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ANALYZING THE IMPACT OF LANDUSE ON EROSION RATES ON THE CAPACITY OF SABO DAMS

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Abstract
Landuse changes in the Bangga Watershed, Sigi Regency, Central Sulawesi, have become the main factor increasing erosion and sedimentation threatening the capacity of Sabo Dam. This study aims to analyze the effect of landuse change on erosion and sedimentation rates and evaluate the Sabo Dam's capacity to reduce sediment. The method used is a quantitative approach using the Universal Soil Loss Equation (USLE) model to calculate erosion rates and the USDA Sediment Delivery Ratio (SDR) method to estimate sediment transport. Analyzes were conducted on landuse data for the 2013–2025 period, rainfall, soil types, and slope gradients using Geographic Information Systems (GIS). The results show that the conversion of 912.99 Ha of secondary forest into shifting cultivation areas exponentially increases erosion, especially on steep slopes (>45%) with erosion values reaching 4,224 Ton/Ha/Year. The highest erosion occurred in 2019 after the flash flood, reaching 106,532.60 Ton/Ha/Year. The Sabo Dam with a capacity of 8,500,000 m^3 is still able to accommodate the highest total sediment (8,176,943.79 m^3) with a remaining capacity of 323,056.21 m^3. Operation and maintenance of the Sabo Dam must be carried out annually to ensure optimal sediment control function. Policy recommendations include restricting secondary forest conversion on steep slopes and critical land rehabilitation programs covering 379.79 Ha.

Keywords: Erosion, sedimentation, land cover, Sabo Dam, Bangga Watershed

1. Introduction

Sediment, a byproduct of soil erosion, poses a persistent challenge to river systems worldwide. The erosion and sedimentation process is governed by a complex interplay of hydrological factors, including rainfall intensity and duration, landuse type, soil erodibility, and topographic characteristics (Arsyad, 2010). Erosion commences with the detachment of soil particles by raindrop impact and surface runoff, followed by their transportation downslope and eventual deposition. The rate of these processes is significantly influenced by anthropogenic activities, particularly land use change.

The upper reaches of the Bangga River in Central Sulawesi were historically forested areas. However, increasing population pressures and shifting economic needs have driven a progressive conversion of these lands into agricultural fields, settlements, and industrial plantations. This transformation has profoundly altered the watershed's hydrological response, leading to increased surface runoff, higher peak discharges, and exacerbated erosion rates (Asdak, 2014). The resulting

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sediment accumulation has caused channel widening, aggradation, and changes in the river's course, impacting downstream communities and infrastructure.

The situation was critically compounded by a 7.8 Mw earthquake in 2018, which triggered numerous landslides in the upstream mountainous regions. Subsequently, in 2019, prolonged and intense rainfall culminated in a catastrophic flash flood. The flood, reaching heights of up to 1 meter and carrying significant amounts of sediment and woody debris, devastated three villages, destroying homes and agricultural lands, and causing substantial social and economic hardship (BWS Sulawesi III, 2020).

In response to these recurring events, the Indonesian government, through the Ministry of Public Works and Housing (PUPR), constructed a new, larger-capacity Sabo Dam in 2020. This structure was designed to supersede existing, less effective sediment control works (check dams, consolidation dams) and mitigate the sediment transport problem. The primary functions of a Sabo Dam are to reduce riverbed gradients, control sediment flow, stabilize stream banks, and protect downstream areas from debris flows (Sulistiyono & Pratikso, 2019).

This research seeks to provide a comprehensive quantitative analysis of the effectiveness of this new Sabo Dam. The specific objectives are to: (1) quantify the potential erosion and sediment yield resulting from landuse changes in the upper Bangga watershed; (2) evaluate the Sabo Dam's capacity to reduce the sediment load generated by these land use changes; and (3) determine the necessary operational and maintenance strategies required to ensure the dam's long-term functionality. The findings of this study are intended to inform sustainable watershed management policies and practices, not only for the Bangga watershed but also for other regions facing similar challenges globally.

2. Literature Review

2.1. Watershed

A watershed is an area bounded by mountain ridges where rainwater falling in that area is collected and drained through small rivers to the main river (Asdak, 2014). Law No. 17 of 2019 defines a watershed as a land area that is a unified unit with the river and its tributaries, functioning to collect, store, and drain water originating from rainfall to lakes or to the sea naturally.

A watershed consists of three parts: the upstream, the middle, and the downstream. Biogeophysically, the upstream part of the watershed is a conservation area with higher drainage density and has large slope gradients (>15%), is not a flood area, water usage regulation is determined by the drainage pattern, and the vegetation type is generally forest stands (Asdak, 2014). Watershed damage in Indonesia is increasing every year, causing very detrimental excesses. Every year, there are floods, landslides, droughts, and other disasters. One of the causes of watershed damage is the planning of land use forms and management practices that are not appropriate (Nugroho, 2011).

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2.2. Metode USLE (Universal Soil Loss Equation)

The potential erosion estimation model can be seen from the magnitude of erosion expressed in the amount of soil lost in tons per hectare per year (Ton/Ha/Year) which can be calculated using the USLE formula (Wischemeier & Smith, 1978 in Suripin, 2007):

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

Where: E = Amount of soil lost (Ton/Ha/Year), R = Rainfall erosivity index, K = Soil erodibility index, LS = Slope length and gradient index, C= Crop management index, P = Soil conservation practice index

Table 1. Soil Erosion Classification

Class	**Erosion Magnitude (Ton/Ha/Year)**	**Description**
1	< 15	Very Low
2	15 – 60	Low
3	60 – 180	Moderate
4	180 – 480	High
5	> 480	Very High

The advantage of the USLE method is that it is an erosion estimation method that is easy to manage, relatively simple, feasible to use in tropical regions, and has a relatively small number of parameters compared to other methods with more complex parameter.

2.3. Sediment Delivery Ratio (SDR)

Geographic Information System is a computer-based system or technology built with the aim of collecting, storing, processing and analysing, as well as presenting data and information about an object or phenomenon related to its location or existence on the earth's surface (Setianingrum, 2014). Sediment material eroded from the watershed land reaches the watershed outlet, or the nearest river/channel. The ratio between the sediment measured at the outlet and the erosion on the land is called the Sediment Delivery Ratio (SDR). The SDR value can be calculated using the Boyce formula (1975) in Susilowati et al. (2014):

$$SDR = 0{,}41 \times A\_Dwatershed^{-0{,}3} \quad (2)$$

Where: SDR = Sediment Delivery Ratio, A_Dwatershed = Watershed Area (Ha)

The amount of sediment yield per watershed unit per unit time can be formulated as:

$$SY = SDR \times E \quad (3)$$

Where: SY = Sediment yield (Ton/Ha/Year), SDR = Sediment Delivery Ratio, E = Land erosion (Ton/Ha/Year)

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2.4. Sabo Dam

Sabo is an engineering term originating from Japanese, namely *Sa* (sand) and *bo* (control), so Sabo means sand control. Broadly, Sabo means erosion and sediment control works. Sabo structures are structures for mitigating sand and gravel which essentially are efforts to prevent mountain land from damage due to erosion, protect downstream populations and infrastructure from disasters due to erosion and sedimentation.

The functions of a Sabo Dam include:

1. Flattening the riverbed slope, thereby reducing flow velocity and preventing vertical erosion.
2. Regulating flow direction to prevent lateral erosion.
3. Stabilizing foothills to prevent slope landslides.
4. Retaining and controlling sediment that will flow downstream.

3. Research Method

3.1. Location and Time of Research

Administratively, the Bangga Watershed is located in the administrative area of Dolo Selatan District, Sigi Regency, Central Sulawesi Province. The Bangga Watershed is part of the Palu River sub-basin. Based on the initial survey conducted, there are several sediment control structures already in the Bangga River, namely 3 Sabo Dams, 1 Dam Bridge, 2 Consolidation Dams with a storage capacity of 3,100,000 m^3.

Figure 1. Location of Sediment Control Structures
(Source: BWS III Palu)

3.2. Data Processing Techniques

Data processing used the USLE (Universal Soil Loss Equation) method to calculate erosion rates and the USDA SDR method for sediment yield. Analysis was performed using Geographic Information Systems (GIS) with ArcGIS 10,8 software.

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4. Results and Discussion

4.1. Factors Affecting the Erosion Process in the Bangga Watershed

4.1.1. Rainfall Erosivity Index (R)

Based on calculations using the Lenvain formula ($R = 2,21 \times P^{1,36}$), the annual rainfall erosivity values are as follows:

Table 2. Rainfall Erosivity Index (R) from 2013 to 2025

Year	Annual Rainfall (P) cm	Annual R
2013	183,439	2,646.92
2014	167,644	2,341.85
2015	120,122	1,488.26
2016	192,869	2,833.67
2017	190,922	2,794.84
2018	142,638	1,879.98
2019	273,719	4,561.70
2020	150,065	2,014.34
2021	203,262	3,043.33
2022	209,225	3,165.39
2023	136,108	1,763.90
2024	228,306	3,564.31
2025	161,467	2,225.29

Source: Rainfall data processing results (2025)

Figure 2. Image of Sediment Control Structures in the Bangga River
Source: BWS III Palu

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An overview of the water flow patterns in the Bangga Watershed can be seen in Figure 3 below.

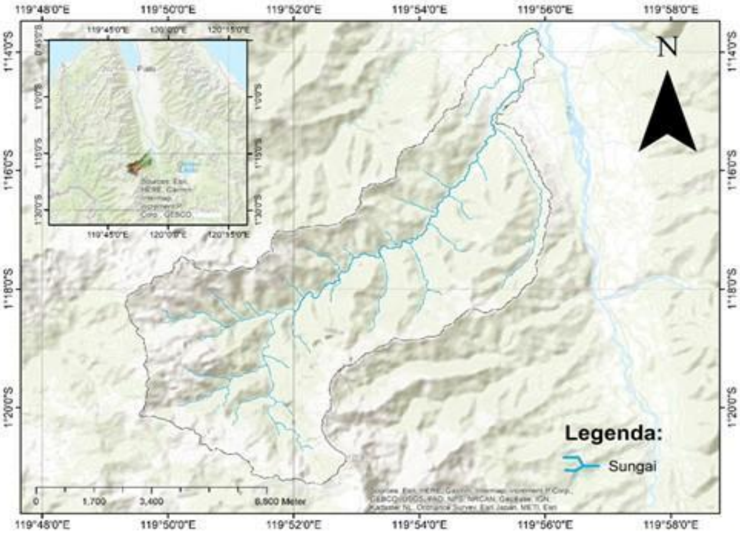

Figure 3. Water Flow Patterns in the Bangga Watershed
Source: Spatial data analysis (2025)

Based on the available maps, the river flow patterns in the Bangga watershed tend to form dendritic or elongated patterns, depending on the local lithological and morphological structures. In general, dendritic patterns indicate that the area consists of relatively homogeneous rock and has varying slope gradients that are not strongly controlled by geological structures such as faults or folds.

4.1.2. Soil Erodibility Index (K)

The Bangga River Basin has five soil types: alluvial, podzolic, gleisol, cambisol, and lithosol. The Soil Erosion Vulnerability Index (K) values are shown in the table below:

Table 3. Soil Erosion Vulnerability Index (K) Values in the Bangga River Basin

No	Soil Type	K Value	Area (Ha)	No
1	Kambisol	0.32	2,509.07	34
2	Gleisol	0.23	44.54	1
3	Litosol	0.26	18.28	0
4	Alluvial	0.47	142.21	2
5	Podsolik	0.32	4,577.66	63
Total (Ha)			**7,291.76**	**100**

Source: Soil data processing results (2025)

4.1.3 Slope Length and Gradient Index (LS)

The Bangga Watershed area covers 7,291,76 Ha with very varied relief, from low elevation around 94,994 masl to the highest 1,801,44 masl, The presence of contour lines with a wide elevation range indicates that the Bangga Watershed has a topography dominated by hills to steep mountains in the upstream part, while in the downstream part it tends to be flatter, Using GIS tools, the average values for the length and slope (LS) factors in the watershed were obtained, as shown in the following table:

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Table 4. Slope Length and Gradient Index (LS) Values in the Bangga Watershed

No,	Slope	LS Value	Area (Ha)
1	0-8%	0.4	161.78
2	8-15%	1.4	248.31
3	15-25%	3.1	433.65
4	25-45%	6.8	1,410.59
5	>45%	9.5	5,037.42
Total (Ha)			**7,291.76**

Source: Spatial data processing results (2025)

The Bangga Watershed features a wide range of slope gradient classes, with the slope length and steepness index (LS) values increasing as the slopes become steeper. The Bangga Watershed is dominated by very steep slopes (>45%), which pose a high risk of soil erosion, as high LS values can increase the risk of erosion. The distribution of slope classes in the Bangga Watershed can be seen on the following map:

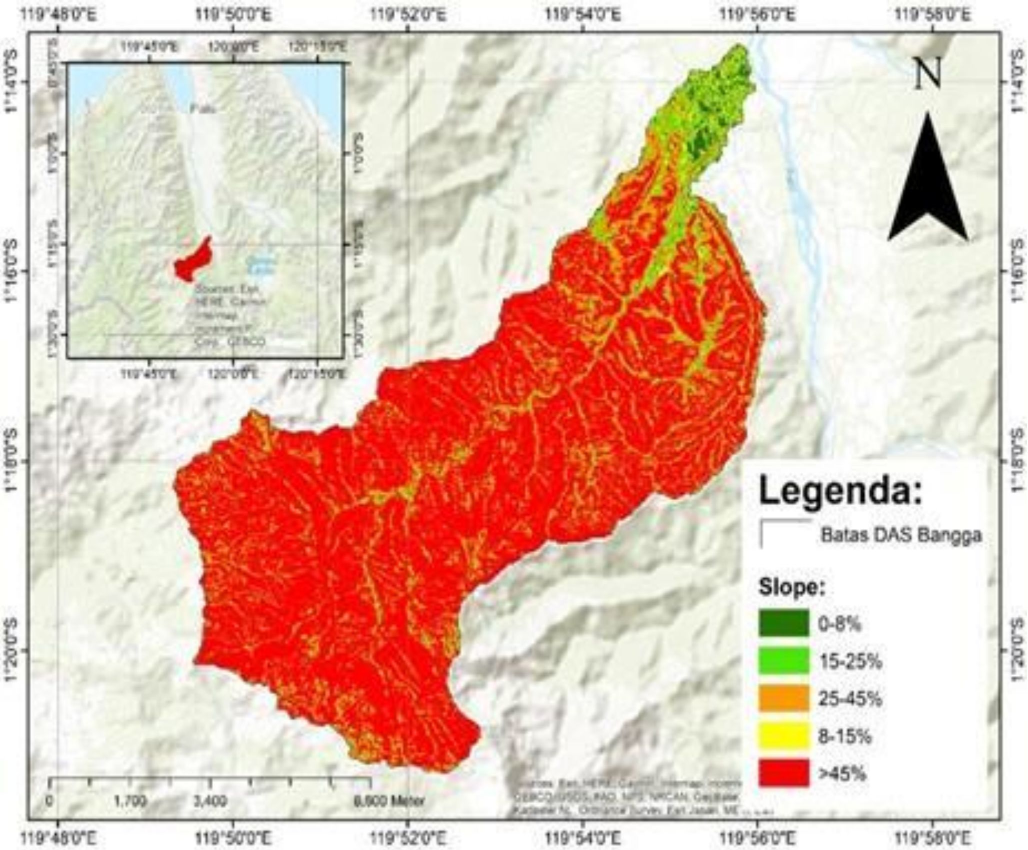

Figure 4. Water Flow Patterns in the Bangga Watershed
Source: Spatial data analysis (2025)

4.1.4. Crop Management Index (C)

Over the past 13 years, from 2013 to 2025, the Bangga Watershed area has undergone various significant changes in land use.

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Table 5. Land Use Conditions in the Bangga Watershed Area in 2013

No.	Land Type	C Value	Area (Ha)	%
1	Primary Dryland Forest	0.02	5,809.54	79.67
2	Settlement	0.75	10.43	0.14
3	Water Body	0.001	29.58	0.41
4	Secondary Dryland Forest	0.03	912.99	12.52
5	Shrubs	0.3	158.76	2.18
6	Grassland	0.29	95.42	1.31
7	Shifting Cultivation	0.7	13.17	0.18
8	Mixed Garden	0.2	159.84	2.19
9	Wetland Rice Paddy	0.01	17.75	0.24
10	Coconut Plantation	0.4	84.29	1.16
	Total (Ha)		**7,291.76**	**100**

Source: Spatial data processing results (2025)

By the final observation in 2025, the main concern in the Bangga Watershed area had shifted from post-disaster recovery towards sustainable land management,

Table 6. Landuse Conditions in the Bangga Watershed Area in 2025

No.	Land Type	C Value	Area (Ha)	%
1	Primary Dryland Forest	5,809.54	79.67	
2	Settlement	13.83	0.19	
3	Water Body	29.58	0.41	
4	Secondary Dryland Forest	894.02	12.26	
5	Shrubs	213.42	2.93	
6	Grassland	50.24	0.69	
7	Shifting Cultivation	89.72	1.23	
8	Mixed Garden	165.97	2.28	
9	Wetland Rice Paddy	8.47	0.12	
10	Coconut Plantation	16.96	0.23	
	Total (Ha)	**7,291.76**	**100**	

Source: Spatial data processing results (2025)

As delineated in the multi-temporal geospatial analysis presented in Figure 5, the chronological sequence of cartographic data from 2013 to 2025 provides empirical evidence of profound spatio-temporal dynamics within the Bangga Watershed. These observations unequivocally substantiate that the catchment is currently undergoing a severe, disaster-driven landscape transformation, catalyzed by extreme hydro-meteorological and geological stressors. Within this rapidly evolving geomorphological paradigm, primary forested areas demonstrate substantial ecological and structural resilience, acting as a critical buffer against catastrophic physical degradation. Conversely, anthropogenic environments—specifically cultivated agricultural lands—emerge as the most dynamically unstable and highly vulnerable components of the watershed system. This pronounced susceptibility of cultivated land underscores a critical deficiency in morphodynamical stability,

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rendering these agrarian zones disproportionately prone to acute structural alteration, accelerated erosion, and sustained degradation in the aftermath of extreme hazard events.

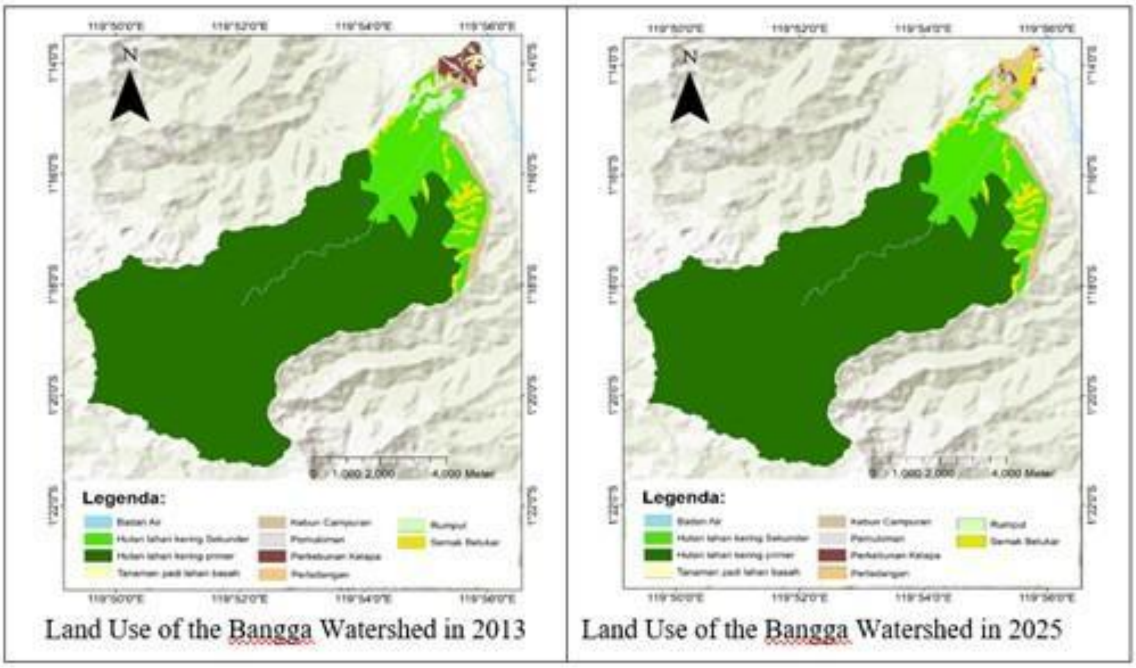

Figure 5. Land Use Comparison in the Bangga Watershed Area, 2013–2025
Source: Spatial data analysis (2025)

Periodic dynamics from 2013 to 2025 are further illustrated via the Landuse change chart to enhance the interpretation of sharp variations in land utilisation, particularly around the 2019 flash flood disaster that occurred in 2019.

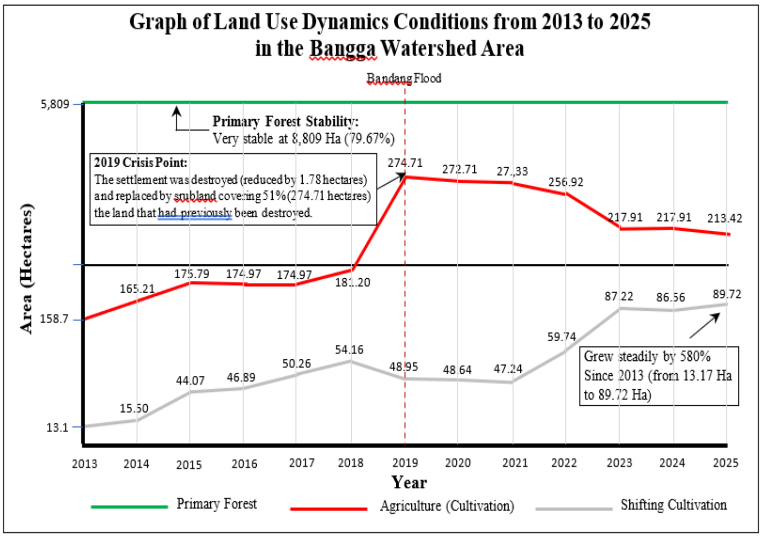

Figure 6. Landuse Dynamics from 2013 to 2025 in the Bangga Watershed Area
Source: Spatial data processing results (2025)

Based on the graph and table above, the 2019 flash flood became a tipping point that drastically cut the historical continuity of land cover. The extreme impacts that occurred from 2018 to 2019 include:

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- Settlements drastically destroyed from 10.70 Ha to only 1.78 Ha.
- Coconut plantations dropped sharply from 78.54 Ha to 25.86 Ha (a decrease of almost 67%).
- Wetland rice paddy fell from 19.82 Ha to 7.93 Ha.
- Shrubs jumped from 181.20 Ha to 274.71 Ha.

The Bangga Watershed has landuse types that can be grouped into 10 landuse categories spread throughout the area. By combining these physical factors using GIS, a total of 10 landuse units were obtained, The index values based on the type of landuse in the Bangga Watershed are shown in the table below.

Table 7. Crop Management Index (C) Values in the Bangga Watershed

No	Land Type	C Value
1	Primary Dryland Forest	0.02
2	Settlement	0.75
3	Water Body	0.001
4	Secondary Dryland Forest	0.03
5	Shrubs	0.3
6	Grassland	0.29
7	Shifting Cultivation	0.7
8	Mixed Garden	0.2
9	Wetland Rice Paddy	0.01
10	Coconut Plantation	0.4

Source: Data processing results (2025)

4.1.5. Land Conservation Action Index (P)

Regarding land conservation actions in the Bangga watershed area over the last 13 years, it can be seen in the table below.

Table 8. Land Conservation Index in the Study Area

No	Conservation and Land Management	P Value
1	Undisturbed Forest	0.01
2	Settlement	0.2
3	Water Body	0.01
4	Secondary Forest	0.03
5	Shrub	0.3
6	Wild Grass	0.4
7	Dryland Farm	0.75
8	Plantation crops with moderate ground cover	0.5
9	Irrigated Rice	0.02

Source: Data processing results (2025)

4.2. Erosion Calculation Results and Erosion Hazard Levels

Based on the calculation of erosion rates using the USLE method with ArcGIS, it shows that each year (2013 to 2023) with total area 7,291.76 Ha, the distribution of erosion hazard levels in the area changes, and even erosion in the high and very high categories continues to expand, as can be seen in the following table.

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Table 9. Distribution of Erosion Hazard Levels in the Bangga Watershed from 2013 to 2025

Year	Area of Erosion Hazard Level (Ha)				
	Very Low	**Low**	**Moderat e**	**High**	**Very High**
2013	6,769.85	65.49	93.21	108.35	254.85
2014	6,771.43	80.89	81.93	165.44	192.06
2015	6,769.83	61.32	184.39	263.31	12.92
2016	6,769.21	43.14	71.33	143.58	264.49
2017	6,760.78	43.86	82.22	136.44	268.45
2018	6,754.55	60.61	147.13	186.73	142.74
2019	6,717.93	77.07	30.11	174.69	291.96
2020	6,742.02	78.09	152.92	161.02	157.71
2021	6,742.02	62.80	84.36	134.25	268.32
2022	6,741.61	53.53	87.49	133.68	275.44
2023	6,746.06	60.84	171.59	162.16	151.10
2024	6,741.61	43.57	75.83	133.91	296.84
2025	6,741.61	56.05	114.30	158.18	221.61

Source: Data processing results (2025)

The data above shows that the peak of the erosion crisis occurred in 2019 after the flash flood, with total annual erosion reaching 106,532.60 Ton/Ha/Year and the area of land with a very high erosion hazard level jumping to 291.96 Ha.

Based on the research results in the Bangga Watershed for the 2013-2025 period, there is a very close relationship between landuse change in the upstream area and the increase in erosion potential and sediment yield.

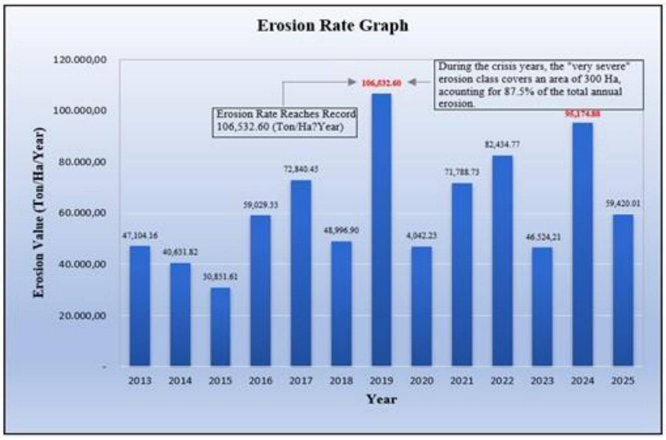

Figure 7. Erosion Rates Occurring in the Bangga Watershed Area from 2013 to 2025
Source: Spatial data processing results (2025)

The upstream area of the Bangga Watershed, dominated by very steep slopes (>45%) covering 5,037.42 Ha (about 69% of the total watershed area) with an LS factor value reaching 9.5, is the area most vulnerable to erosion. Over 13 years of observation, although primary dryland forest covering 5,809.54 Ha (79.67%) showed extraordinary stability with erosion values of only 0.07-1.61 Ton/Ha/Year on various slopes, changes in land use in secondary forest areas and cultivated land in the upstream part have triggered a significant increase in erosion potential.

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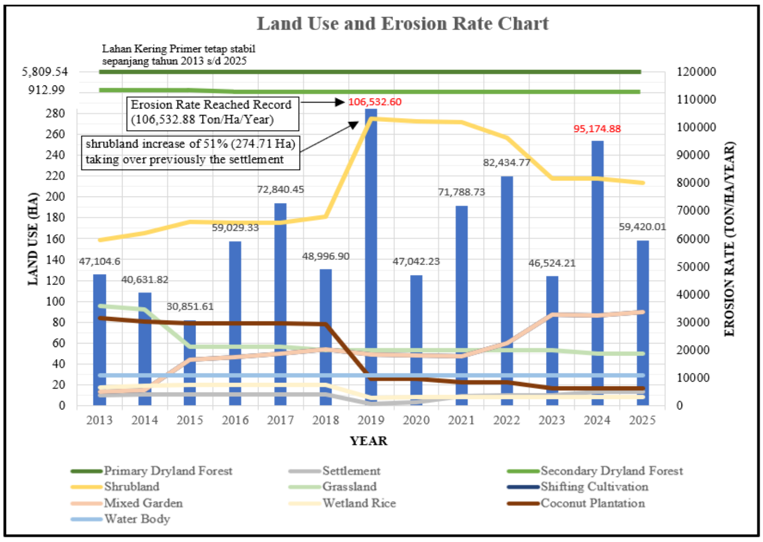

Figure 8. Erosion and Land Use Change
Source: Spatial data processing results (2025)

The most impactful landuse change was the decrease in secondary dryland forest area from 912.99 Ha (2013) to 894.02 Ha (2025), which was converted into mixed gardens and shifting cultivation, Data shows that on steep slopes (>45%), mixed gardens (C value = 0,2) produced erosion reaching 804.66 Ton/Ha/Year (very high), while shifting cultivation (C value = 0,7) produced erosion up to 4,224.49 Ton/Ha/Year, This value is more than 2,600 times higher than primary forest on the same slope, The peak of the erosion crisis occurred in 2019 after the flash flood, with total annual erosion reaching 106,532.60 Ton/Ha/Year and the area of land with a very high erosion hazard level jumping to 291.96 Ha. Based on the research results, there was an accumulation of impacts from land degradation that significantly worsened the intensity and impact of the flash flood.

First, the decrease in secondary forest area in the upstream area before the disaster was the main trigger for the increase in the runoff coefficient, Data shows that secondary dryland forest decreased from 912.99 Ha (2013) to 895.62 Ha (2018), a reduction of about 17.37 Ha. Although it seems small, the conversion of secondary forest, generally located on slopes of 25%-45% to >45%, into mixed gardens and shifting cultivation has increased erosion values from 56,06 Ton/Ha/Year (secondary forest) to 804-4,224 Ton/Ha/Year on shifting cultivation land on the same slope, This increase in erosion has a direct impact on reducing soil infiltration capacity and increasing surface runoff, Podzolic soils (63% of watershed area) and Cambisols (34% of watershed area), which are dominant in the upstream area, have slow to moderate permeability, so when forest cover is disturbed, rainwater more quickly becomes direct runoff into the river.

Second, the rapid increase in shifting cultivation area from 44.07 Ha (2015) to 54.16 Ha (2018) or an increase of 22.9% in the three years before the disaster, coupled with the increase in mixed gardens reaching 159.54 Ha (2017), has significantly altered the hydrological function of the watershed, The root systems of annual crops in shifting cultivation are not able to bind the soil as strongly as forest

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root systems, while intensive tillage causes the soil surface to be more easily dispersed by raindrop impact. On slopes >45%, shifting cultivation land produces erosion reaching 4,224 Ton/Ha/Year, meaning that a 2-3 cm thick layer of topsoil can be lost in just one rainy season. This eroded sediment material then accumulates at the riverbed as sediment deposits, which progressively reduces the storage capacity of the river cross-section.

Third, the increase in shrub area from 165.21 Ha (2014) to 181.20 Ha (2018) or an increase of 9.7% actually indicates abandoned land after degradation. Shrubs with a C value of 0,3 and low canopy density (<50%) are unable to protect the soil surface effectively, On steep slopes (>45%), shrubs produce erosion reaching 4,310-9,394 Ton/Ha/Year. This condition creates a positive feedback cycle: degraded land → increased surface runoff → worsening erosion → increased river sedimentation → reduced river capacity.

Fourth, the peak of the April 2019 flash flood occurred when annual rainfall reached 273.72 cm (the highest value in the 2013-2025 period) with a rainfall erosivity index (R) reaching 4,561.70, the highest value ever recorded and almost double the annual average (around 2,700), The combination of extreme rainfall and the degraded landuse condition of the watershed produced a very rapid hydrological response. The short concentration time due to the elongated shape of the watershed and steep slope gradients caused rainwater falling in the upstream area to reach settlements in the middle and downstream areas within hours.

The impact of the flash flood on post-disaster landuse change was very dramatic. Data shows that:

1. Settlements were drastically destroyed from 10.70 Ha (2018) to only 1.78 Ha (2019), a decrease of 83.4%, indicating total damage to existing settlement infrastructure.
2. Coconut plantations dropped sharply from 78.54 Ha to 25.86 Ha (a 67% decrease), because coconut trees, which have fibrous root systems, were not strong enough to withstand the flash flood currents carrying sediment material and logs.
3. Wetland rice paddy fell from 19.82 Ha to 7.93 Ha (a 60% decrease), due to sedimentation covering irrigation canals and paddy fields.
4. Shrubs jumped from 181.20 Ha to 274.71 Ha (an increase of 93.51 Ha or 51.6%)—the highest increase in the period, Land that was previously settlements, plantations, and mixed gardens that were damaged was then naturally overgrown with shrubs as the initial stage of post-disaster succession.
5. Total land with a very high erosion hazard level reached 291.96 Ha (a record high at that time) with total annual erosion of 106,532.60 Ton/Ha/Year, meaning extraordinary sedimentation occurred along the river flow.

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A very interesting phenomenon is that primary dryland forest remained intact at 5,809.54 Ha with very low erosion rates (21.47 Ton/Ha/Year), This proves that primary forest with dense canopy and complex root systems is able to withstand even extreme flash floods, while also providing evidence that the main cause of the flash flood was not solely due to high rainfall, but land degradation in the watershed buffer zone (secondary forest, mixed gardens, and shifting cultivation) that had occurred gradually since 2013. Thus, the 2019 Bangga River flash flood was an anthropogenic disaster triggered by natural factors: extreme rainfall was the trigger, but the degraded condition of the watershed due to land use changes in the upstream area was the root cause, An important lesson from this event is that sustainable watershed management is not enough only by protecting primary forests, but also requires strict regulation of secondary forest conversion, restrictions on shifting cultivation on steep slopes, and the mandatory application of soil and water conservation techniques on cultivated lands in the upstream area.

The interaction between slope gradient factors (LS) and crop management factors (C) is the main determinant of the sediment yield rate, In the upstream area dominated by Podzolic soils (63% of watershed area, K value = 0.32) and Cambisols (34%, K value = 0.32), both very susceptible to erosion, the conversion of secondary forest into shifting cultivation on steep slopes has produced alarming annual erosion rates, Even in 2024, the area of land with a very high erosion hazard level reached a record 296.84 Ha with total annual erosion of 95,174.88 Ton/Ha/Year.

Despite inherent interannual temporal variability, the longitudinal trajectory of erosion and sediment delivery rates within the Bangga Watershed exhibits a progressive and critical exacerbation. This severe morphodynamic degradation is primarily catalyzed by the unchecked proliferation of shifting agricultural practices, which expanded dramatically to encompass 89.72 Ha by 2025—representing a staggering 580% spatial escalation relative to the 2013 baseline. Consequently, these profound anthropogenic land-use and land-cover (LULC) alterations in the upper catchment, specifically the extensive conversion of resilient forested tracts into agrarian zones devoid of requisite soil and water conservation interventions, have induced a non-linear, exponential amplification in both hillslope erosion susceptibility and cumulative fluvial sediment yield.

Ultimately, this accelerated and disproportionate sediment dynamic fundamentally jeopardizes the long-term hydrological and morphodynamic integrity of the entire watershed system. The continuous aggradation of fluvial channels systematically diminishes their natural hydraulic conveyance capacity, thereby exacerbating flow unsteadiness during peak precipitation events. Consequently, this morpho-hydrological imbalance acts as a critical threat multiplier; it significantly magnifies the physical vulnerability and exposure of downstream socio-ecological systems and critical civil infrastructure. This systemic degradation creates a highly volatile risk environment,

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predisposing the lower catchment to severe, compounding hydrometeorological hazards. Chief among these threats is the heightened probability of highly destructive, debris-laden hyperconcentrated flows and catastrophic flash floods, phenomena that possess the kinetic potential to completely overwhelm existing flood-defense mechanisms and trigger cascading socioeconomic losses.

4.3. Sedimentation Analysis

4.3.1. Bed Sediment Sieve Analysis

Table 10. Results of Testing and Calculation of Sieve Analysis for Bed Sediment Samples

Sieve No.	Opening Diameter (mm)	Weight Retained (gr)	Cumulative Retained (gr)	% Retained	% Finer
2"	50	0	0	0	100
1 1/2"	38	50.6	50.6	1.99	98.01
1"	25,4	222.69	273.29	10.74	89.26
3/4"	12,7	227.2	500.49	19.66	80.34
3/8"	9,52	330.26	830.75	32.64	67.36
4	4.75	189.57	1,020.32	40.08	59.92
10	2	208.11	1,228.43	48.26	51.74
20	0.85	226.78	1,455.21	57.17	42.83
40	0.42	352.1	1,807.31	71	29
60	0.25	365.1	2,172.41	85.35	14.65
80	0.18	158.03	2,330.44	91.55	8.45
100	0.15	38.84	2,369.28	93.08	6.92
200	0.075	79.63	2,448.91	96.21	3.79
PAN		96.49	2,545.4	100	0

Source: Data processing results (2025)

From the plot results of the graph above, the bed sediment grain sizes obtained are: d50 = 1.78 mm; d_{90} = 26.46 mm. After conducting the sieve analysis test on the bed sediment sample, the next step was to determine the specific gravity of the bed sediment, The following table shows the test results:

Table 11. Results of Testing and Calculation of Specific Gravity of Bed Sediment

Test Number		HB3	
Pycnometer Number		1	2
Weight of pycnometer (W1)	gram	70,430	69,200
Weight of pycnometer + Sample (W2)	gram	101,250	100,450
Weight of pycnometer + Sample + Water (W3)	gram	193,250	192,630
Weight of pycnometer + Water at t 0 (W4)	gram	174,040	173,140
Temperature Correction	gram	173,849	172,950
Temperature	°C	29,000	29,000
Sample Weight, Wt = W2 - W1	gram	30,820	31,250
W5 = W2 - W1 + W4	gram	204,860	204,390
Soil Volume, V = W5 - W3	cc	11,610	11,760
Sample Specific Gravity, Gs = Wt / V		**2.655**	**2.657**
Average Specific Gravity (Gs)		**2.66**	

Source: Data processing results (2025)

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4.3.2. Calculation of Sediment Delivery Ratio (SDR)

Based on the characteristics of each watershed, the SDR value for the Bangga Watershed is obtained as follows, With the Bangga Watershed area being 7,291.76 Ha, the SDR value is:

SDR = 0.41 x $7{,}291.76^{-0,3}$ = 0.028

The SDR value obtained through the calculation above indicates that the sediment yield transported to the river is relatively small, as evidenced by the SDR value in the watershed still being below 1, This indicates that in the erosion process, only a portion of the material is transported into the river, Factors suspected to influence this are that most of the slope gradients of the area surrounding the river are categorized as quite gentle, ranging from slopes of less than 8% to 15%.

4.3.3. The Capacity of the Sabo Dam to Retain Sediment in the Bangga Stream

With an SDR value of 0.028 and the land erosion value (E), for example the highest sediment yield in 2019 of 106,532.60 Ton/Ha/Year, the potential sediment yield is:

SY = SDR x E

= 2,982.91 Ton/Ha/Thn

Furthermore, the total sediment volume is obtained from the conversion of the sediment yield value using the following equation,

$$Vs = \frac{Sy\ x\ A}{Specific\ Gravity\ of\ Sediment} \quad (4)$$

Based on the previous analysis results, the sediment yield (Sy) is 2,982.91 Ton/Ha/Year, the specific gravity of sediment at the research location is 2.66 and the Bangga Watershed area is 7,291.76 Ha, then the sediment volume (Vs) in cubic meters is: Vs = 8,176,943.79 m^3

To determine the ability of the Sabo dam to accommodate sediment in the Bangga River, it is done by calculating the remaining capacity of the Sabo dam after being reduced by the total sediment volume transported in the river. For example, the ability of the Sabo dam to accommodate the total sediment volume that occurred in 2019 in the Bangga River is:

$$= \text{Total Sediment Volume} - \sum \text{Sabo Dam Capacity} = 323{,}056.21\ \mathrm{m}^3 \quad (5)$$

From the calculation above, the result shows that after being reduced by the total sediment volume that occurred in the Bangga River in 2019, it can be seen that there is still remaining capacity in the Sabo dam of 323,056.21 m^3. Thus, this indicates that the capacity of the Sabo dam located on the Bangga River is sufficient to accommodate the total sediment yield flowing in the river. For a clearer understanding of the ability of the Sabo dam to reduce the amount of sediment over a certain period due to land use changes in the upstream of the Bangga River and the time frame for operation and maintenance actions, it is necessary to look at the analysis results presented by the researcher in the following table.

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Table 12. The Ability of the Sabo Dam to Accommodate Total Transported Sediment and the Time Frame for Operation and Maintenance Actions,

Year	E Value (Ton/Ha/Year)	Potential Sediment (Ton/Ha/Year)	Total Sediment Volume (m^3/Year)	Remaining Sabo Dam Capacity (m^3/Year)	Operation and Maintenance Action (Year)
2013	47,104.16	1,318.92	3,615,495	4,884,505	0.6
2014	40,631.82	1,137.69	3,118,708	5,381,292	0.6
2015	30,851.61	863.84	2,368,025	6,131,975	0.7
2016	59,029.33	1,652.82	4,530,815	3,969,185	0.5
2017	72,840.45	2,039.53	5,590,892	2,909,108	0.3
2018	48,996.90	1,371.91	3,760,773	4,739,227	0.6
2019	106,532.60	2,982.91	8,176,944	323,056.2	0.0
2020	47,042.23	1,317.18	3,610,741	4,889,259	0.6
2021	71,788.73	2,010.08	5,510,167	2,989,833	0.4
2022	82,434.77	2,308.17	6,327,307	2,172,693	0.3
2023	46,524.21	1,302.68	3,570,981	4,929,019	0.6
2024	95,174.88	2,664.90	7,305,178	1,194,822	0.1
2025	59,420.01	1,663.76	4,560,802	3,939,198	0.5

Source: Data processing results (2025)

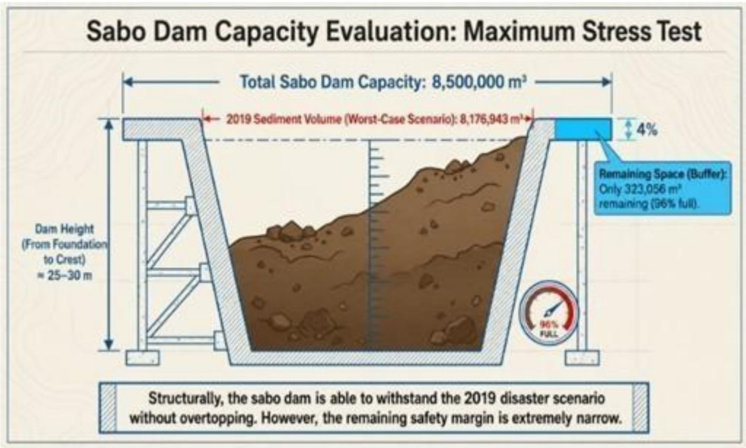

Figure 9. Illustration of the Sabo Dam's Ability in Maximum Stress Test

Based on the analysis results presented in the table above, it shows that from the total sediment volume produced by the Bangga River each year, the Sabo dam on the Bangga River still leaves a considerable capacity for subsequent sediment yield, This indicates that each year the Sabo dam is considered capable of reducing the amount of sediment due to land use changes in the upstream of the Bangga River. Furthermore, the data above also shows that operation and maintenance actions can be carried out annually, as seen in 2019 which showed the highest total sediment volume in the last 13 years in the river. Thus, with the current capacity, it is necessary to carry out operation and maintenance efforts every year to overcome sediment accumulation in the river, especially in the Sabo dam, so that the Sabo dam continues to operate well and is able to reduce the sediment that occurs every year in the river. In addition, efforts to control land conversion by the local community need to be carried out properly to prevent land use changes that could increase the risk of greater

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erosion in the area, which could result in high sediment yield in the river, potentially causing uncontrolled sediment accumulation in the river, especially in the Sabo dam structures, leading to river shallowing which can trigger flood disasters due to the river's inability to accommodate surface runoff as a result of shallowing.

5. Conclusion

a. Landuse changes in the upstream of the Bangga Watershed have a very significant effect on increasing erosion potential and sediment yield, On very steep slopes (>45%), shifting cultivation land produces erosion up to 4,224 Ton/Ha/Year, more than 2,600 times higher compared to primary forest, The peak of erosion occurred in 2019 after the flash flood, with total annual erosion reaching 106,532.60 Ton/Ha/Year.

b. The Sabo Dam in the Bangga Watershed with a total capacity of 8,500,000 m^3 is considered capable of reducing the amount of sediment produced due to landuse changes, The highest total sediment volume in 2019 was 8,176,943.79 m^3, which can still be accommodated with a remaining capacity of 323,056.21 m^3.

c. Operation and maintenance actions for the Sabo Dam need to be carried out regularly every year to overcome sediment accumulation and maintain the optimal function of the Sabo dam, In addition, efforts are needed to control land conversion by the community to prevent landuse changes that could increase the risk of erosion.

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