

## Analysis of Erosion Rate and Sedimentation Rate at Batujai Dam Using USLE and MUSLE Methods

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### ABSTRACT

The main source of reservoir sedimentation is land erosion in rivers. According to the Nusa Tenggara 1 River Basin Center, the Batujai Dam is 38 years old and has had very significant shallowing. The Batujai Dam is a dam that has problems with sedimentation, compounded by the presence of water weeds such as water hyacinths and land erosion. As a result of the sedimentation process, the dam that was built does not function properly, and its storage capacity decreases, leading to a reduction in the dam's function and agricultural land productivity. This study aims to determine the magnitude of the erosion and sedimentation rate that occurs in the Batujai Dam as a reference for controlling and maintaining the reservoir to overcome sedimentation in the future. The methods used in the analysis of erosion rates are the USLE and MUSLE methods, and sedimentation analysis is calculated using the Boyce SDR equation. Obtained erosion in the Batujai Dam with the USLE method is 630,273.84 m<sup>3</sup>/year, and with the MUSLE method is 654,369.59 m<sup>3</sup>/year. The annual sedimentation rate with the Boyce equation is obtained at 97,185.80 m<sup>3</sup>/year with the USLE method and 99,496.57 m<sup>3</sup>/year with the MUSLE method.

**Keywords:** Erosion, Sedimentation, SDR, USLE, MUSLE.

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### INTRODUCTION

Dams are one of the water resource development infrastructures that are widely developed in Indonesia. As an irrigation structure, dams store river water in a reservoir and can be used as a hydropower plant for flood control and tourism. According to the age of the dam, the reservoir volume can decrease due to sedimentation in the inundation area. If the change in reservoir volume is significant, the dam's operating pattern needs to be re-evaluated, and this will affect the dam's function. The main factor causing the decrease in water storage capacity in Indonesia reservoirs is the high sedimentation rate. Land degradation due to erosion in the Watershed Area upstream of the reservoir is believed to contribute significantly to the high sedimentation (Ikawati *et al.*, 2019). One source of sedimentation in the reservoir is land erosion in the river basin, which is then carried by the water flow into the reservoir. In general, geography, soil properties, ground cover vegetation, land use, and meteorological factors—

particularly rainfall intensity—all influence the likelihood of erosion (Asdak, 2010). Sedimentation can result from land erosion processes in the reservoir's watershed area or landslides from riverbanks or the reservoir banks. A portion of the sediment that enters the reservoir will settle at the bottom, and the rest will be released with the outflow. Sediment that enters the reservoir will settle on every surface of the reservoir. Depending on the operating system, the size of the sediment particles, and the reservoir's structure, each reservoir has a characteristic sediment dispersion pattern (Putra *et al.*, 2019). The sedimentation process of the dam causes the water structure that has been built to function less optimally and leads to a decrease in the dam's capacity, which impacts the reduction of the dam's function (Widalia *et al.*, 2015), the decrease in agricultural land productivity, and the reduction of channel capacity (Hardiyatmo, 2006). Based on data collected by facilitators from the relevant agencies, most existing dams are damaged and cannot be properly operated. The decline in function, characterized by reduced capacity to store water due to uncontrolled sedimentation, is a common problem. Wild plants that can damage dam structures thrive when rivers and reservoirs experience siltation. This issue needs careful attention because, if not addressed promptly, it could damage the dam's structure, disrupting the best irrigation system and reducing the dam's effectiveness (Diwandono *et al.*, 2024).

Batujai Dam is the largest dam in Central Lombok, located in Batujai Village, Praya Barat District. The Batujai Dam is a realization of utilizing available water potential, namely the Dodokan Watershed potential. The Batujai Dam is a dam that has problems with sedimentation, compounded by the presence of water weeds such as water hyacinths and land erosion. According to the BWS NT 1 (2020), the Batujai Dam is already 38 years old, and significant sedimentation has occurred. At the beginning of its construction, the reservoir had a depth of 18 m, whereas, by 2019, the depth had decreased to 12 m, with more than 35% of the reservoir's surface covered by a population of water hyacinths, causing the reservoir's capacity to decrease from 25 million m<sup>3</sup> to 18.4 million m<sup>3</sup> (Miftayugi *et al.*, 2022). The government has carried out sediment dredging for two years to increase the reservoir's capacity. In addition, the government has been conducting cleaning operations for roughly a decade but have not yielded good results (Apzani *et al.*, 2023).

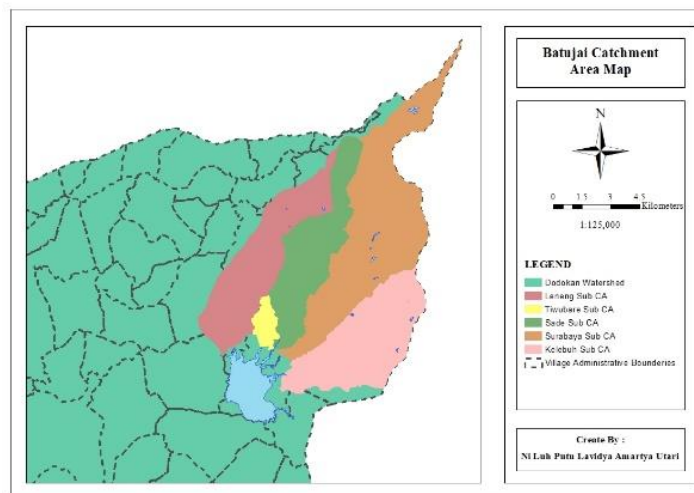
The primary source of reservoir sedimentation is land erosion in river basins. Several methods can be used to estimate the magnitude of erosion; the first is USLE (Universal Soil Loss Equation), a parametric model used to predict erosion from a land area by Wischmier and Smith (1965, 1978). The more data and information generated from research and experiments, the more U.S. soil conservation experts continue to refine the USLE, culminating in the development of the RUSLE (Revised Universal Soil Loss Equation) (Arsyad, 2012) and MUSLE (Modified Universal Soil Loss Equation) is an extension of the USLE equation by replacing the rainfall erosivity factor (R) with the surface runoff factor. The sediment carried into the river is only a portion of the eroded soil.

Based on the erosion rate, the estimation of sedimentation occurring in the watershed area can be calculated. The sediment carried to the watershed outflow should be accurately estimated to create efficient soil erosion management strategies at the watershed scale. The sediment delivery ratio (SDR) is used to explain the potential deposition of eroded soil in the watershed (Park *et al.*, 2010).

This research aims to identify the erosion rate in the Batujai watershed area, which can cause sedimentation in the Batujai dam. The results of the erosion rate and sedimentation rate analysis in this reservoir can be used as a reference for reservoir management and maintenance to address future sedimentation. Along with the development of technology, a spatial database processing system is needed that can accelerate and simplify location detection while also providing an overview of events from the study results so it can be used as a basis for decision-making by agencies. Geographic Information Systems are used with GIS software to achieve that goal.

## RESEARCH METHOD

The location of this research is in the Dodokan watershed, which serves as the rain catchment area for the Batujai Dam. The Batujai Dam is located in Batujai Village, Praya Barat District, Central Lombok Regency, West Nusa Tenggara Province. The analysis was conducted on 5 tributaries that flow into the reservoir, as shown in Figure 1, including the Leneng River (Leneng Sub CA), Tiwubare River (Tiwubare Sub CA), Sade River (Sade Sub CA), Surabaya River (Surabaya Sub CA), and Kelebu River (Kelebu Sub CA) with a catchment area of Batujai of approximately 130.42 km<sup>2</sup> or 13,042 ha.



**Figure 1. Batujai Catchment Area Map**

The empirical models used to predict soil erosion in this study are the USLE (Universal Soil Loss Equation) method and the MUSLE (Modified Soil Loss Equation) method. The general formula used is

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

where E is the amount of land erosion (tons/ha/year), R is the rainfall erosivity index, K is the soil erodibility factor, LS is the length and slope factor, C is the land use factor, and P is the erosion control-practice factor (Saadi *et al.*, 2022).

The driving force that causes soil particles to be detached and transported to lower areas is known as rain erosivity. Rain erosivity partly occurs due to the impact of raindrops directly hitting the ground and partly due to water flow over the surface of the soil. The R factor in the USLE and MUSLE methods differs because the USLE approach uses yearly rainfall erosivity, which may be computed from rainfall data received from rain gauges. The method for determining the magnitude of the rainfall erosivity index, as proposed by Lenvain (Rampu *et al.*, 2021), is as follows

$$R = 2,21 (\text{Rain})^{1,36} \quad (2)$$

Where R is the rainfall erosivity index and (Rain) is monthly rainfall (cm).

Meanwhile, the R Factor in the MUSLE method, which is a modification of the USLE, uses the surface runoff factor to replace the rainfall erosivity factor (Nugraheni *et al.*, 2013) The formula used

$$R = a \times (Vq \times Qp)^b \quad (3)$$

Where R is surface runoff (m<sup>2</sup>/), Vq is surface runoff volume (m<sup>3</sup>), Qp is peak discharge (m<sup>3</sup>/h), a is 11.8 (constant), and b is 0.56 (constant).

Hydrological analysis is conducted to determine the design rainfall that will be used in the peak discharge (Qp) value analysis (Palupi *et al.*, 2023). In the design rainfall analysis, statistical parameter calculations are performed, followed by rainfall distribution analysis to determine the appropriate rainfall distribution type for calculating the design rainfall, and then a goodness-of-fit test for the rainfall data distribution is conducted.

The average rainfall in the Batujai River Basin is determined as the first stage in this study using the Thiessen Polygon method (Rastanto *et al.*, 2022). The R factor of USLE dan MUSLE methods can be calculated using equation (2) and (3).

Factor K indicates the sensitivity level of the soil to erosion. The soil erodibility index shows the vulnerability level of the soil to erosion, which is the retention of particles against erosion and the displacement of soil by the kinetic energy of rainwater. This is influenced by the soil texture, namely the percentage of very fine sand, silt, and clay, soil structure, soil permeability, and soil organic matter content (Auliyani & Wijaya, 2017). The slope length factor (LS) is determined based on the slope class (Kironoto *et al.*, 2021). Factor C is the ratio between the amount of erosion from cultivated land with certain management practices and from uncultivated and clean-tilled land. The effectiveness of plants in preventing erosion increases gradually according to the growth phase of the plants (Arsyad, 2012). Meanwhile, the land conservation factor (P) is the ratio of the amount of soil erosion with a specific conservation action to the amount of soil erosion from the land processed according to the slope direction.

Conservation actions include strip planting, contour tillage, bunding, and terracing (Arsyad, 2012).

Table 1 shows the value of the K factor for the Batujai Catchment Area. In this study, the K factor value is determined based on the guidelines and publications of soil conservation practices in Indonesia published by the institution, namely the Balai Penelitian Tanah (BPT, 1985).

The LS factor values are combined because erosion will increase with the slope and length of the hill. The LS factor values can be seen in Table 2. The C and P factors can be seen in Tables 3 and 4. The C value is based on land use, and the P value is based on conservation actions according to slope gradient.

**Table 1. K-factor values for a few Indonesian soils (BPT, 1985)**

Type of Soil	K-Values
Complex of brown-gray regosol and lithosol	0.172
Brown Mediterranean complex and reddish-brown Mediterranean complex	0.188
Mediterranean brown complex and lithosol	0.323
Mediterranean Chocolate	0.210

**Table 2. LS-factor values and slope class (Kironoto *et al*, 2021)**

Slope Classes	Slope	LS-Values
I	0 - 8	0,40
II	8 - 15	1,40
III	15 - 25	3,10
IV	25 - 40	6,80
V	> 40	9,50

**Table 3. C-factor values based on land use (Arsyad, 2021)**

Land Use Types	C-Values
Settlement	1.00
Rice Field	0.01
Swampy Bush	0.07
Dryland Agriculture	0.10
Water Body	0.05

**Table 4 P-factor values for a range of special soil conservation techniques (Arsyad, 2012)**

Specialized Soil Conservation Techniques	P-values
Bench terrace :	
a. Good construction	0.04
b. Medium construction	0.15
c. Bad construction	0.35
d. Traditional terrace	0.40
Bahlia grass	0.40
Soil management and planting according to slope lines :	
a. slope 0 - 8%	0.50
b. slope 9 - 20%	0.75
c. slope > 20%	0.90

Specialized Soil Conservation Techniques	P-values
No erosion control measures	1.00

The rest of the eroded soil will settle somewhere in the watershed's lower part of the erosion site. The ratio between the amount of sediment transported into the river and the amount of erosion occurring in the watershed is called the Sediment Delivery Ratio (SDR). The sediment delivery ratio (SDR) explains the potential deposition of eroded soil in the watershed. Its definition is the proportion of net soil erosion that leaves a watershed. The formula is :

$$SDR = Y/E \tag{4}$$

where Y is the average annual sediment yield per unit area, and E is the average yearly erosion over the same area (Park *et al.*, 2010).

It estimates the sediment yield transported from the watershed to the watershed outlet. Due to the potential of eroded soil deposition during transportation to the watershed outlet, it usually has a value between 0 and 1. This event is only likely to occur in small watersheds or sub-watersheds that do not have flat areas but have steep slopes, many fine particles (clay) being transported, high drainage density, or are generally said to lack properties that tend to cause sediment deposition on the watershed land. There are several methods available to calculate SDR, one of which is the Boyce equation (Sabila *et al.*, 2020) :

$$SDR = 0.41A^{-0.3} \tag{5}$$

where SDR is the Sediment Delivery Ratio and A is the Area of the catchment basin (km<sup>2</sup>).

## RESULT AND DISCUSSION

The average rainfall is obtained using the Thiessen Polygon method. Based on Figure 2, it can be seen that out of the 4 rain stations, only 3 have an impact on the Batujai Catchment Area: the Batujai Station, with an area of 5.97 km<sup>2</sup>, the Pengadang Station, with an area of 86.69 km<sup>2</sup>, and the Lingkok Lime Station, with an area of 37.76 km<sup>2</sup>.

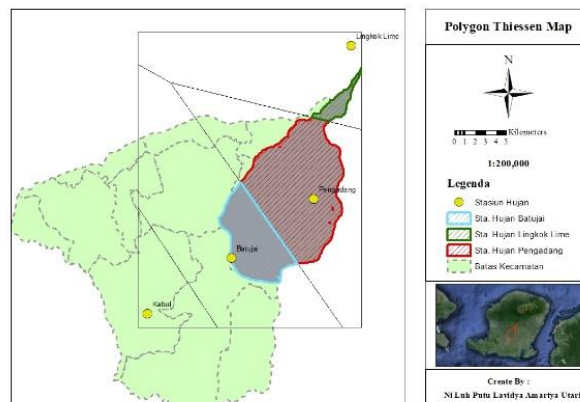


Figure 2. Polygon Thiessen Map

As shown in Table 5, the average annual rainfall can be calculated by multiplying the area of the rain gauge stations obtained from the Thiessen polygon method with the maximum annual daily rainfall.

**Table 5. Maximum Average Rainfall**

Year	Maximum Average Rainfall (mm)	Year	Maximum Average Rainfall (mm)
2000	65.89	2011	75.06
2001	39.55	2012	74.4
2002	66.8	2013	76.17
2003	71.94	2014	88.4
2004	74.35	2015	92.11
2005	72.2	2016	60.16
2006	86.14	2017	81.36
2007	58.58	2018	61.34
2008	42.8	2019	3.6
2009	229.83	2020	75.22
2010	60.43		

The R factor in the USLE method uses monthly rainfall data. The average monthly rainfall in the watershed is calculated using the percentage of the area of each rain gauge station from the Thiessen Polygon calculation, and Parameter R is calculated using the equation (2). The rainfall erosivity value in the Batujai Catchment Area was 25,672.92 cm, and the average rainfall erosivity over 21 years was 1,222.52 cm/year.

In the MUSLE method, the value of R represents the surface runoff. A rain distribution type analysis is then conducted based on the average maximum rainfall results in Table 5. The rain distribution type in the data must be analyzed based on the average maximum rainfall data. The design rainfall for each particular return period will be determined using the type of rain distribution. The data in Table 5 indicates that the kind of distribution is Log Normal; however, there are other forms of rain distribution (Agustian *et al.*, 2018). The short-term rainfall estimates were analyzed using the Log-Normal distribution. This helps determine the depth and intensity of the highest rainfall for different durations at all stations. The rainfall design result using the Log normal distribution is 304.33 mm. To determine the value of R, the values of TC and rainfall intensity (I) need to be determined first using the Nakayasu method and the Mononobe equation (Sihaloho *et al.*, 2020). The value is calculated for each Sub-Catchment Area, as shown in Table 6.

**Table 6. Value of Intensity (I) and coefficient C**

Sub CA	I-Values mm/hour	C-Values
Leneng	95.147	0.25
Tiwubare	170.576	0.44
Sade	102.167	0.23
Surabaya	102.167	0.21
Kelebu	129.815	0.20

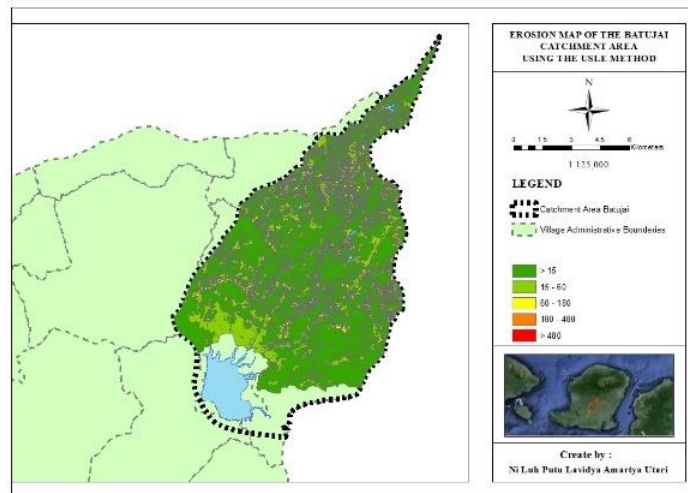
Then, the surface runoff value can be calculated using Equation (3). The value of R is calculated for each Sub-Catchment Area. In the Leneng Sub-CA, the value of R is 969.67 m<sup>2</sup>/hour; in the Tiwubare Sub-CA is 739.03 m<sup>2</sup>/hour; in the Sade Sub-CA is 799.37 m<sup>2</sup>/hour; in the Surabaya Sub-CA is 1,133.91 m<sup>2</sup>/hour; and in the Kelebuh Sub- Catchment Area is 1,064.64 m<sup>2</sup>/hour.

The K factor in the Batujai Catchment Area is determined based on the soil type. The Batujai Catchment Area consists of a complex of grayish-brown regosol and lithosol with a K value of 0.172, a complex of brown Mediterranean and reddish-brown Mediterranean with a K value of 0.188, a complex of brown Mediterranean and lithosol with a K value of 0.323, and brown Mediterranean soil with a K value of 0.210. The LS value is determined based on the slope obtained through GIS analysis and then adjusted according to the values in Table 2. The value of factor C was obtained from land use data provided by the BWS NT-1 agency. The land cover in the Batujai Catchment Area area consists of settlements, rice fields, swampy shrubs, dryland agriculture, and water bodies. The value of P was analyzed based on the slope of the Batujai Catchment Area.

After all factors are known, the erosion rate is calculated using Equation (1). The erosion rate for each Batujai Sub Catchment Area, as in Tables 7 and 8, is calculated using GIS software. The erosion map can be seen in Figures 3 and 4.

**Table 7. Erosion value using the USLE method.**

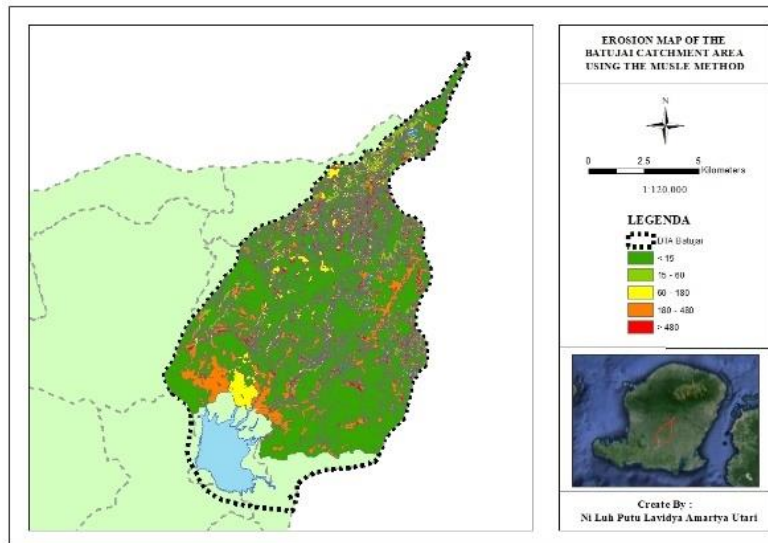
Sub CA	Erosion	
	ton/year	m <sup>3</sup> /year
Leneng	34,173.40	96,768.30
Tiwubare	8,030.13	22,738.78
Sade	32,032.56	90,706.12
Surabaya	106,008.04	300,181.35
Kelebuh	42,334.97	119,879.29
<b>Total</b>	<b>222,579.11</b>	<b>630,273.84</b>



**Figure 3. Erosion Map Using USLE Method**

**Table 8. Erosion value using the MUSLE method.**

Sub CA	Erosion	
	ton/year	m <sup>3</sup> /year
Leneng	41,101.16	116,385.54
Tiwubare	4,854.32	13,745.91
Sade	25,805.28	73,072.41
Surabaya	104,848.53	296,897.98
Kelebu	54,479.14	154,267.76
<b>Total</b>	<b>231,088.44</b>	<b>654,369.59</b>



**Figure 4. Erosion Map Using MUSLE Method**

The Sediment Delivery Ratio (SDR) value of the Batujai Dam was analyzed using the Boyce equation, the results can be seen in Table 9. Then, based on the values in Table 9, the sediment yield value can be calculated using Equation (4).

**Table 9. SDR Value**

Sub CA	Area ha	SDR Boyce
Leneng	2,339.76	0.159
Tiwubare	251.96	0.311
Sade	1,975.33	0.168
Surabaya	3,980.41	0.136
Kelebu	2,479.36	0.156

According to Table 10, it can be estimated that the sedimentation of Batujai Dam based on the Boyce equation is 97,185.80 m<sup>3</sup>/year using the USLE method and 99,496.57 m<sup>3</sup>/year using the MUSLE method.

**Table 10. Sediment Yield value Using Boyce equation**

<b>Sub CA</b>	<b>SDR Boyce</b>	<b>SY (USLE) m<sup>3</sup>/year</b>	<b>SY (MUSLE) m<sup>3</sup>/year</b>
Leneng	0.159	15,408.68	1,8532.38
Tiwubare	0.311	7,065.64	4,271.28
Sade	0.168	15,195.98	12,241.81
Surabaya	0.136	40,755.79	40,310.01
Kelebu	0.156	18,759.71	24,141.10
<b>total</b>		<b>97,185.80</b>	<b>99,496.57</b>

From the analysis results, the total erosion value occurring in the Batujai Catchment Area using the USLE method is 630,273.84 m<sup>3</sup>/year and using the MUSLE method is 654,369.59 m<sup>3</sup>/year. The sedimentation value obtained using the SDR Boyce equation for the USLE method is 97,185.80 m<sup>3</sup>/year and for the MUSLE method is 99,496.57 m<sup>3</sup>/year. The calculation results show that the Surabaya Sub Catchment Area contributes the most erosion and sedimentation to the Batujai Catchment Area compared to other sub catchment area.

## **CONCLUSION**

The conclusion in this study successfully identified the level of erosion and sedimentation in Batujai Reservoir using the USLE and MUSLE methods. The analysis results showed that the annual erosion rate with the USLE method was 630,273.84 m<sup>3</sup>/year and the MUSLE method was 654,369.59 m<sup>3</sup>/year. While the annual sedimentation rate by Boyce method for USLE is 97,185.80 m<sup>3</sup>/year and for MUSLE is 99,496.57 m<sup>3</sup>/year. Surabaya sub-watershed contributes the most to erosion and sedimentation compared to other sub-watersheds. Factors such as rainfall erosivity, soil type, slope length and slope, and land use and soil vegetation directly influence the increase in erosion rates. Erosion tends to be low in areas with gentle slopes and dense vegetation cover. For future research, existing erosion values can be used and grouped into erosion hazard classes, so that subsequent conservation actions can also be determined based on areas with high erosion.

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