Analysis of The Effectiveness of Sediment Control Structures and River Improvement on The Omu River Post-Earthquake in Sigi Regency

Analisis Efektivitas Bangunan Pengendali Sedimen dan Perbaikan Sungai di Sungai Omu Kabupaten Sigi Setelah Bencana Gempa Bumi

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Accepted: 15 June 2023; Revised: 15 November 2023; Approved: 29 June 2024

ABSTRACT

This study aims to analyze the effectiveness of sediment control structures, such as sabo and consolidation dams, and river normalization on sediment control in the Omu River after the earthquake in Sigi Regency on September 28, 2018. The analysis was conducted using the Universal Soil Loss Equation (USLE) method based on average rainfall data over 20 years. Erosion and sedimentation volumes before and after the earthquake were analyzed to understand the changes. The results showed that in 2020, the erosion volume reached 120,700.27 m³/year, and sedimentation was 17,030.81 m³/year, an increase from 2017, which recorded an erosion volume of 91,282.60 m³/year and sedimentation of 12,879.97 m³/year. Sediment transport simulation with daily discharge over 12 years indicated that in Scenario-1, sediment could be reduced by 10.81%, and in Scenario-3 by 23.18%. Meanwhile, simulation with Q100 flood discharge in Scenario-2 showed sediment reduction by 47.18%, and in Scenario-4 by 62.96%. The general conclusion of this study is that sediment control structures and river normalization are effective in reducing sediment volumes. Specifically, the construction of sediment control structures has proven to significantly reduce erosion and sedimentation. This research highlights the importance of structural improvements in mitigating post-disaster erosion impacts. The results of this study can serve as a reference for planning and implementing sediment control in disaster-prone areas.

Keywords: sediment control, sabo dam, consolidation dam, river normalization, Omu river

ABSTRAK

Penelitian ini bertujuan untuk menganalisis pengaruh efektivitas struktur pengendali sedimen, seperti sabo dan konsolidasi dam, serta normalisasi sungai terhadap pengendalian sedimen di Sungai Omu pasca gempa bumi di Kabupaten Sigi pada tanggal 28 September 2018. Analisis dilakukan dengan menggunakan metode USLE (Universal Soil Loss Equation) berdasarkan data curah hujan rata-rata selama 20 tahun. Volume erosi dan sedimentasi sebelum dan sesudah gempa bumi dianalisis untuk mengetahui perubahan yang terjadi. Hasil analisis menunjukkan bahwa pada tahun 2020, volume erosi mencapai 120,700.27 m³/tahun dan sedimentasi sebesar 17,030.81 m³/tahun, meningkat dari tahun 2017 yang mencatat volume erosi sebesar 91,282.60 m³/tahun dan sedimentasi sebesar 12,879.97 m³/tahun. Simulasi transport sedimen dengan debit banjir sebesar 12 tahun menunjukkan bahwa dalam Scenario-1, sedimen dapat direduksi hingga 10,81%, dan pada Scenario-3 hingga 23,18%. Sementara itu, simulasi dengan debit banjir Q100 pada Scenario-2 menunjukkan reduksi sedimen sebesar 47,18%, dan pada Scenario-4 sebesar 62,96%. Kesimpulannya dari penelitian ini adalah bahwa struktur pengendali sedimen dan normalisasi sungai efektif dalam mengurangi volume sedimen. Secara spesifik, pembangunan pengendali sedimen terbukti mampu mereduksi erosi dan sedimentasi secara signifikan. Penelitian ini menunjukkan pentingnya perbaikan struktural dalam mitigasi dampak erosi pasca bencana alam. Hasil penelitian ini dapat menjadi acuan dalam perencanaan dan pelaksanaan pengendalian sedimen di daerah rawan bencana.

Kata Kunci: pengendali sedimen, sabo dam, konsolidasi dam, normalisasi sungai, sungai Omu

DOI: https://doi.org/10.32679/jth.v15i1.749
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INTRODUCTION

On September 28, 2018, there was an earthquake in Central Sulawesi Province, this incident resulted in a tsunami, liquefaction, and landslides in several locations in Central Sulawesi. One of the locations where landslides occurred was in the upper reaches of the Omu River, which is a 3rd order river from the Palu River. (BWS Sulawesi III, JICA, 2022)

The landslide resulted in the entry of avalanche material in the form of soil and rocks into the river flow and carried away by the river flow, causing sedimentation in the lower reaches of the Omu River so that when there is high-intensity rain, the river's capacity cannot accommodate the water discharge. The water mixed with the rest of the avalanche in the form of mud and rocks causing debris flooding which caused damage to the area it was passing through.

The flood incident report stated that due to one day’s rain, there was a debris flood that hit Omu Village, in Gumbasa District, Sigi Regency on April 27, 2019, and July 23, 2020. The debris flood was caused by the overflow of the Omu river which carried sedimentary material in the form of sand and rock, as shown in Figure 1. (BWS Sulawesi III, JICA, 2022)

To handle flooding and sedimentation on the Omu River, the Ministry of Public Works and Housing (PUPR), through BWS Sulawesi III is carrying out work in the form of constructing a sediment control building consisting of 1 sabo dam, 2 consolidation dams, and river improvement (bank strengthening and river normalization) which functions to control the flow of floods and sedimentation downstream of the Omu River where there are settlements.

METHODOLOGY

A. Study Area

The location of this research is on the Omu River in Omu Village, Gumbasa District, Sigi Regency, Central Sulawesi. The Omu River is an order 3 river in the Palu river basin and is a tributary of the Miu River which is a small river with a catchment area of ±12 km². The Omu River is in the Palu-Lariang River Basin (WS). In the lower reaches of the Omu River, it is crossed by the Palu-Kulawi axis provincial road.

The Omu River can be divided based on its flow in the upstream area in the mountains with steep slopes, in general, the river is straight with a little twist with a high flow velocity, while at the mouth it flows into the Miu River which is relatively gentler which causes a lower flow velocity and causes sedimentation, as shown in Figure 2.
For data analysis in this study, the Omu river basin will be divided into 3 (three) sub-basins, the characteristics of each Omu sub-basin can be seen in Table 1 below:

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Sub-basin 1</th>
<th>Sub-basin 2</th>
<th>Sub-basin 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large (Km²)</td>
<td>5.90</td>
<td>5.27</td>
<td>0.83</td>
</tr>
<tr>
<td>Main river length (Km)</td>
<td>7.11</td>
<td>7.64</td>
<td>2.46</td>
</tr>
<tr>
<td>Main river slope</td>
<td>0.175</td>
<td>0.151</td>
<td>0.062</td>
</tr>
<tr>
<td>Subbasin slope</td>
<td>0.566</td>
<td>0.592</td>
<td>0.159</td>
</tr>
</tbody>
</table>

Sources: Delineation Analysis, 2023

B. USLE (Universal Soil Loss Equation)

USLE is an erosion model created to predict the long-term erosion rate of sheet erosion or furrows under certain conditions. USLE was created in collaboration with Purdue University at the National Runoff and Soil Loss Data Center, which was founded in 1954 by The Science And Education Administration, United States (formerly known as the Agricultural Research Service). For statistical analysis, more than 10,000 plot years of surface erosion and runoff data have been submitted on an initiative by federal and state research projects (Alewell et al., 2019) in (Wischmeier & Smith, 1978). Here is the USLE equation:

\[ A = R \cdot K \cdot L \cdot S \cdot C \]  

The USLE equation considers various factors that contribute to erosion and helps to predict the long-term rate of erosion for a specific site. The factors are multiplied to produce a single value that represents the predicted rate of erosion. The resulting value can be used to guide erosion control and conservation practices (Tamire et al., 2022), (Zhidkin et al., 2023).

1) **Rain Erosivity Factor (R):** The rainfall erosivity factor (R factor) is an important factor for soil erosion prediction models such as the Universal Soil Loss Equation Rain (Yue et al., 2020). Erosion is the ability of rainwater to cause erosion which originates from the rate and distribution of raindrops, both of which affect the amount of kinetic energy of rainwater (Qiankun et al., 2022). Rain erosivity factor (R) can be calculated using Lenvain’s equation (1975):

2) **Soil Erosivity Factor (K):** Soil erodibility factor is a quantitative index of soil susceptibility to water erosion (Abdelrahman et al., 2019) (Hong-fen et al., 2019). The K factor is the average annual soil loss in tons/ha/unit El30 as calculated from soil loss in 22.1 m plots on bare land and tilled parallel to a 9% slope (Corral-Pazos-de-Provens et al., 2023), (Yang et al., 2022). The experimentally calculated values range from 0.00 for the most resistant soil to 0.69 for the most eroded soil.

3) **Slope Factor (LS):** L and S values are calculated simultaneously in the form of the LS factor (Wang et al., 2020), which is the ratio of soil lost from one plot to another plot with a length of 22 meters and a slope of 9% (Helmi, 2022) without any effort to prevent erosion, the combination of the slope length factor (L) and slope (S) are slope characteristic factors which are one of the factors influencing erosion.

4) **Land Cover Type Factor (C):** Factor C is shown as a comparative figure related to the annual loss of soil in a vegetated area with the same area if the
area is empty and planted regularly (Bircher et al., 2021). Factor C values ranged from 0.001 in undisturbed forest to 1.0 in bare soil. Among the USLE factors, the cover-management factor (C-factor) is perhaps the most important factor regarding the sensitivity of the computed soil loss (Prasuhn, 2022).

5) Land Management Factor (P): Soil conservation factor is a preservation measure that includes efforts to reduce soil erosion, namely mechanically and biologically/vegetation. P values range from 0 for soils with perfect erosion control practices, to 1 for soils with no erosion control measures. The vegetation cover index (C) and land management index or soil conservation measures (P) can be combined into a CP factor

6) Sediment Delivery Ratio (SDR): SDR comes with a long history of criticism regarding incomplete or ineffective accounting for sediment transfer between source and sink (Jong et al., 2022). Many studies related to SDR have been carried out around the world. (Roehl, 1962) in (Kironoto et al., 2020) argue that the size of the SDR tends to be inversely proportional to the area of the watershed, the wider the watershed, the smaller the SDR value. According to (Boyce 1975) the steepest area of the watershed is the main sediment-producing zone, and since the average slope decreases with increasing watershed size, sediment production per unit area will also decrease. Large watersheds also have larger sediment deposition sites which are located between the sediment source area and the watershed outlet or measurement point. This study will use the SDR equation developed by the USDA (1971) as follows:

$$ SDR = 0.375 \ A_{DAS}^{-0.135} - 0.127 \ ......................(2) $$

Where:
- SDR : Sediment Delivery Ratio (in %)
- A_DAS : Watershed area (in Km²)

C. Debris Flow Discharge Design

Based on the guidelines of the Sabo Work Manual (DPWH & JICA, 2010), the flood discharge containing sediment is determined using the 100 years-flood return period (Q100) design discharge. The flood discharge flow containing sediment is determined by the following equation:

$$ Q_s = Q_w \times (1 + Cd) \ ......................(3) $$

Where:
- Qs : Flood discharge with sediment (m³/sec),
- Qw : Design flood discharge (m³/sec)

To find the value of Cd can use the formula developed by Takahashi (Takahashi, 2007) as follows:

$$ Cd = \frac{\rho_w Tan \theta}{(\rho_m - \rho_w)(Tan \theta - Tan \theta)} \ ......................(4) $$

Where:
- Cd : concentration of sediment in the stream (%)
- C* : concentration of sediment deposited (0.6)
- \( \rho_w \) : density of water (tons/m³)
- \( \rho_m \) : density of sediment (tons/m³)
- \( \theta \) : internal shear angle (°)
- \( \theta \) : average slope of the riverbed

If the calculated value (Cd) is greater than 0.9 C*, Cd should be considered as 0.9 C*, and if it is less than 0.3, then it is considered as 0.3.

D. Sediment Transport

The sediment transport modeling is crucial to simulating and predicting big-scale and long-term morphological changes in different natural environmental areas (Bautista-Parada et al., 2022). Sediment transport or transport is the movement of sediment caused by river flow. According to (Fredsoe & Deigaard, 1992) sediment transport is divided into three, namely:

1) Bedload Sediment Transport: The sediment that is continuously moving with the bed during sediment transport is known as Bedload sediment transport which is part of the total sediment, especially when it comes to sand grains rolling, shifting, or hopping along the bed. The bed load sediment transport is governed by active shear stresses acting directly on the grain surface. Depending on the velocity of the sediment, the three main ways that sediment particles travel during movement are rolling, sliding, and saltation.

2) Suspended Load: The sediment known as Suspended load is that part of the total sediment which is not in direct contact with the moving bed as a result of agitation and fluid movement resulting from turbulence. For a certain period, the turbulent flow keeps the sediment floating.

3) Wash Load: Very few particles in the Wash load are carried by the water but do not sink to the bottom. Wash load is not taken into account when calculating the total sediment discharge because knowledge of the base composition cannot predict the amount of transported wash load.

In the HEC-RAS software, sediment transport modeling is carried out using a quasi-unsteady flow scheme, where the duration of the flow is then divided into intervals called computational increments, then in the computational increments it is further divided into several intervals to account for the armoring that occurs in the river. This process is referred to as the bed mixing time step.
Calculation of sediment load flux in the Exner equation as follows:

\[
(1 - \lambda_p)B \frac{g_n}{\partial t} = - \frac{\partial g_{se}}{\partial x} \quad \ldots \ldots \ldots (5)
\]

Calculation of sediment load flux in the Exner equation above uses the sediment transport equation which in this study will use the equation of the Toffaleti function (Toffaleti, 1968), (Pietroń et al., 2015), (Bidorn et al., 2016). (Toffaleti 1968) in (Gibson & Sánchez, 2020) is a total load function developed especially for sand-sized particles, which follows the basic principles of the Einstein approach, replacing some empirical assumptions. Toffaleti is usually applied to 'large rivers' since most of the data used to develop them comes from large suspended load systems, this function describes the relationship between sediment, hydraulics, and water temperature by a series of regression functions.

4) The Toffaleti model divides the water column into four vertical zones and the sediment transport is calculated independently for each zone and summed to obtain the total sediment transport value. The four zones are based on theoretical inflection points and transitions in the vertical velocity profile. The function then calculates the sediment transport in each zone based on "sediment discharge reference units" (Gibson & Sánchez, 2020). In general, the form of the Toffaleti equation for each zone is as follows:

**Upper Zone**:  
\[
g_{ssl} = M \left( \frac{R}{152} \right)^{0.244z} \left( \frac{R}{25} \right)^{0.52z} \left[ \frac{1+n_v^{1.5z}}{0.1198 + 0.000048T} - 0.756z \right] \quad \ldots \ldots (6)
\]

**Bed Zone**:  
\[
g_{sb} = M(2d_m)^{1+n_v^{0.756z}} \quad \ldots \ldots \ldots (7)
\]

**Middle Zone**:  
\[
g_{ssl} = M \left( \frac{R}{152} \right)^{0.244z} \left( \frac{R}{25} \right)^{0.52z} \left[ \frac{1+n_v^{1.5z}}{0.1198 + 0.000048T} - 0.756z \right] \quad \ldots \ldots (7)
\]

**Lower Zone**:  
\[
g_{ssl} = M \left( \frac{R}{152} \right)^{0.244z} \left( \frac{R}{25} \right)^{0.52z} \left[ \frac{1+n_v^{1.5z}}{0.1198 + 0.000048T} - 0.756z \right] \quad \ldots \ldots (7)
\]

E. Data Collection

Hydraulic analysis was carried out to model flood conditions with the influence of sediment in the study area. Modeling is done with the help of HEC-RAS software for unsteady flow types. The data used for this modeling include:

1) Data on topographic measurements and cross sections of the Omu River obtained from BWS Sulawesi III and DEM (Digital Elevation Model) obtained from BIG in the existing conditions and after the construction of sabo and dam consolidation and river improvement work (bank strengthening and river normalization).

2) Rain data from the Tuva station, this post is ± 2.7 km from the Omu watershed. Based on data from the BWS Sulawesi Hydrology Unit III, Tuva Station has a data length of 20 years from 2002 to 2021.

The boundary conditions in the upstream section are in the form of flood discharge with a return period of Q100 in sub-basin 1 and 2, this return period is based on the reference from the Manual of Sabo Work issued by JICA for sediment control structures in the form of sabo. By using the HEC-HMS (Scharffenberg et al., 2018) software, the respective hydrographs of the Omu sub-basin are obtained, namely sub-basin 1 (Figure 5) and sub-basin 2 (Figure 6) with the Snyder synthetic unit hydrograph. Then the results of the hydrograph on sub-basin 2 above are multiplied by the discharge coefficient which is affected by sediment based on the results of the previous C_d (sediment concentration) calculation with a coefficient value of 1.3 or Q_s = 1.3 Q_w.
4) Bed gradation data uses grain size data from the results of data collection in the field with a total of 5 (five) samples. The following are the coordinates of the location for sampling bed gradation data on the Omu River (green spots), as shown in Figure 9.

3) Upstream boundary condition data, namely synthetic daily discharge data using the Sacramento model for 12 years (2010-2021), as shown in Figure 7 and Figure 8.

The grain gradation sample data is then carried out by grain size analysis to obtain a grain size distribution curve at each collection point, where this data will be used as input properties for each cross-section in HEC-RAS. At locations where there is no grain size distribution curve data, interpolation is carried out using the data between the blank data. The grain size distribution curve at the upstream of each sub-basin can be seen in Figures 10 and 11 below:
5) Sediment boundary data upstream, namely in the form of sediment rating curve from measurements in the field in July-August 2022 which were taken from sub-basin 1 and sub-basin 2 respectively. The location of sediment sampling can be seen in Figure 12 below:

![Figure 12 Location of sediment sampling](sources)

The sediment rating curve was calculated using instantaneous discharge primary data and discharge data taken under normal conditions and during rainy conditions where the water of the Omu River is cloudy. The results of calculating instantaneous discharge and sediment discharge at the study location can be seen in the Table 2 and Table 3 below:

<p>| Table 2 Sediment Discharge in Sub-basin 1 |</p>
<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Qw (m³/sec)</th>
<th>C (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25/7/2022</td>
<td>0.117</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>25/7/2022</td>
<td>0.127</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>5/8/2022</td>
<td>0.141</td>
<td>16.2</td>
</tr>
<tr>
<td>4</td>
<td>5/8/2022</td>
<td>0.151</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Sources: Analysis, 2023

<p>| Table 3 Sediment Discharge in Sub-basin 2 |</p>
<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Qw (m³/sec)</th>
<th>C (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14/7/2022</td>
<td>0.214</td>
<td>655.4</td>
</tr>
<tr>
<td>2</td>
<td>25/7/2022</td>
<td>0.199</td>
<td>387</td>
</tr>
<tr>
<td>3</td>
<td>25/7/2022</td>
<td>0.203</td>
<td>390</td>
</tr>
<tr>
<td>4</td>
<td>5/8/2022</td>
<td>0.153</td>
<td>199.8</td>
</tr>
<tr>
<td>5</td>
<td>5/8/2022</td>
<td>0.155</td>
<td>208.6</td>
</tr>
</tbody>
</table>

Sources: Analysis, 2023

![Figure 13 Sediment Discharge Curve in Sub-Basin 1](y = 44.907ln(x) + 98.784)

**ANALYZE METHOD**

In general, this research is divided into 2 main studies, namely soil erosion analysis (USLE) and sediment transport. USLE (Universal Soil Loss Equation) analysis was carried out with the help of GIS software. From the results of the analysis, a map of the distribution of erosion, the level of erosion hazard, and a map of the sediment transport capacity will be obtained. The steps in this analysis are as follows:

1) Calculation of the erosivity of rain (R): Calculation of the erosivity of rain is carried out using the equation put forward by Lenvain (1975), the data used uses postal rain data from 2002 to 2021 (20 years).

2) Calculation of Soil Erodibility Value (K): Calculation of soil erodibility value is carried out using soil type and texture data issued by FAO.

3) Calculation of Slope Length and Slope (LS) Index Values: Length and slope (LS) index values are obtained by first processing DEM data to obtain a map of slope class classes in the Omu watershed using GIS software.

4) Calculation of Land Cover and Soil Conservation (CP) Index Values: The data needed are land cover maps in 2017 and 2020. The better the protection of the soil surface by food crops/vegetation, the lower the erosion rate.

5) Calculation of the Erosion Rate (USLE): The data is then processed using GIS software using the USLE method and displayed in the form of a graph.
spatial map. Based on the map, an analysis was carried out to obtain the area of eroded land, erosion volume, and sedimentation rate for each erosion hazard class. The sedimentation rate is obtained by dividing the erosion rate by the specific gravity of the soil and then multiplying it by the SDR (Sediment Delivery Ratio) value.

Then for sediment transport analysis using the toffaleti function equation and using HEC-RAS (Brunner, 2021) software. Simulations will be carried out with Q100 flood discharges and daily discharges for 12 years to see changes in river morphology and the amount of sediment transport in existing conditions and designs where sabo dams, consolidation dams have been built and river improvement (bank strengthening and river normalization).

The flow of the implementation of this research can be seen in the Figure 15 below:

![Figure 15 Research Flow Chart](image)

**RESULTS AND DISCUSSION**

A. Land Erosion Analysis

After the parameter values (R, K, LS, CP) for calculations are obtained, these values are overlaid using GIS software to obtain a map of the magnitude of land erosion. The following is the result of a map of the magnitude of land erosion in the Omu watershed in 2017 (Figure 17) and 2020 (Figure 16):

![Figure 16 Omu Watershed Erosion Hazard Map 2020](image)

![Figure 17 Omu Watershed Erosion Hazard Map 2017](image)

Based on the map, an analysis was carried out to obtain the area of eroded land, erosion volume, and sedimentation rate for each erosion hazard class (KBE). Erosion hazard assessment, also called erosion hazard level (TBE), is determined based on a comparison between the actual level of soil erosion and the level of soil erosion that can be tolerated. The erosion risk criteria aim to determine the regional distribution of erosion levels so that recommendations for conservation action can be prepared. Classes based on the calculation of the level of erosion hazard can be determined by entering the classification in the following Table 4:
The sedimentation rate is obtained by dividing the erosion rate by the specific gravity of the soil and then multiplying it by the SDR (Sediment Delivery Ratio) value. For the calculation of the SDR value using the equation from USDA (1972) as follows:

\[
SDR = 0.375 A_D^{0.135} - 0.127 \quad \ldots \ldots (17)
\]

\[
= 0.375 \times 12^{0.135} - 0.127
\]

\[
= 14.11\% 
\]

Based on the calculation above, the SDR value for the Omu watershed with an area of 12 km² is 14.11%, then the calculation of the sedimentation rate for the Omu watershed in 2017 and 2020 is carried out. The calculation results can be seen in Table 5 and Table 6 below:

**Table 4 Classification of Erosion Hazard Levels**

<table>
<thead>
<tr>
<th>No</th>
<th>KBE (Erosion Hazard Class)</th>
<th>Soil Loss (ton/ha/year)</th>
<th>TBE (Erosion Hazard Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I</td>
<td>&lt;15</td>
<td>Very Light</td>
</tr>
<tr>
<td>2.</td>
<td>II</td>
<td>15-60</td>
<td>Light</td>
</tr>
<tr>
<td>3.</td>
<td>III</td>
<td>&gt;60-180</td>
<td>Medium</td>
</tr>
<tr>
<td>4.</td>
<td>IV</td>
<td>&gt;180-480</td>
<td>Heavy</td>
</tr>
<tr>
<td>5.</td>
<td>V</td>
<td>&gt;480</td>
<td>Very Heavy</td>
</tr>
</tbody>
</table>

*Sources: Ministry of Forestry, 1998*

B. Layout and Modelling

The following is the layout and modeling scheme used in the sediment transport simulation using HEC-RAS (Brunner, 2021) 1D software, as shown in Figure 18 and Figure 19.

**Figure 18 Model Schematic and Boundary Conditions**

**Figure 19 Layout of Modeling**
To model the Sabo dam using an inline structure based on planning data, where the Sabo dam is a closed type with 8 drip holes with a size (1.2 x 3 meters), the base elevation of the drip hole is +196.5 and for the crest elevation it is at an elevation of +196.5 with a width at the bottom of the crest 30 meters. The crest of the sabo functions as a traffic bridge for residents and access to the raw water bridge. Sabo Dam modeling as shown in Figure 20.

![Figure 20](image)

Figure 20 Sabo Dam Modeling

For dam consolidation, it is planned to build 2 units, which are the same as the previous Sabo Dam building, where the inline structure will be used for modeling. For Consolidation Dam 1 (CD-1) is a closed type with a crest elevation of +151.35. Whereas Consolidated Dam 2 (CD-2) is also a closed type with 6 drip holes in the shape of a circle with a diameter of 0.5 meters, for the drip hole configuration at the bottom consists of 4 drip holes at an elevation of +162, the top consists of 2 fruit drip hole at +163 elevation. Dam Consolidation modeling as shown in Figure 21 and Figure 22:

![Figure 21](image)

Figure 21 Consolidation Dam-1 Modelling (CD-1)

![Figure 22](image)

Figure 22 Consolidation Dam-2 Modelling (CD-2)

For modeling the river improvement in the form of strengthening the cliffs using concrete and river normalization at STA-A2 to STA-A15, the river improvement will be built between Consolidation Dam-1 (CD-1) and Consolidation Dam-2 (CD-2), with a plan channel width of 15 meters and a channel base elevation according to existing conditions of +150.75 at the river estuary and +161.03 at the end of the channel.

C. Manning Value and Boundary Conditions

Because the Omu River is a natural river with relatively natural conditions and consists of rocks and sand from upstream to downstream, the Manning value will be made uniform with one value. Using the Manning equation with the assumption of uniform flow, an analysis can be carried out to determine the Manning value for the Omu River using hydrometric data (discharge and river cross section) and topographic data (river bed slope). The following are the results of Manning's roughness coefficient analysis:

Based on the calculation of the Manning roughness coefficient (Table 7), a value of 0.0486 is obtained, where this value needs to be calibrated using steady flow simulation using the HEC-RAS software.

For the boundary condition of the downstream part of the Omu River, which is the confluence of the Omu River and the Tuva River, where the water level in the Tuva River is relatively constant and there is limited water level data in the Tuva River, a decision was made for the downstream boundary condition using normal dept based on the slope of the Omu River with a value 0.04.

### Table 7 Calculation of Manning Roughness Coefficient

<table>
<thead>
<tr>
<th>No</th>
<th>Q (m³/s)</th>
<th>D (m)</th>
<th>B (m)</th>
<th>P (m)</th>
<th>A (m²)</th>
<th>R (m)</th>
<th>S</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.343</td>
<td>0.120</td>
<td>2.250</td>
<td>2.518</td>
<td>0.277</td>
<td>0.110</td>
<td>0.042</td>
<td>0.0380</td>
</tr>
<tr>
<td>2</td>
<td>0.345</td>
<td>0.120</td>
<td>2.250</td>
<td>2.518</td>
<td>0.277</td>
<td>0.110</td>
<td>0.042</td>
<td>0.0378</td>
</tr>
<tr>
<td>3</td>
<td>0.283</td>
<td>0.134</td>
<td>2.150</td>
<td>2.450</td>
<td>0.298</td>
<td>0.122</td>
<td>0.042</td>
<td>0.0529</td>
</tr>
<tr>
<td>4</td>
<td>0.294</td>
<td>0.146</td>
<td>2.150</td>
<td>2.476</td>
<td>0.324</td>
<td>0.131</td>
<td>0.042</td>
<td>0.0582</td>
</tr>
<tr>
<td>5</td>
<td>0.338</td>
<td>0.131</td>
<td>2.650</td>
<td>2.944</td>
<td>0.357</td>
<td>0.121</td>
<td>0.042</td>
<td>0.0530</td>
</tr>
<tr>
<td>6</td>
<td>0.348</td>
<td>0.131</td>
<td>2.650</td>
<td>2.944</td>
<td>0.357</td>
<td>0.121</td>
<td>0.042</td>
<td>0.0515</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.0486</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: Analysis, 2023
D. Model Verification

Due to the limited collection of sediment data in the field, model verification was carried out using the sediment volume approach for 1 (one) year based on USLE analysis after the landslide occurred. The value of the USLE will be compared to the hydraulic simulation of sediment transport for 1 (one) year based on the sediment rating curve data that has been obtained in the field. The concept of sediment modeling verification can be seen in Figure 24 below:

![Figure 24: Sediment modeling verification concept](image)

Sources: DEMNAS, Analysis, 2023

Based on the USLE 2020 analysis, a sediment value of 17,031 m³/year was obtained, and based on a sediment transport simulation using quasi-unsteady with 2020 data using the HEC-RAS software for 1 year, a sediment value of 15,858 m³/year was obtained, where there was a difference of 1,173 m³/year or 7.4%, where these results are good enough and representative for sediment analysis using a sediment rating curve which will be used as a boundary condition in the upper reaches of the Omu river considering the limitations in data collection in the field.

E. Modeling Scenario

Before carrying out the sediment transport modeling scenario, a simulation will be carried out in the existing conditions to see changes in morphology and sediment transport in the Omu River in the existing conditions before the construction of sediment control structures (sabo and consolidation dam) and river improvement (bank strengthening and river normalization). Using the boundary condition of low flow discharge data for 12 years (2010-2021), and the Q100 flood discharge obtained in the previous hydrological analysis. After simulating sediment transport under existing conditions, simulations will then be carried out using several scenarios (Table 8) as follows:

1) Scenario-1: namely 1D sediment transport modeling in conditions after the construction of Sabo dam and consolidation dam-1 and river improvement (without consolidation dam-2) using boundary condition data of low flow discharge for 12 years (2010-2021).

2) Scenario-2: the same as scenario 1 but using the boundary condition in the form of a Q100 flood discharge obtained in the previous hydrological analysis.

3) Scenario-3: namely 1D sediment transport modeling in conditions after the construction of a complete sediment control structures (sabo and consolidated dams 1-2) and river improvement using low flow discharge boundary condition data for 12 years (2010-2021).

4) Scenario-4: the same as scenario 3 but using the boundary condition in the form of a Q100 (100 Years Return Period) discharge obtained in the previous hydrological analysis.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Discharge (Boundary Condition)</th>
<th>Building Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing (12 Years)</td>
<td>Daily Discharge</td>
<td>Sabo Dam</td>
</tr>
<tr>
<td>Existing (Q100)</td>
<td>Q100 Discharge</td>
<td>No</td>
</tr>
<tr>
<td>Scenario-1</td>
<td>Daily Discharge</td>
<td>Yes</td>
</tr>
<tr>
<td>Scenario-2</td>
<td>Q100 Discharge</td>
<td>Yes</td>
</tr>
<tr>
<td>Scenario-3</td>
<td>Daily Discharge</td>
<td>Yes</td>
</tr>
<tr>
<td>Scenario-4</td>
<td>Q100 Discharge</td>
<td>Yes</td>
</tr>
</tbody>
</table>

F. Modeling Results

To see the effectiveness of the construction of sediment control structures and river improvement (bank strengthening and river normalization) in
reducing the sediment load on the Omu River, a 12-year simulation will be carried out.

After simulating using synthetic daily discharge (Sacramento model) for 12 years under existing conditions, at STA-A2 which is the estuary of the Omu river, a total sediment of 92,647.22 m$^3$ / 12 years was obtained. After conducting simulations using sediment control structures in the form of sabo-dam, consolidation dam, and river enhancement (bank strengthening and river normalization) it was found that these buildings can reduce sediment to 71,175.91 m$^3$ / 12 years or 23.18%. The following is a recapitulation of sediment transport over 12 years, as shown in Table 9 and Figure 25.

**Table 9 Sediment Transport for 12 Years**

<table>
<thead>
<tr>
<th>No</th>
<th>STA</th>
<th>Cumulative Sediment Transport (m$^3$)</th>
<th>% Reduction From Existing Conditions</th>
<th>Description/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Existing</td>
<td>Scenario-1</td>
<td>Scenario-3</td>
</tr>
<tr>
<td>1</td>
<td>A49</td>
<td>89,027.27</td>
<td>79,614.69</td>
<td>79,914.70</td>
</tr>
<tr>
<td>2</td>
<td>A47</td>
<td>89,233.86</td>
<td>79,620.05</td>
<td>79,872.77</td>
</tr>
<tr>
<td>3</td>
<td>A46</td>
<td>89,514.00</td>
<td>79,970.63</td>
<td>80,210.54</td>
</tr>
<tr>
<td>4</td>
<td>A45</td>
<td>89,587.41</td>
<td>80,116.26</td>
<td>80,369.39</td>
</tr>
<tr>
<td>5</td>
<td>A14</td>
<td>91,956.31</td>
<td>82,601.89</td>
<td>70,833.27</td>
</tr>
<tr>
<td>6</td>
<td>A13</td>
<td>92,017.08</td>
<td>82,554.96</td>
<td>70,853.45</td>
</tr>
<tr>
<td>7</td>
<td>A12</td>
<td>92,101.51</td>
<td>82,607.99</td>
<td>70,945.88</td>
</tr>
<tr>
<td>8</td>
<td>A11</td>
<td>92,296.29</td>
<td>82,638.74</td>
<td>70,999.73</td>
</tr>
<tr>
<td>9</td>
<td>A2</td>
<td>92,647.22</td>
<td>82,633.98</td>
<td>71,175.91</td>
</tr>
</tbody>
</table>

**Figure 25 Comparison of Cumulative Sediment Transport in Existing Conditions and Scenarios Using Daily Discharge for 12 Years**

Based on the cumulative sediment transport comparison graph above (Figure 25), it can be seen that when the existing conditions at STA-A2 or the Omu river estuary there was a cumulative sediment transport of 92,647.22 m$^3$/12 years, after simulating with scenario-1, the cumulative sediment transport decreased to 82,633.98 m$^3$/12 years or 10.81%. In the simulation using scenario-3, the sediment transport decreased to 71,175.91 m$^3$/12 years or 23.18%.

Based on the graph, it can also be seen that in scenario-3 at the location of Sabo and consolidation dam-2 there is a change in sediment transport where downstream of Sabo dam there is a decrease of 10% while in downstream consolidation of dam-2 there is a decrease of 23%.

The following is a recapitulation of sediment effectiveness/reduction from existing conditions based on scenario-1 and scenario-3 using daily discharges for 12 years from 2010 to 2021 (12 years) at the STA-A2 location or the estuary of the Omu River.

Based on the graph below the effectiveness of the sediment control building (Figure 26)
scenario-1, the equation value is obtained, namely $y = 0.3206x^2 - 7.1263x + 50.99$ with $R^2 = 0.9923$ and in scenario-3, the equation value is obtained, namely $y = 0.365x^2 - 8.6538x + 75.834$ with $R^2 = 0.9829$.

It can be seen that the effectiveness of sediment control structures at STA-A2 or the estuary of the Omu River (Table 10) in scenario-1 in the first year (2010) only reached 45.48%, while in scenario-3 it reached 70.69%. In the 12th year (2021) the effectiveness value in scenario-1 drops to 10.81% and in scenario-3 it becomes 23.18%. Assuming the effectiveness of the control structure is in the range of 50%, to improve the function of the sediment control structure, it is necessary to carry out dredging or sabo maintenance in the 4th year in scenario-3 and the 1st year for scenario-1.

**Table 10 Sediment Control Effectiveness for 12 Years**

<table>
<thead>
<tr>
<th>Years</th>
<th>Cumulative Sediment Transport (m³)</th>
<th>% Reduction From Existing Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing</td>
<td>Scenario-1</td>
</tr>
<tr>
<td>2010</td>
<td>15,902.62</td>
<td>8,670.15</td>
</tr>
<tr>
<td>2011</td>
<td>18,693.28</td>
<td>11,538.02</td>
</tr>
<tr>
<td>2012</td>
<td>27,255.45</td>
<td>18,697.38</td>
</tr>
<tr>
<td>2013</td>
<td>34,351.33</td>
<td>25,480.74</td>
</tr>
<tr>
<td>2014</td>
<td>40,280.86</td>
<td>31,284.69</td>
</tr>
<tr>
<td>2015</td>
<td>43,903.72</td>
<td>34,830.87</td>
</tr>
<tr>
<td>2016</td>
<td>50,428.97</td>
<td>41,355.02</td>
</tr>
<tr>
<td>2017</td>
<td>65,180.11</td>
<td>55,523.05</td>
</tr>
<tr>
<td>2018</td>
<td>74,448.02</td>
<td>64,633.04</td>
</tr>
<tr>
<td>2019</td>
<td>78,823.31</td>
<td>69,028.41</td>
</tr>
<tr>
<td>2020</td>
<td>89,361.36</td>
<td>79,328.10</td>
</tr>
<tr>
<td>2021</td>
<td>92,647.22</td>
<td>82,633.98</td>
</tr>
</tbody>
</table>

Figure 26 Sediment Control Effectiveness for 12 Years

Then based on the simulation using the Q100 flood discharge in the existing conditions (Table 11), at STA-A2 which is the estuary of the Omu river, a total sediment of 2,566.84 m³ was obtained. After the simulation with scenario-2, the sediment transport decreased to 1,355.91 m³ or 47.18%. In the simulation using scenario-4 it was found that the building can reduce sediment to 950.84 m³ or 62.96%. The following is a summary of the sediment transport simulation with the Q100 flood discharge:

Based on the cumulative sediment transport comparison graph below (Figure 27), it can be seen that in scenario-4 at the location of the sabo building and consolidation dam, there is a change in sediment transport, whereas downstream of the sabo dam there is a decrease of 80-93%, while at the...
downstream consolidation of dam-2, there is a decrease of 72-79%.

Based on simulations using daily discharge and Q100 flood discharge, it was found that when simulating using daily discharge for 12 years (Figure 25) the CD-2 dam was more effective in capturing sediment than the sabo-dam. When the simulation uses Q100 flood discharge (Figure 27), sabo-dam building is more effective than consolidation dam.

**Table 11** Sediment Transport with Q100 (100 Years Return Period) Flood Discharge

<table>
<thead>
<tr>
<th>No</th>
<th>STA</th>
<th>Cumulative Sediment Transport (m³)</th>
<th>% Reduction From Existing Conditions</th>
<th>Description/ Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Existing</td>
<td>Scenario-2</td>
<td>Scenario-4</td>
</tr>
<tr>
<td>1</td>
<td>A49</td>
<td>2,054.86</td>
<td>142.86</td>
<td>93.05</td>
</tr>
<tr>
<td>2</td>
<td>A47</td>
<td>2,229.41</td>
<td>355.03</td>
<td>84.08</td>
</tr>
<tr>
<td>3</td>
<td>A46</td>
<td>2,302.20</td>
<td>422.27</td>
<td>81.66</td>
</tr>
<tr>
<td>4</td>
<td>A45</td>
<td>2,320.38</td>
<td>448.75</td>
<td>80.66</td>
</tr>
<tr>
<td>5</td>
<td>A14</td>
<td>2,374.02</td>
<td>932.96</td>
<td>79.36</td>
</tr>
<tr>
<td>6</td>
<td>A13</td>
<td>2,386.53</td>
<td>975.47</td>
<td>77.34</td>
</tr>
<tr>
<td>7</td>
<td>A12</td>
<td>2,415.46</td>
<td>1,041.33</td>
<td>74.85</td>
</tr>
<tr>
<td>8</td>
<td>A11</td>
<td>2,442.42</td>
<td>1,094.86</td>
<td>72.93</td>
</tr>
<tr>
<td>9</td>
<td>A2</td>
<td>2,566.84</td>
<td>1,355.91</td>
<td>62.96</td>
</tr>
</tbody>
</table>

**Figure 27** Comparison of cumulative sediment transport in existing conditions and scenarios using Q100 (100-year return period) flood discharge.

**CONCLUSION**

The analysis using the Universal Soil Loss Equation (USLE) conducted before (2017) and after (2020) the earthquake, utilizing 20-year average rainfall data, reveals a significant increase in erosion and sedimentation volumes in the Omu River. Specifically, the erosion volume rose from 91,282.60 m³/year in 2017 to 120,700.27 m³/year in 2020, while sedimentation increased from 12,879.97 m³/year to 17,030.81 m³/year over the same period. These results indicate that the earthquake had a considerable impact on the erosion and sedimentation dynamics in the region.

In terms of sediment control effectiveness, simulations of sediment transport under existing conditions at STA-A2 produced a total sediment volume of 92,647.22 m³ over 12 years. Following the implementation of sediment control structures and river improvements, notable reductions in sediment volume were observed. In Scenario-1, the sediment volume decreased to 82,633.98 m³ over 12 years, representing a reduction of 10.81%, as described by the equation $y=0.3206x^2-7.1263x+50.99$ with $R^2=0.9923$. Scenario-3 saw an even greater reduction, with the sediment volume decreasing to 71,175.91 m³ over 12 years, a
Analysis of The Effectiveness of Sediment Control Structures and River Improvement on The Omu River...
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reduction of 23.18%, described by the equation y=0.365x² + 8.6538x + 75.834 with R²=0.9829.

When simulating sediment transport using Q100 flood discharge, the existing conditions at STA-A2 yielded a total sediment volume of 2,566.84 m³. After implementing sediment control measures, Scenario-2 reduced the sediment volume to 1,355.91 m³, a reduction of 47.18%, while Scenario-4 achieved a reduction to 950.84 m³, or 62.96%.

The study concludes that sabo dams are more effective in capturing sediment during flood conditions or when flows are characterized by high speed and energy, compared to consolidation dams which are more effective at capturing sediment during low flow rates or daily discharges. This underscores the critical role of structural improvements, such as sabo and consolidation dams, and river normalization in mitigating the impacts of erosion and sedimentation, particularly in the aftermath of natural disasters. The research highlights the need for tailored sediment control strategies to address specific flow conditions and enhance sediment management in disaster-prone areas.

ACKNOWLEDGMENT
This study was supported by Institut Teknologi Bandung Research (Riset ITB 2022), P2MI ITB 2022, Riset Unggulan 3P 2022, and the Ministry of Public Works and Housing, Indonesia.

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