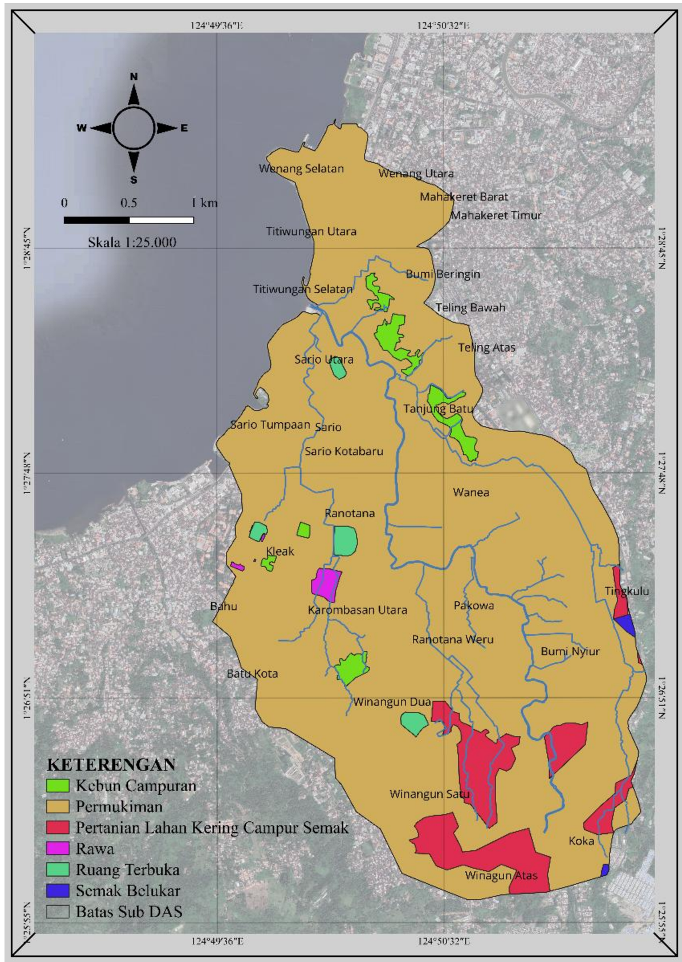

Figure 4. Land Cover Map of the Sario Sub-Watershed

Settlement is the most dominant land-cover class in the Sario Sub-Watershed, covering 1,097.03 ha or 90.88% of the total sub-watershed area, distributed fairly evenly from upstream to downstream, with a C value of 0.50. This high proportion of settlement land is a major concern, since built-up land has a low capacity to dissipate the impact energy of rainfall or retain surface runoff compared with natural vegetation, consistent with Harliando et al. (2023), who noted that dense vegetation cover corresponds to a low C value and plays a major role in suppressing erosion, whereas open or built-up land tends to have a high C value. The conservation-practice factor (P) was set equal to the C value for each land-cover class, since none of the land-use classes in the sub-watershed - including dense settlement areas - apply conservation practices such as terracing or contour planting, consistent with Harliando et al. (2023) and Moniaga and Takumansang (2016) regarding the dominance of built-up areas in urban catchments.

Erosion Rate (USLE Results)
Applying the USLE equation ($A = R \times K \times LS \times C \times P$) through overlay of all factor layers in QGIS shows that total annual erosion across the 1,207.10 ha Sario Sub-Watershed is 715,436.74 tons/year, with an area-weighted average erosion rate of 592.69 tons/ha/year. This value falls within Erosion Hazard Class V (very severe) under Indonesian Ministry of Forestry Regulation No. 32/2009 (>480 tons/ha/year).

Erosion by Land Use and Slope Combination
Erosion rate per unit area (tons/ha/year) increased consistently with slope steepness across nearly all land-cover classes, in line with the increase in LS value from 0.4 on flat terrain (0-8%) to 9.5 on very steep terrain (>40%). For example, in settlement areas on Eutric Cambisol soil, the erosion rate increased more than 23-fold, from 145.80 tons/ha/year on flat slopes to 3,462.82 tons/ha/year on very steep slopes. A similar pattern was found in mixed gardens (58.32 to 1,385.13 tons/ha/year) and dryland agriculture mixed with shrubs (68.45 to 1,939.18 tons/ha/year), confirming the dominant role of the LS factor in determining erosion intensity at the land-unit scale.

The combination of settlement on flat slopes (0-8%) with Eutric Cambisol soil had the largest area among all combinations (503.16 ha) and a moderate per-hectare erosion rate (Class III, 145.80 tons/ha/year), yet because of its dominant area it still contributed 73,361.89 tons/year, or about 10.26% of total sub-watershed erosion. In contrast, the largest single contribution to total annual erosion came from settlement on moderately steep slopes (15-25%) with Eutric Cambisol soil, amounting to 204,508.68 tons/year (28.59% of total erosion), despite covering a much smaller area (180.99 ha), owing to its very high per-hectare erosion rate (1,129.97 tons/ha/year, Class V). Conversely, combinations with very high per-hectare erosion but very small area, such as shrubland on slopes >40% (1,800.67 tons/ha/year over only 0.01 ha), contributed just 20.19 tons/year to total erosion. These findings indicate that both the per-hectare erosion rate and the affected area must be considered together when prioritizing erosion control, since areas with dominant coverage - such as settlement on gentle to moderately steep slopes - contribute the greatest absolute sediment load reaching the Sario River, even where their per-hectare erosion rate is not extreme.

When averaged by land-cover class across all slope variations, shrubland showed the highest mean erosion rate (910.02 tons/ha/year), followed by dryland agriculture mixed with shrubs (722.99 tons/ha/year) and mixed gardens (599.40 tons/ha/year). Nonetheless, the absolute contribution to total sub-watershed erosion remained dominated by settlement given its much larger area (1,097.03 ha). Swamp recorded the lowest mean erosion rate (5.28 tons/ha/year), reflecting the effectiveness of swamp vegetation cover in dissipating the erosive energy of rainfall, consistent with its very low C value (0.01).

Distribution by Erosion Hazard Class
The calculated erosion rates were classified into five erosion hazard classes following Ministry of Forestry Regulation No. 32/2009, with the resulting area distribution shown in Table 5.

Table 5. Distribution of Erosion Hazard Class Area in the Sario Sub-Watershed

Class	Erosion Rate (tons/ha/year)	Description	Area (ha)	%
I	<15	Very low	47.03	3.90
II	>15-60	Low	1.41	0.12
III	>60-180	Moderate	524.47	43.45
IV	>180-480	Heavy	37.22	3.08
V	>480	Very heavy	596.96	49.45
Total			**1,207.10**	**100**

Source: secondary data processing

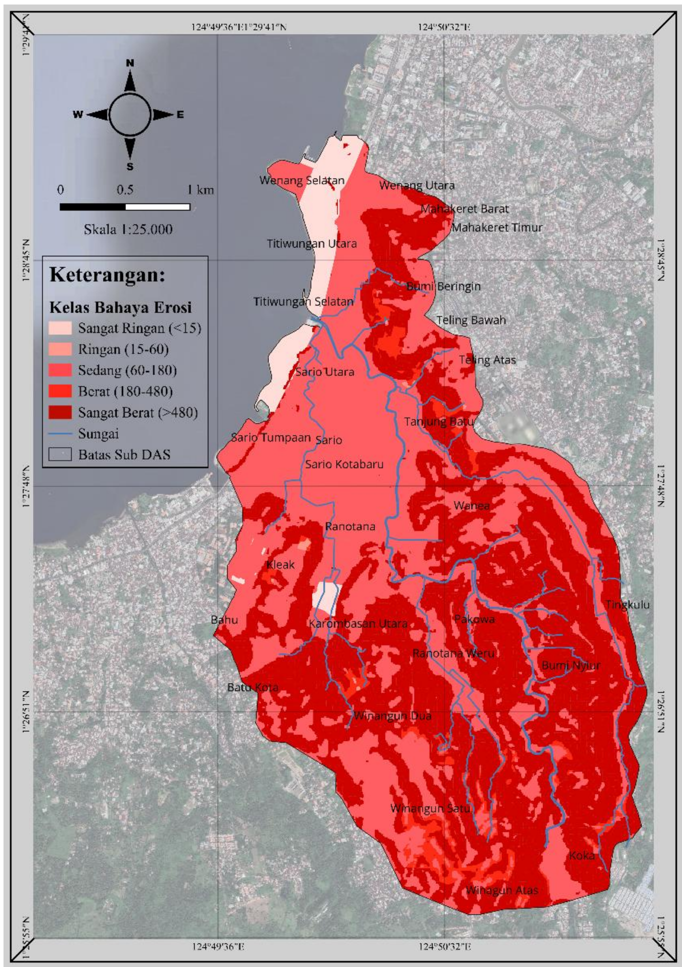

Figure 5. Erosion Hazard Class Map of the Sario Sub-Watershed

Class V (very heavy) dominates the sub-watershed with an area of 596.96 ha (49.45%), followed by Class III (moderate) covering 524.47 ha (43.45%), while Classes I, II, and IV together cover only a small portion of the area (3.90%, 0.12%, and 3.08%, respectively). Areas classified as very heavy are concentrated in the upstream to central parts of the sub-watershed, where topography is steep, including the wards of Tingkulu, Bumi Nyiur, Winangun, Pakowa, and Koka, whereas very low and low classes are limited to relatively flat coastal areas such as Wenang Selatan and Titiwungan. The dominance of the very heavy class indicates that erosion conditions in the Sario Sub-Watershed are already at a level of serious concern, far higher than the 53.89 tons/ha/year average erosion reported by Turangan et al. (2019) for the entire Sario

Watershed. This difference suggests that the specific biophysical characteristics of the sub-watershed - particularly its steep slopes combined with dominant built-up land use - produce erosion levels far higher than the average obtained at the broader watershed scale. A comparable contrast can be seen with the Marawas Micro-Watershed within the Tondano Watershed Management Unit, where Kumendong et al. (2013) reported a much lower average erosion rate of 49.45 tons/ha/year, dominated by very light to moderate hazard classes under mostly forested and mixed-garden cover with minimal settlement, further underscoring how the extensive built-up land use in the Sario Sub-Watershed drives its markedly higher erosion severity.

Distribution by Land Use

Table 6 presents the recapitulation of erosion hazard class area by land-use class.

Table 6. Recapitulation of Erosion Hazard Class Area by Land Use

No	Land Use	I	II	III	IV	V	Total (ha)
1	Mixed garden	-	1.23	-	12.46	7.45	21.14
2	Settlement	42.55	-	506.77	4.54	543.16	1,097.03
3	Dryland agri./shrubs	-	-	9.91	19.17	44.29	73.37
4	Swamp	4.48	0.18	-	-	-	4.66
5	Open space	-	-	7.79	0.83	0.50	9.11
6	Shrubland	-	-	0.003	0.23	1.57	1.80
	Grand Total						**1,207.10**

Source: secondary data processing

Table 6 shows that settlement is not only the most extensive land-cover class but also the largest contributor to Erosion Hazard Class V (very heavy), covering 543.16 ha. This occurs in settlement areas on steep to very steep slopes, where the combination of high LS values and the settlement C value (0.50) produces very high erosion rates despite the built-up surface conceptually being impervious. This is consistent with Ridwan and Sarjito (2024), who found that land conversion to settlement increases surface runoff and erosion, especially where drainage systems and conservation measures are inadequate. In contrast, swamp shows the lowest erosion rates, with its entire area (4.66 ha) falling in Class I (very low) and Class II (low), consistent with its very low C value (0.01), indicating that swamp vegetation effectively dissipates the erosive energy of rainfall. In mixed gardens and dryland agriculture mixed with shrubs, the largest erosion occurs on steep to very steep slopes (dominated by Classes IV and V respectively), confirming that on non-built-up land, slope (LS) is the primary determinant of high erosion rates, consistent with the findings of Sitepu et al. (2017) that steeper and longer slopes produce greater erosion. Overall, these results confirm that the high erosion rate in the Sario Sub-Watershed results from a complex interaction of high rainfall erosivity, erosion-susceptible soil (particularly Eutric Cambisol), steep topography in the upstream-central area, and dominant built-up land use with minimal soil-conservation practice. A similar pattern was found in the Kuala Saluhwua Sub-Watershed, Minahasa Regency, where settlement, shrubland, and agriculture on steep slopes produced heavy to very heavy erosion, while secondary dryland forest produced only very low to low erosion (Bulawan, 2025), confirming that dense vegetation cover consistently suppresses erosion across different sub-watersheds in North Sulawesi.

The high erosion rate in the downstream Sario Sub-Watershed is closely related to the recurring siltation and flooding of the Sario River reported by Suadnya et al. (2017), who found that overflow has already occurred at a 10-year return period in the Citraland area. Eroded material from land in the Heavy to Very Heavy hazard classes - particularly dense settlement and steep-sloped agricultural and garden land - is likely to be carried by surface runoff into the river and deposited downstream, reducing the channel's conveyance capacity. It should be noted that this study covers only the downstream part of the Sario Sub-Watershed, so the results represent the sediment contribution from the study area alone; the actual condition of the Sario River is also influenced by erosion and sediment originating from upstream areas outside the scope of this study, meaning the total sediment load reaching the river mouth is likely higher than the estimate presented here.

Sediment Yield (SDR and Boyce Method)

The Sediment Delivery Ratio (SDR) was calculated using the Auerswald (1992) approach based on the total sub-watershed area of 1,207.10 ha: $SDR = -0.02 + 0.358(1{,}207.10)^{-0.02} = 0.291$. This value indicates that on average, about 29.1% of total erosion in the sub-watershed is estimated to actually reach and settle as sediment in the Sario River, while the remaining 70.9% is retained or deposited along slopes, depressions, or flat areas before reaching the river. This relatively low SDR is expected, since larger watershed areas correspond to longer sediment transport distances and travel times, increasing the likelihood of intermediate deposition, consistent with Moha et al. (2020), who noted that the amount of sediment reaching a river is influenced by topography, land cover, and sediment transport distance.

Sediment yield was then calculated using the Boyce method as applied by Purwadi et al. (2016), by multiplying the area-weighted average erosion rate ($\bar{X}$), the SDR value, and the total sub-watershed area: $Y = \bar{X} \times SDR \times A = 592.69 \times 0.291 \times 1{,}207.10 = 208{,}191.90$ tons/year. This value represents the estimated annual sediment load potentially accumulating in the Sario River channel, either as bed siltation or as a reduction in channel conveyance capacity, ultimately contributing to recurring flood events as reported by Suadnya et al. (2017) concerning overflow of the Sario River in the Citraland area. Since this result represents only the contribution from the downstream sub-watershed, the actual sediment load received by the Sario River as a whole is likely greater, given additional sediment inputs from upstream areas of the Sario Watershed outside the scope of this study.

Implications for Forestry-Based Watershed Management

The findings show that the Sario Sub-Watershed experiences an average erosion rate of 592.69 tons/ha/year (Erosion Hazard Class V - very severe), with an estimated 208,191.90 tons/year of sediment reaching the Sario River. Both figures reflect a single degradation process - soil loss on critical land (erosion) that largely ends up as sediment load in the river channel (sedimentation) - linked through an SDR of 0.291. These high values are consistent with the dominance of low-conservation-value settlement land (CP = 0.50) and steep topography in the upstream-central sub-watershed. This is consistent with Manga (2025), whose study on the Kembes River in Minahasa Regency found that forest-covered areas consistently maintain better hydrological conditions than plantation and settlement areas, confirming that minimal vegetation cover on built-up land increases surface runoff and worsens downstream river conditions.

The limited protective vegetation cover in the Sario Sub-Watershed is consistent with the broader condition of urban green open space (RTH) in Manado City, which remains far below the minimum standard. According to Pangemanan et al. (2017) and Seroan et al. (2025), green open space in Manado City covers only about 14.51% of the total urban area, whereas Indonesian Law No. 26/2007 on Spatial Planning requires a minimum of 30% green open space (20% public and 10% private) for every urban area. More specifically, the Sario and Wenang districts, which overlap directly with the study area, have only about 7% green open space, making them among the most critical areas in the city in this respect. This is consistent with the present finding that open space covers only 9.11 ha, or about 0.75% of the total sub-watershed area (Table 6), far below the vegetation proportion needed to effectively suppress surface runoff and erosion. The high erosion and sedimentation found in this study are therefore not merely a hydrological issue, but also reflect a long-standing deficit in urban green space planning in Manado City. Beyond its hydrological role, urban forest cover of this kind also carries direct social value, as shown by Bato et al. (2024) in nearby Tomohon City, where the local community rated the urban forest highly for recreation and environmental functions, indicating that expanding tree cover in the Sario Sub-Watershed could simultaneously reduce erosion risk and provide a much-needed public green space for residents.

As part of watershed management, the forestry sector has a central role in addressing both processes, since the root causes identified in this study - low conservation value of built-up land and minimal protective vegetation cover - fall directly within the scope of silviculture and soil-and-water conservation interventions. This is consistent with the national policy framework, namely Ministry of Environment and Forestry Regulation No. 23/2021 on the Implementation of Forest and Land Rehabilitation, which mandates rehabilitation through reforestation (either intensive or agroforestry-based) and the application of soil-conservation techniques, as well as Ministry of Environment and Forestry Regulation No. 10/2022 on Watershed-Based Forest and Land Rehabilitation, which affirms that such rehabilitation aims to restore watershed hydrological function and improve land carrying capacity and productivity.

Several prior forestry studies support the relevance of vegetative approaches to the problems identified in the Sario Sub-Watershed. Naharuddin (2017) showed that vegetation composition and structure, particularly canopy stratification, play a major role as a hydrological and erosion parameter by reducing rainfall interception and surface runoff. Harliando et al. (2023), through RUSLE-based spatial modeling of vegetation cover, demonstrated that increased vegetation cover measurably reduces erosion at the watershed scale. Sumanto et al. (2023), studying erosion and sedimentation in the Lesti Sub-Watershed, recommended using erosion-sedimentation analysis as a basis for land-conservation planning, an approach consistent with the objective of the present study. These findings reinforce that forestry-based intervention is not merely a supplementary option but a core component in reducing erosion and sedimentation in the Sario Sub-Watershed.

Given the specific condition of the Sario Sub-Watershed as a densely populated urban catchment, several relevant forestry-based conservation measures include: (1) environmental greening and vegetation rehabilitation on critical land, directing tree planting under Ministry of Environment and Forestry Regulation No. 23/2021 toward Heavy-Very Heavy erosion hazard areas that remain open or vacant, particularly on steep to very steep slopes in Tingkulu, Bumi Nyiur, and Winangun; (2) development of urban green corridors and green open space, given the dominance of settlement (90.88% of the sub-watershed area) and the low green open space coverage (about 7%) in Sario and Wenang districts, as recommended by Moniaga and Takumansang (2016) for green infrastructure development in Manado City; such interventions align with the broader principle that conservation-oriented landscape planning - integrating ecological corridors, buffer zones, and spatial prioritization tools rather than isolated plantings - offers a more effective framework for reconciling ecological function with the realities of dense urban development (Saroinsong et al., 2026); (3) establishment of riparian buffer strips along the Sario River, where dense vegetation along the riverbank can act as a filtering zone that slows runoff and traps sediment before it reaches the channel, thereby directly reducing the actual field SDR; and (4) implementation of agroforestry-based reforestation on community cultivation land, particularly in mixed gardens and dryland agriculture mixed with shrubs showing high erosion on steep slopes, combining conservation function with economic benefits for landowners under Ministry of Environment and Forestry Regulation No. 23/2021.

The erosion and sedimentation results of this study therefore serve not only as quantitative environmental data for the Sario Sub-Watershed, but also as a scientific basis for prioritizing Watershed-Based Forest and Land Rehabilitation (RHL-DAS) activities consistent with the national forestry policy framework, contributing to the forestry discipline's role in supporting sustainable urban watershed management in Manado City.

CONCLUSION

The erosion rate in the Sario Sub-Watershed, estimated using the USLE method with a GIS approach, totals 715,436.74 tons/year with an area-weighted average of 592.69 tons/ha/year, classified as Erosion Hazard Class V (very severe) under Indonesian Ministry of Forestry Regulation No. 32/2009. The very severe class dominates the study area, covering 596.96 ha (49.45%), mainly on steep, settled terrain with Eutric Cambisol soil. The estimated sediment reaching the Sario River is 208,191.90 tons/year, derived from an SDR of 0.291 using the Auerswald (1992) and Boyce approaches. This substantial sediment load contributes to recurring siltation and flooding in the area, indicating a need for sub-watershed management through Forest and Land Rehabilitation (RHL-DAS), development of urban green open space, riparian vegetation buffer strips, and agroforestry on community cultivation land.

REFERENCES

Andriyani, I., & Fadila, Y. Z. (2024). The influence of soil characteristic changes on erosion rates based on the Universal Soil Loss Equation (USLE) method. Jurnal Teknik Pertanian Lampung, 13(1), 278-287. https://doi.org/10.23960/jtep-l.v13i1.278-287

Auerswald, K. (1992). Predicted and measured sediment loads of large watersheds in Bavaria. In Erosion, Debris Flows and Environment in Mountain Regions (Proceedings of the Chengdu Symposium), IAHS Publication No. 209.

Bato, A. N., Saroinsong, F. B., & Pangemanan, E. F. S. (2024). Pemanfaatan Hutan Kota Tomohon oleh Masyarakat Tomohon Tengah. Silvarum, 3(1), 26-30. https://doi.org/10.35791/sil.v3i1.49047

Bulawan, J. R. (2025). Analisis erosi dan sedimentasi pada Sub DAS Kuala Saluhwua, Kabupaten Minahasa, Sulawesi Utara [Undergraduate thesis]. Sam Ratulangi University.

Djufri, A. N. H., Rombang, J. A., & Tasirin, J. S. (2021). Erodibilitas tanah pada kawasan Hutan Lindung Gunung Masarang. Cocos. https://doi.org/10.35791/cocos.v4i4.34506

Gusma, F., Azmeri, A., Jemi, F. Z., & Rahmatan, H. (2023). Soil erosion rate and hazard level at the Sianjo-anjo Reservoir watershed in Indonesia. Journal of Water and Land Development, 57(4), 181-187. https://doi.org/10.24425/jwld.2023.145348

Haikal, A., Musa, R., & Sar, M. (2023). Model sedimentasi dengan menggunakan aplikasi Hec-Ras (studi kasus: Sungai Pappa Kab. Takalar). Innovative: Journal of Social Science Research, 3(3), 8004-8013.

Harliando, D. P., Setyawan, C., & Mawandha, H. G. (2023). Spatial modeling of vegetation cover for soil erosion control based on ArcGIS and the RUSLE model. Jurnal Teknik Pertanian Lampung, 12(1), 14-27. https://doi.org/10.23960/jtep-l.v12i1.14-27

Manga, G. D. (2025). Kajian tutupan lahan terhadap kualitas air di Sungai Kembes, Kabupaten Minahasa, Sulawesi Utara [Undergraduate thesis]. Sam Ratulangi University.

Kementerian Kehutanan. (2009). Peraturan Menteri Kehutanan Republik Indonesia No. P.32/Menhut-II/2009 tentang Tata Cara Penyusunan Rencana Teknik Rehabilitasi Hutan dan Lahan Daerah Aliran Sungai (RTkRHL-DAS).

Kementerian Lingkungan Hidup dan Kehutanan. (2021). Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor 23 Tahun 2021 tentang Pelaksanaan Rehabilitasi Hutan dan Lahan.

Kementerian Lingkungan Hidup dan Kehutanan. (2022). Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor 10 Tahun 2022 tentang Penyusunan Rencana Umum Rehabilitasi Hutan dan Lahan Daerah Aliran Sungai dan Rencana Tahunan Rehabilitasi Hutan dan Lahan.

Kumendong, N. R., Walangitan, H. D., Tasirin, J. S., & Thomas, A. (2015). Analisa tingkat bahaya erosi dalam rangka perencanaan rehabilitasi dan konservasi tanah areal Model Mikro DAS (MDM) Marawas SWP DAS Tondano. Cocos. https://doi.org/10.35791/cocos.v6i13.8648

Kusumo, P., & Nursari, E. (2016). Zonasi tingkat kerawanan banjir dengan sistem informasi geografis pada DAS Cidurian Kab. Serang, Banten. Jurnal String, 1(1), 29-38.

Moha, S., Taslim, I., & Jaya, R. (2020). Pendugaan laju sedimentasi dengan menggunakan model USLE di Sub DAS. Jurnal Sains Informasi Geografi, 3(1), 53-64. https://doi.org/10.31314/jsig.v3i1.559

Moniaga, I. L., & Takumansang, E. D. (2016). Pengembangan RTH kota berbasis infrastruktur hijau dan tata ruang studi kasus: Kota Manado. Jurnal Lingkungan Binaan Indonesia, 5(4), 210-214.

Naharuddin. (2017). Komposisi dan struktur vegetasi dalam potensinya sebagai parameter hidrologi dan erosi. Jurnal Hutan Tropis, 5(2), 134-142.

Nazuhan, M., Rahaman, Z. A., & Othman, Z. (2018). A review on rainfall erosivity (R factor) in Universal Soil Loss Equation. International Journal of Academic Research in Business and Social Sciences, 8(2), 801-806. https://doi.org/10.6007/ijarbss/v8-i2/3988.

Nurrohman, A., & Adlin, A. (2018). Pemetaan kondisi tutupan lahan di Sub Daerah Aliran Sungai (DAS) sebagai tolok ukur perencanaan tata ruang wilayah. Prosiding Seminar Nasional Geomatika 2018, 1(1), 269-279.

Pamungkas, D.. 2020. Pemetaan Tingkat Bahaya Erosi Dengan Metode RUSLE di Sub DAS Garang Hulu [Undergraduate thesis], Universitas Negeri Semarang.
Pangemanan, R. R. R., Laoh, O. E. H., & Katiandagho, T. M. (2017). Analisis ruang terbuka hijau (RTH) Kota Manado. Agri-Sosioekonomi Unsrat, 13(3), 57-76.
Pratama, R. A., Sulistyo, B., Riwandi, & Listyowati, E. A. (2024). Analisis faktor C menggunakan indeks vegetasi citra Landsat OLI sebagai masukan analisis tingkat bahaya erosi di Sub DAS Air Bengkulu. Prosiding Seminar Nasional Pertanian Pesisir, 3(1), 334-346.
Puno, G. R., Marin, R. A., Puno, R. C. C., & Toledo-Bruno, A. G. (2021). Geographic information system and process-based modeling of soil erosion and sediment yield in agricultural watershed. Global Journal of Environmental Science and Management, 7(1), 1-14. https://doi.org/10.22034/gjesm.2021.01.01
Purwadi, D. (2016). Analisis sedimentasi menggunakan metode Boyce. [As cited in Bulawan (2025)].
Raco, B., Wicaksono, A., & Triweko, R. W. (2022). Tingkat bahaya erosi akibat perubahan tutupan lahan pada daerah tangkapan air Danau Tondano. Jurnal Teknik Sipil, 11(1), 63-76.
Ragentu, D. W., Rombang, J. A., & Sumakud, M. Y. M. A. (2025). Identifikasi medan banjir di Bentang Alam Binerean, Kabupaten Bolaang Mongondow Selatan, Provinsi Sulawesi Utara. Silvarum, 4(1), 26-31. https://doi.org/10.35791/sil.v4i1.58055
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
Salma, C. N., Sukmono, A., & Firdaus, H. S. (2024). Analisis laju erosi di Sub DAS Serayu Hulu pada tahun 2022 menggunakan sistem informasi geografis. JGISE: Journal of Geospatial Information Science and Engineering, 7(1), 53-61.
Saroinsong, F. B., Cumentas, J. M., Pangemanan, E. F. S., & Sumakud, M. Y. M. A. (2026). Concepts of landscape planning and design for the conservation of target species and target ecosystems in biodiversity management for sustainable tourism. Asia Pacific Journal of Interdisciplinary Studies, 2(1), 1-7. https://doi.org/10.57207/asnvet90
Seroan, F. R., Pondaag, H., & Baftim, F. (2025). Tinjauan hukum Peraturan Menteri Agraria dan Tata Ruang/Badan Pertanahan Nasional Nomor 14 Tahun 2022 tentang penyikapan dan penerapan ruang terbuka hijau (RTH) di Perumahan Citraland Manado. Jurnal Fakultas Hukum Unsrat, 16(1), 1-14.
Seto, K. C., & Pandey, B. (2019). Urban land use: Central to building a sustainable future. One Earth, 1(2), 168-170. https://doi.org/10.1016/j.oneear.2019.10.002
Sitepu, F., Selintung, M., & Harianto, T. (2017). Pengaruh intensitas curah hujan dan kemiringan lereng terhadap erosi yang berpotensi longsor. Jurnal Penelitian Enjiniring, 21(1), 23-27. https://doi.org/10.25042/jpe.052017.03
Suadnya, D. P., Sumarauw, J. S. F., & Mananoma, T. (2017). Analisis debit banjir dan tinggi muka air banjir Sungai Sario di titik kawasan Citraland. Jurnal Sipil Statik, 5(3), 143-150.
Sudiartono, U., Razak, A., Kamal, E., & Berd, I. (2022). Review: Impact of the spatial development patterns on water ecology of Cisadane Watershed. Science and Environmental Journals for Postgraduate, 5(1), 8-16.

Sumanto, H., Darmawan, V., & Asmaranto, R. (2023). Erosion and sedimentation analysis as basic reference for land conservation planning on Lesti sub-watershed. Civil and Environmental Science Journal, 6(1), 1-10. http://doi.org/10.21776/ub.civense.2023.00601.1

Supatno, A., & Asih, A. S. (2016). Analisis karakteristik hidrologi Sungai Gajahwong Daerah Istimewa Yogyakarta. Jurnal Angkasa, 7(1), 17-31.

Turangan, P. Y. C., Mawara, J. M., & Kamagi, Y. E. B. (2019). Kajian erosi di Daerah Aliran Sungai Sario Sulawesi Utara. Cocos, 1(4), 1-12.

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