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ANALYSIS OF THE IMPACT OF THE BAWAKARAENG MOUNTAIN LANDSLIDE ON THE SEDIMENTATION OF THE BILI-BILI RESERVOIR

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Abstrak

The landslide in the Bawakaraeng Caldera in March 2004 produced approximately 200–300 million m³ of debris, which flowed into the Jeneberang River and caused sedimentation in the Bili-Bili Reservoir. This study aims to analyze the potential for landslides, the impact of landslides on sediment transport at Sabo Dams 7-7, 7-6, and 7-5, and the rate of sedimentation entering the reservoir. The methods employed include the MUSLE (Modified Universal Soil Loss Equation) for erosion analysis, the Meyer-Peter Müller (MPM) method for bedload sediment transport, and analysis of suspended sediment discharge using AWLR data. The results indicate that the landslide potential reaches 313,349.10 tonnes/year (0.830 m³/year), classified as very high. The highest sediment transport occurs at Sabo Dam 7-7 at 39,555,957 m³/year, followed by a decrease at Sabo Dam 7-6 at 2,285,596 m³/year and Sabo Dam 7-5 at 5,627,700 m³/year. Sediment entering the Bili-Bili Reservoir exhibits a seasonal pattern, with total accumulation reaching 799,170,000 m³ by 2025. The conclusions of this study indicate that landslides from Mount Bawakaraeng have a significant impact on increased sedimentation, and that the presence of sabo dams is capable of retaining some sediment, although they are not yet fully optimal.

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INTRODUCTION

The Jeneberang River is one of the rivers that originates on Mount Bawakaraeng. The landslide in the Mount Bawakaraeng caldera in March 2004 produced approximately 200–300 million m³ of debris, which flowed into the Jeneberang River and caused sedimentation in the Bili-Bili Reservoir. The Sand Pocket

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sediment control structures SP-1 and SP-2 have storage capacities of 325,153 m³ and 493,381 m³, respectively. Following the debris flow in January 2006, infrastructure damage occurred, including to bridges, and a flash flood took place in February 2007. Sediment volume increased again in 2014– 2015 due to damage to the SP-1 structure; following rehabilitation, it continued to rise in 2017–2018 to approximately 3,194,132 m³. This increase was triggered by collapsed or nonfunctional structures as well as mining activities around the site, which accelerated erosion and destabilized sediment control structures (Maulana Khaqqi Akyas, Musa R, 2024).

The Bili-Bili Reservoir in Gowa Regency, which has been in operation since 1997, is now facing serious sedimentation. The 29 million m³ dead storage volume has been completely filled with sediment, most of which originated from the 2004 landslide in the Bawakaraeng Volcano caldera, so the reservoir's operation still depends on dredging to maintain the intake's functionality. (Wahyuningrum, 2025)

Erosion is the primary cause of land degradation. The Jeneberang Watershed, as one of Indonesia's priority watersheds, faces serious erosion problems in its upstream areas (Aisyah et al., 2022). Based on echosounder measurements, a 2019 bathymetric map of the Bili-Bili Reservoir was created and compared with the 1997 map to calculate sediment volume. The results of the study show that the total sedime (Placeholder1) (Placeholder2)nt volume for the 1997–2019 period was 110.371 million m³, while in 2017 it was 108.050 million m³, resulting in a sedimentation rate of 2.321 million m³ for 2017–2019. (Sanjaya et al., 2020)

Landslides in the watershed impede natural flow due to the sediment carried by the water. Sediment transport calculations show that the Meyer-Peter-Müller method yields a higher value (0.0248 m³/day) than the Van Rijn method (0.0156 m³/day). The greatest sediment transport distance occurs at a full opening of 0.66 m, followed by a ¾ opening (0.59 m) and a ½ opening (0.49 m).(Putra, 2022). Research results based on Geographic Information Systems (GIS) using weighting and map overlay methods with ArcGIS indicate that flood vulnerability levels are divided into five classes: very high, high, moderate, low, and very low. (Arifin et al., 2023)

However, the sedimentation rate in the Jeneberang River continues to increase, necessitating sediment control measures to maintain the reservoir's effectiveness and prevent its capacity from continuing to decline, which would threaten the sustainability of its function. One of the primary sources of sediment originates from Mount Bawakaraeng, particularly at Sabo Dams 7-7, 7-6, and 7-5. The main issues addressed in this study are the magnitude of the landslide potential at Mount Bawakaraeng, the impact of landslides on sediment transport at the Sabo Dams, and the sedimentation rate entering the Bili-Bili Reservoir.

RESEARCH METHODS

This study was conducted on a river that originates at Mount Bawakaraeng and flows into the Bili-Bili Reservoir in Gowa Regency. Data collection in the upstream section focused on sedimentation. Results from the field survey of the reservoir were obtained based on echosounding measurements in the reservoir, and secondary data included characteristics of the watershed. Data analysis methods included:

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Erosion Analysis (Musle)

Using parameters such as surface runoff, peak discharge, and land, The baseline data used include rainfall data (2009– 2025), soil maps, land cover maps, digital elevation model (DEM) data, the Gowa Regency Spatial Planning Map (RTRW), and the Forest Area Map for the Jeneberang Watershed. The tools used were a computer equipped with ArcGIS 10.8 and Microsoft Office 2024 software, a global positioning system (GPS), soil sampling tools, a ring sampler, and laboratory equipment necessary for soil analysis.

Bed Sediment Transport (MPM)

Based on the hydraulic characteristics and sediment grain size, field data (velocity, river width, slope, D50). Sediment transport rates from field measurements (echosounding) to analyze the sedimentation rate in the Bili-Bili reservoir. The study was conducted in April 2026. The study location is shown in Figure 1.

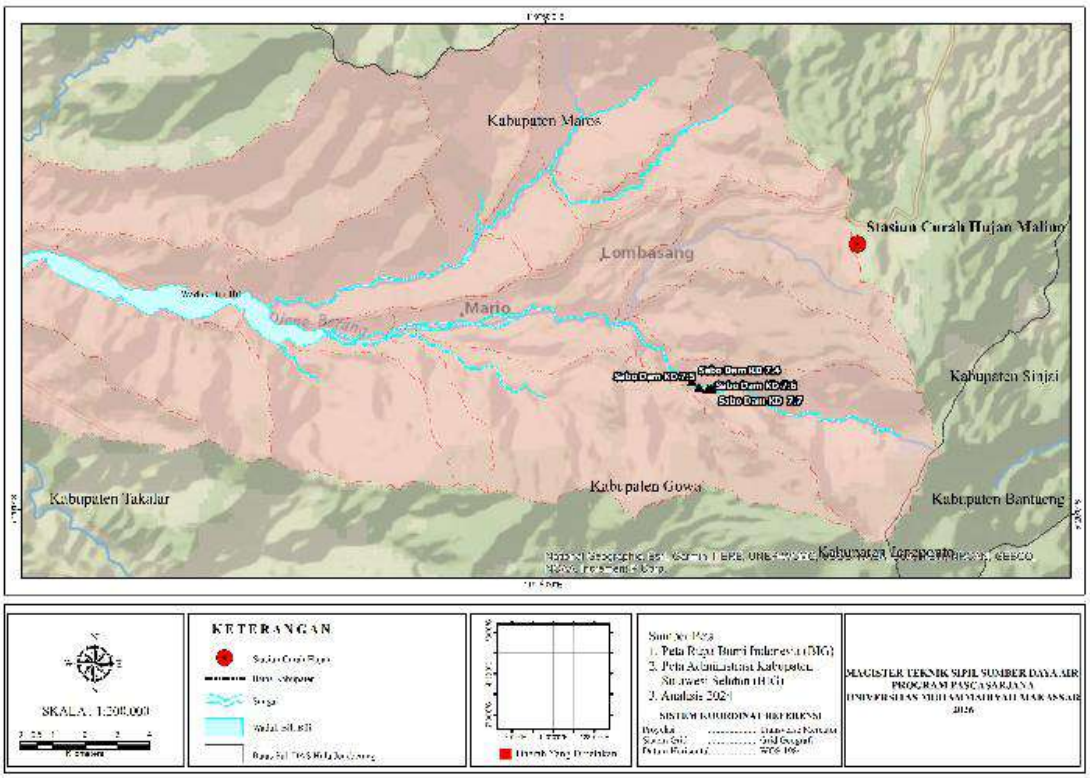


Figure 1. Map of the Jeneberang River Basin

RESULTS AND DISCUSSION.

Landslide Potential of Mount Bawakaraeng

The analysis was performed using the MUSLE method. In the MUSLE method, the rainfall erosivity factor (R) is modified into a surface runoff factor (Rw). This method accounts for erosion and sediment movement in the Watershed based on a single rainfall event.

Rainfall Analysis

The rainfall data used in this study is from the Malino Station, covering the last 17 years from 2009 to 2025.

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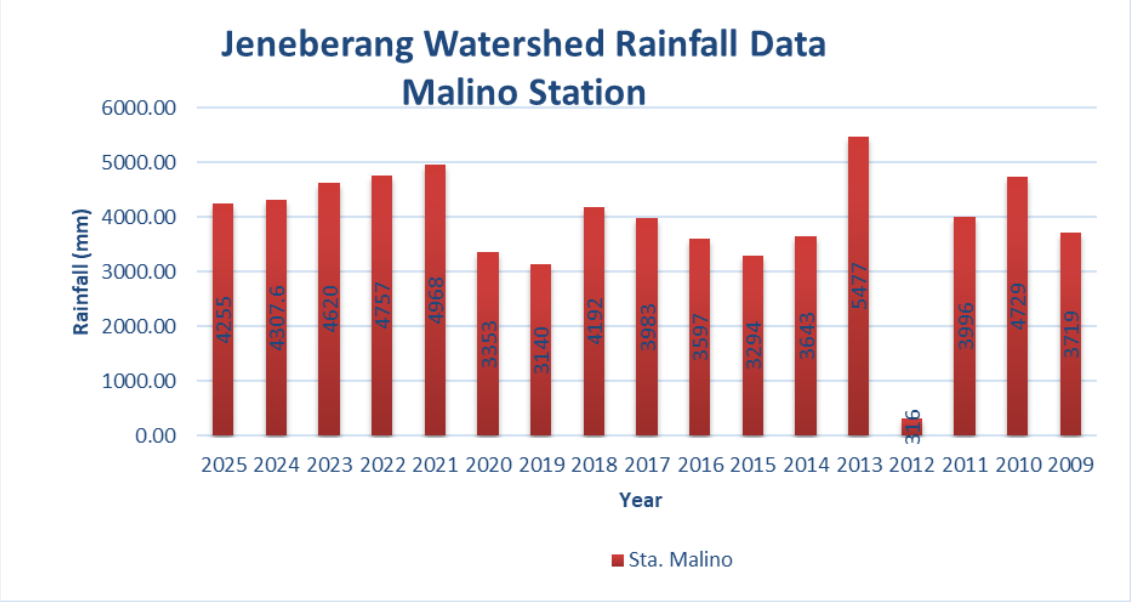


Figure 2. Annual Rainfall at Malino Statio

The graph shows that annual rainfall in the Jeneberang Watershed (Malino Station) fluctuates from year to year. Rainfall values tend to range from 3,000 to 5,500 mm/year, with the highest peak occurring around 2013 and the lowest around 2012. In general, this pattern indicates that the study area has high and unstable rainfall, which has the potential to increase surface runoff, erosion, and landslides, especially in areas with steep slopes. In the synthetic unit hydrograph (Nakayasu HSS) analysis, this can be seen as follows.

Watershed Area (km^2)	= 26.29 km^2
Main River Length (km)	= 12.08 km
Effective Rainfall Unit, Ro(mm)	= 1,000 mm
Hydrograph Parameter (a)	= 2,000
TIME LAG, tg	= 1,202 hours
Tr = (0.5 to 1.0) tg. 0.75	= 0.901 hours
Tp = tg + 0.8 × tg	= 1.923 hours
T 0.3 = a	= 2.403 hours
0.5 T0.3	= 1.202 hours
1.5 × T0.3	= 3.605 hours
2 × T0.3	= 4.806 hours
Tp + T0.3	= 4.326 hours
Tp + T0.3 +1.5T0.3	= 7.931 hours
Qp = CA × Ro/(3.6 × (0.3 × Tp + T0.3))	= 2.450 m^3/s
Qp	= 2.450 m^3/s

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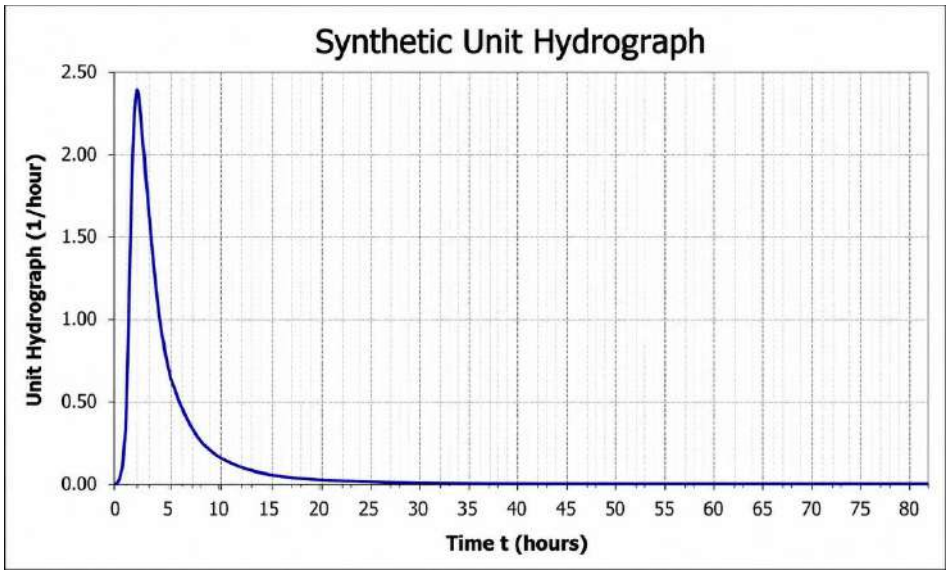


Figure 3. Graph of the Synthetic Unit Hydrograph

Based on this data, the following hydrological parameters were obtained: These values indicate a relatively rapid response of the watershed to rainfall, influenced by the watershed area of 26.29 km². The final peak discharge results are: Qp = 2,450 m^3/Second.

Musle Method Erosivity Analysis

Table 1. Results of Surface Runoff Erosivity in the Upper Watershe

Upstream Point	watershed	Qp (m^3/sec)	Vo (m^3)	Rw (Kj/ha)
	2,628.81	2.450	2,405.61	1,169.81

The formula for the surface runoff erosivity index is

$_{\varrho}b = 1.5$ Mg/m^3

MS = 8% = 0.08 Et/Eo = 0.9

RD = 0.1

To obtain the surface runoff volume, calculate the soil's prior moisture storage capacity:

Rc $= 1000 \times MS \times {}_{\gamma}b \times RD \times \left(\frac{Et}{Eo}\right)^{0,5}$

$= 1000 \times 0.008 \times 1.5$ Mg/$m^3 \times (0.9)^{0.5}$

$= 11.38419$

R $= 3902.7411$ mm

Rn $= 165.8823$

Ro $= \left(\frac{R}{Rn}\right)$ Ro $= 23.5271 = -0.4838$

The results for surface runoff volume are as follows:

$Vo = R \cdot \exp\left(\frac{-Rc}{Ro}\right)$

Vo = 2405.612 m^3

Thus, the erosivity of surface runoff is:

Rw = 1169.805 kJ/ha

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Thus, the erosivity of surface runoff is: Rw = 1169.805 kJ/ha Based on the calculations, the total erosivity value was determined to be 1,169,805 kJ/ha. Analysis of the 1:200,000-scale topographic map reveals that the Upper Jeneberang Watershed exhibits varied topography, ranging from flat to extremely steep. Across the entire Jeneberang sub-watershed, the area is dominated by very steep topography, covering 12,743.098 ha. The land use map of the Jeneberang sub-watershed shows that the majority of the area is dominated by forest, covering 16,455.766 ha (42.746%). As for soil types in the Jeneberang sub-watershed, Kambisol soils dominate, covering an area of 22,325.308 ha (57.9%). This is illustrated in greater detail in Tables 2, 3, and 4.

Table 2. LS Values for Slope Class

No	Slope (%)	Class	Area (ha)	LS
1	0 - 8	Flat	4,990.693	0.4
2	8 - 15	Gentle	4,306.987	1.4
3	15 - 25	Somewhat	6,910.966	3.1
4	25 - 40	Steep	9,452.192	6.8
5	>40	Very Steep	12,743.098	9.5
Total			**38,496.477**	

Table 3. C Values for Land Use Classes

No	Open Lande	Area (Ha)	Percentage (%)	Value C
1	Water Bodies	1576.775	4.096	0.001
2	Forest	16455.766	42.746	0.05
3	Orchards	418,024	1.086	0.20
4	Residential	410.480	1.066	0.60
5	Rice fields	5756.090	14.952	0.01
6	Scrub	9244.803	24.015	0.30
7	Grassland	3814.171	9.908	0.70
8	Open Land	820.368	2.131	1.00
Total		**38496.477**	**100**	

Table 4. K Values by Soil Typ

No	Soil Type	Area (ha)	Percentage (%)	K
1	Alluvial	1873.489	4.867	0.315
2	Andosol	10502.803	27.283	0.140
3	Gleisol	892.871	2.319	0.243
4	Kambisol	22325.308	57.993	0.14
5	Regosol	2902.007	7.538	0.346
Jumlah		**38496.477**	**100.000**	

The Erosion Hazard Level (EHL) is a classification used to indicate the severity of erosion based on the rate of soil erosion. The higher the EHL class, the greater the extent of land damage caused by erosion, as shown in Table 5.

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Table 5. TBE (Erosion Hazard Level) Class Table

Erosion Hazard Class	Erosion Rate (tons/ha/year)	Notes
I	< 15	Very Light
II	16 - 60	Mild
III	60 -180	Moderate
IV	18 - 480	Severe
V	> 480	Very Heavy

Table 6. Calculation Results

Notes	Results		
Watershed Area (ha)	2,628.81	26.288	Km^2
Total Erosion (tons/ha/year)	3,711,805.22		
Erosion Rate (tons/year)	1,400,681.22		
SDR	0.224		
Sedimentation Rate (tons/year	313,349.10		

Source: calculation results

Based on the results of geospatial data analysis using ArcMap, the landslide potential was determined to be 313,349.10 tons/year or 0.830 m^3/year; this value indicates the volume of soil material that could potentially be dislodged as a result of landslides. Based on the erosion severity classification, this value falls into the Very Severe (>480) category. The high landslide potential is influenced by steep slope gradients, high rainfall, and minimal vegetation cover. Thus, the landslide potential at Mount Bawakaraeng is classified as Very Severe with a high risk level.

Impact of Landslides on Sediment in Sabo Dams 7-7, 7-6, and 7-5

Based on the results of the analysis using the Meyer-Peter Müller (MPM) method, bed load values were obtained for Sabo Dams 7-7, 7-6, and 7-5 using the specified hydraulic parameters and sediment characteristics.

To calculate the sediment transport rate, field data was collected directly; data collection was conducted in March 2026. The following are the results of the field data collection:

Table 7. Field Data Collection Results

Structure Name	Sabo Dam 7.7	Sabo Dam 7.6	Sabo Dam 7.5
Distance (m)	115	279	366
Slope (%)	16.50	6.18	8.53
Velocity (m/s)	0.14	0.05	0.07
River Width (m)	124	85	92
Water Level (h)	0.50	0.50	0.50
D50 (mm)	0.60	6.08	0.84
Q (m^3/s)	8.49	2.17	3.25
Sediment Rate (m^3/yr)	39.555.957	2.285.596	5.627.700

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The effect of landslides on sediment at Sabo Dams 7-7, 7-6, and 7-5. Landslides have a significant effect on increasing sediment transport, particularly in the upstream section. Based on the Meyer-Peter Müller method, the following values were obtained: Sabo Dam 7-7: 39,555,957 m^3/year, Sabo Dam 7-6: 2,285,596 m^3/year, and Sabo Dam 7-5: 5,627,700 m^3/year. These results indicate that the highest sediment transport occurs at Sabo Dam 7-7 (upstream), then decreases downstream due to gradual sedimentation processes. Thus, the sabo dams function effectively as sediment control structures, but sediment distribution is still heavily influenced by landslides from the upstream area.

Sedimentation Rate Entering the Bili-Bili Reservoir

Sedimentation in the Bili-Bili Reservoir became extraordinary due to a large landslide on Mount Bawakaraeng that occurred in 2004. The estimated sedimentation volume and sedimentation rate in the Bili-Bili Reservoir can be calculated based on the sediment volume from the measurement results.

Based on the analysis results, the sediment entering the reservoir consists of sediment that has passed through the sabo dam structure. Sedimentation in the Bili-Bili Reservoir is a critical parameter in reservoir planning and management because a portion of the available volume will be filled by sediment deposits, thereby reducing the effective volume. Additionally, sediment can accumulate in front of the intake, which will disrupt reservoir operations. Based on echo-sounding measurement data, the annual volume of sediment entering and settling in the Bili-Bili Reservoir through 2025 is 799,170,000m^3, as shown in Table 8:

Table 8. Volume and Sedimentation Rate of Bili-Bili Reservoir (Echosounding Data and Calculations)

Year	Year of Operation	Annual Sediment 10^6 m^3	Cumulative Sediment 10^6 m^3	Sedimentation Rate 10^6 m^3/ Year
1997	-	0.000	0.000	0.000
2012	14	86.490	86.490	21.623
2016	18	100.800	187.290	33.600
2019	21	106.240	293.530	106.240
2020	22	103.040	396.570	103.040
2021	23	106.260	502.830	106.260
2022	24	108.080	610.910	108.080
2023	25	102.160	713.070	102.160
2025	27	86.100	799.170	86.100

These figures indicate that not all of the material from the landslide reached the reservoir, as some of it was retained by the sabo dam or settled along the river channel. Nevertheless, the sediment that did enter the reservoir continues to reduce its storage capacity due to the process of siltation

CONCLUSION

The landslide potential of Mount Bawakaraeng is classified as very high. This is demonstrated by the results of the MUSLE analysis, which yielded an erosivity value of

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1,169,805 kJ/ha, an erosion rate of 1,400,681.216 tons/year, and a sedimentation rate of 313,349.101 tons/year or 0.830 m³/year. These values fall into the very severe category. The impact of landslides on sediment at Sabo Dam 7-7: 39,555,957 m³/year, 7-6: 2,285,596 m³/year, and 7-5: 5,627,700 m³/year. Landslides have a significant impact on increased sediment transport, particularly in the upstream section. These results indicate that the highest sediment volume occurs at Sabo Dam 7-7 (upstream), then decreases downstream due to gradual sedimentation processes. Thus, the sabo dam functions effectively as a sediment control measure; however, sediment distribution is still heavily influenced by landslides from the upstream area.

Sedimentation rate entering the Bili-Bili Reservoir The sedimentation rate entering the Bili-Bili Reservoir originates from sediment not retained by the sabo dam. Based on the analysis results, the volume of sediment that has settled by 2025 will reach 799,170,000 m³/year. This indicates that although some sediment is retained, there is still sediment entering the reservoir, causing siltation and a reduction in the reservoir's storage capacity. Landslide control measures should be implemented in the upstream area through land conservation efforts such as reforestation and land-use management. Routine maintenance of the sabo dam is required to ensure that sediment storage capacity remains optimal.

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