

Study of Sedimentation Control on Bangga River Palu Watershed Central Sulawesi

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Abstract.

Bangga River is located in a mountainous area in the Palu River Basin with an area of 74.82 km² and a river length of 16.97 km. Flood with the approximated water depth of 3 m occur in Bangga's Village. The cliffs upstream of the Bangga River are unstable and can easily collapse due to the disaster. Ministry of Public Works and Housing control through Sabo dam's structure. This study aims to analyze the performance of sabo dam's structure in reducing sediments and the floods. Analysis and modeling using two scenarios, before and after the sabo dam structure's control was built, using HEC-RAS Software with purposeful 1D modeling to simulate flow patterns, total sediment. The HEC-RAS simulation shows that the water surface is stood at 2.1 m depth in the existing condition. Sabo dam structure can reduce of sediment transport, which was computed according to Engelund (81% reduction), Mayer Peter Muller (MPM) with 92% reduction, and Yang (91% sediment yields reduction). So, the sabo dam's structure is not merely utilized to retain the sediment, but it can reduce potential flooding in the future.

Keywords: Sedimentation, sediment control building, HEC-RAS, sabo dam, flood.

Abstrak.

Sungai Bangga terletak di daerah pegunungan di DAS Palu dengan luas 74,82 km² dan memiliki panjang sungai 16,97 km. Banjir dengan kedalaman air + 3 m terjadi di Desa Bangga. Tebing-tebing di hulu Sungai Bangga tidak stabil dan mudah runtuh akibat bencana. Kementerian Pekerjaan Umum dan Perumahan Rakyat mengontrol melalui bangunan Sabo dam. Penelitian ini bertujuan untuk menganalisis kinerja bangunan Sabo dam dalam mereduksi sedimen dan banjir. Analisis dan pemodelan dilakukan dengan dua skenario yaitu sebelum dan sesudah bangunan sabo dam terbangun, menggunakan Software HEC-RAS dengan pemodelan 1D yang bertujuan untuk mensimulasikan pola aliran dan total sedimen. Simulasi HEC-RAS menunjukkan bahwa kedalaman air berada pada 2,1 m pada kondisi eksisting. Bangunan sabo dam dapat mereduksi transpor sedimen, yang dihitung menurut beberapa rumus yaitu Engelund (reduksi 81%), Mayer Peter Muller (MPM) dengan reduksi 92%, dan Yang (reduksi 91%). Jadi, bangunan sabo dam tidak hanya dimanfaatkan untuk menahan sedimen, tetapi dapat mengurangi potensi banjir di masa depan.

Kata-kata kunci: Sedimentasi, bangunan pengontrol sedimen, HEC-RAS, sabo dam, banjir.

1. Introduction

A river is a natural or artificial water channel container which is in the form of a water drainage network from the upstream to the estuary, has right and left boundaries by borderlines (Permen PUPR, 2015 No. 28/PRT/M/2015). Bangga River is a river in Palu City that located in mountainous area. On February 29 and April 21, 2019, the flood in this river flowed through Bangga Villages, Sigi Regency, Palu City, Central Sulawesi Province. It can be shown in **Figure 1**. The

flood carried sediment material, such as sand, rocks, and woods. On September 28, 2018, Palu Earthquake caused tremendous damage to the coastal area of Palu, Central Sulawesi, Indonesia (Sihombing, et al., 2020). The flood and earthquake cause sediment buildup in Bangga River. The potential of sediment is about 13,350,000 m³. Based on the condition, the Ministry of Public Works and Housing through BWS Sulawesi III do the river improvement and sediment control to reduce the risk of flooding caused by sediment, increase river capacity, strengthen riverbanks and

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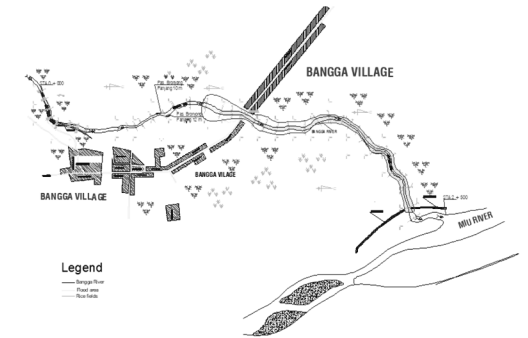


Figure 1. Flood area in Bangga watershed

reduce the amount of sediment in the Bangga River. Hence, the limitation of this study aims to analyze the performance of sediment control in reducing the flood and sediment total only in Bangga Watershed.

2. Study Area

This study was carried out in Bangga River, located on the West of the Palu River. The lower of Bangga River forms an alluvial fan area around the Palu River which is used as residential areas and rice fields (Fauzan, et al., 2021). The length of Bangga River is 17.33 km and 74.92 km² of area. The upstream slope is +0.05 and the downstream slope is +0.01. The river width is 9.29 m in upstream, 47.6 m in the middle stream, and 29.25 m in the downstream. Bangga Watershed contains two sub-watersheds. The study area can be seen in **Figure 2**.

Table 1. Rainfall data

Year	HHMT		
	Bangga Atas Station	Bangga Bawah Station	Tuva Station
2002	89	95	98
2003	49	46	80
2004	70	65	78
2005	52	33	88
2006	67	72	91
2007	79	87	100
2008	72	58	91
2009	98	50	93
2010	111	77	97
2011	96	80	65
2012	61	40	87
2013	63	61	109
2014	103	40	77

3. Materials and Methods

Primary and secondary data collection was carried out to analyze supporting data. The primary data collected includes: grain size, unit weight, and sediment concentration in five samples taken from Bangga River. Secondary data were obtained from previous studies and related Institutions. Hydrology analysis using rainfall data from three rainfall station (Bangga

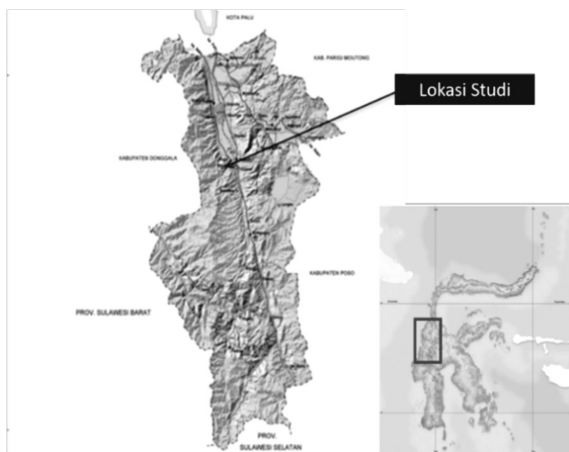


Figure 2. The study area of this research

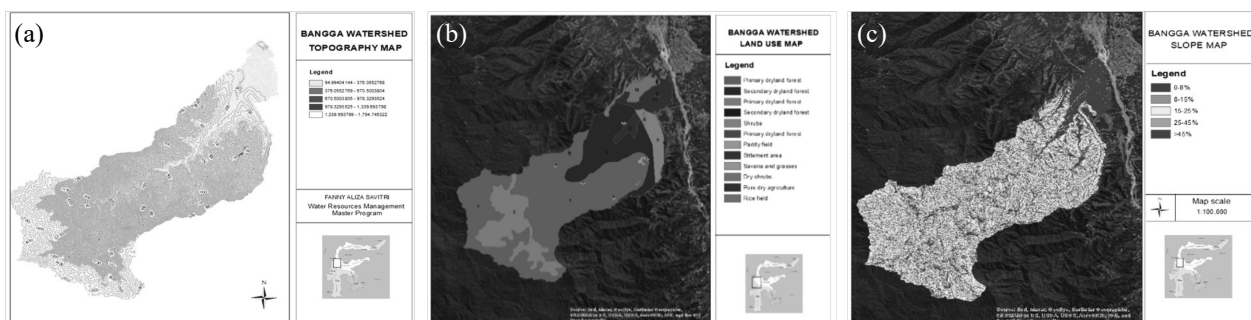
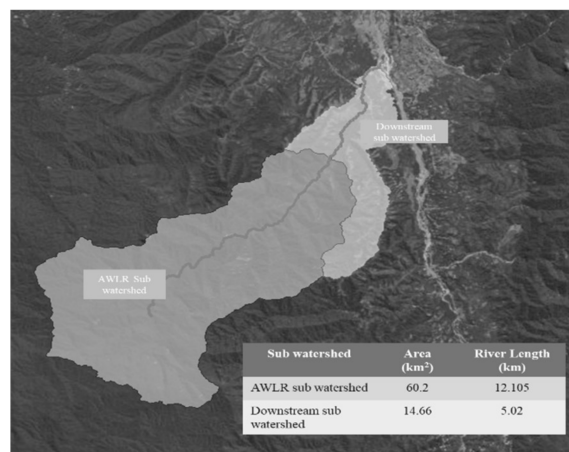


Figure 3. Topography (a) (b) Land use (c) Slope

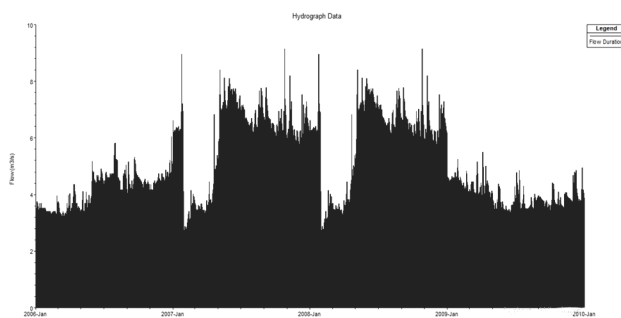


Figure 4. Daily discharge

Atas, Bangga Bawah, and Tuva) on 14 years from 2002 to 2014, daily discharge on 4 years on 2006 to 2009, topography data from Digital Elevation Model (DEM), land use map from Ministry of Environment and Forestry, and also soil data from Harmonized World Soil Database (HWSD). The land map will analyze to obtain the runoff coefficient and Manning's n value for the inflow discharge hydrograph (Yakti, at, al., 2018). **Figure 3** shows the topography map, land use map and slope map from Bangga Watershed. The average slope map provides information on slope distribution over the entire basin and slope maps play a crucial role in addition to flow direction and flow accumulation in hydrological modeling (Eadara, Karanam, 2013). The majority of the slope on this watershed is 15-25% and has an area 22.41 km². The rainfall data are shown in **Table 1**, and daily discharge data are shown in **Figure 4**.

The rainfall data is used for flood discharge design. Daily discharge data is for sediment transport simulation using Engelund-Hansen, Meyer Peter Muller (MPM), and Yang's formula. The hydrological analysis consists of watershed delineation from topographic conditions and rainfall area analysis using Thiessen Method.

Thiessen is a simple and straight forward method, each interpolated location is given the value of closest measurement point and resulting in a typical polygonal pattern (Buytaert, at al., 2006) Hence, the flood frequency analysis was carried out using 3 statistical methods using historical rainfall data which are Normal, Gumbel, Log Normal and Log Pearson III (Jaya, at al.), and HEC-RAS used analysis flood discharge. HEC model is designed to simulate the surface runoff response of a catchment to precipitation by representing the catchment with interconnected hydrologic (Bronswijk, at, al., 1995), and design flood with Synthetic Unit Hydrograph (SUH) namely Soil Conservation Service and Snyder (BSN, 2016). Analysis of flow pattern and sediment transport with HER-RAS 1D Software with unsteady flow condition. The boundary upstream is a 100-years return period of flood discharge design and daily discharge on 4 years. The sediment modeling on upstream using rating curve of sediment concentration and the downstream boundary is normal depth. Modeling is carried out under two conditions, existing conditions and conditions after sediment controllers building. The analysis is to determine the rate of the infrastructure to control the sediment transport. Several types of controller infrastructure are sabo dams, check dams and ground sill. The former is generally a wall-type structure. It is designed to elevate the torrent bed to fix and stabilize the bottom profile (Chanson, 2004).

Table 2. Thiessen area for Bangga watershed

No	Sub watershed	Area (km ²)			Total
		Bangga Atas	Bangga Bawah	Tuva	
1	AWLR	58.31	1.86	4.58	60.2
2	Hilir	5.35	9.22	0.09	14.66

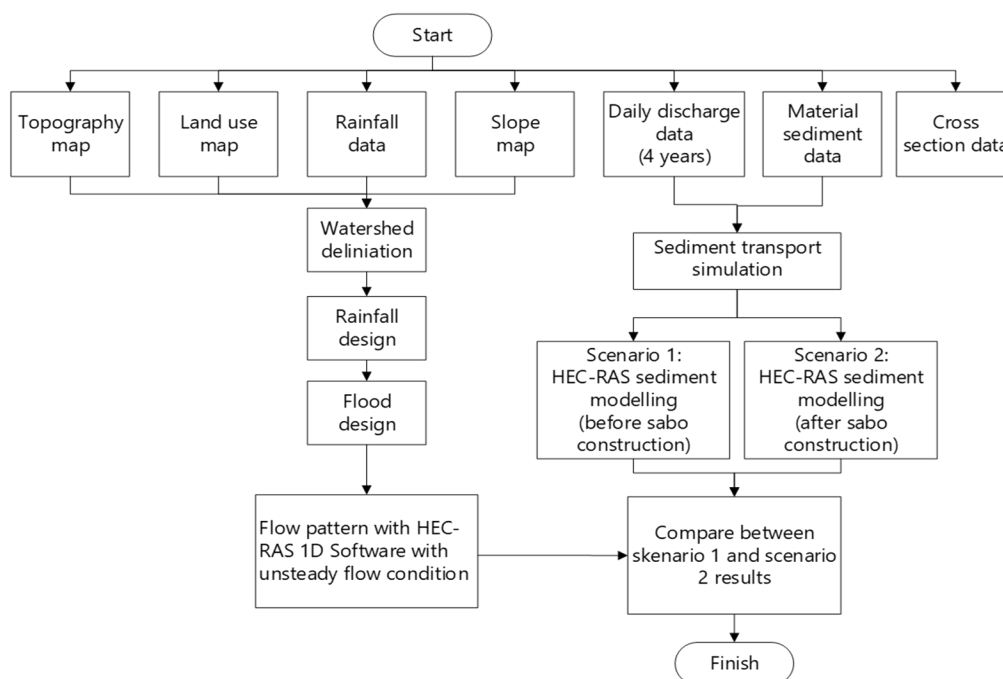


Figure 5. Research flowchart

Table 3. Design rainfall in AWLR sub watershed

No	Return Period (T)	Design Rainfall (mm)			
		Normal	Gumbel	Log Normal	Log Pearson III
1	2	75.56	72.44	73.30	74.12
2	5	91.55	89.24	91.20	91.43
3	10	99.92	100.36	102.24	101.42
4	25	108.84	114.41	115.49	112.77
5	50	114.60	124.83	124.95	120.47
6	100	119.79	135.18	134.11	127.64
7	200	124.53	145.49	143.08	134.40
8	1000	134.30	169.37	163.52	148.90
Smirnov Kolmogorov Test		0.092	0.058	0.094	0.076
		0.368	0.368	0.368	0.368
		accepted	accepted	accepted	accepted
Chi-Square Test		1.231	1.231	2.000	1.231
		5.991	5.991	5.991	5.991
		accepted	accepted	accepted	accepted

Table 4. Design rainfall in downstream sub watershed

No	Return Period (T)	Design Rainfall (mm)			
		Normal	Gumbel	Log Normal	Log Pearson III
1	2	91.00	85.77	86.21	85.11
2	5	117.80	113.92	114.79	114.27
3	10	131.83	132.56	133.34	134.32
4	25	146.78	156.10	156.43	160.50
5	50	156.43	173.57	173.42	180.64
6	100	165.12	190.92	190.28	201.33
7	200	173.06	208.19	207.14	222.74
8	1000	189.44	248.22	246.75	275.88
Uji Smirnov-Kolmogorov Test		0.116	0.083	0.104	0.107
		0.3680	0.3680	0.3680	0.3680
		accepted	accepted	accepted	accepted
Uji Chi-Square Test		3.615	2.000	2.000	2.000
		5.9910	5.9910	5.9910	5.9910
		accepted	accepted	accepted	accepted

4. Results and Discussions

4.1 Rainfall analysis

Watershed area from Geographic Information System (GIS) Software is used for rainfall area analysis. After that, the rainfall area and the abstraction of rainfall can be obtained. The Automatic Water Level Recorder (AWLR) sub watershed area is 60.2 km² and 14.66 km² of downstream sub-watershed. The result of sub-watershed area analysis can be seen in **Table 2**. Meanwhile, the design rainfall distribution analysis using Gumbel and Log Pearson III methods have the best results, and the normality tests are Chi-Square and Smirnov Kolmogorov (Yazici, Yolacan, 2007). The results of the design rainfall analysis described in **Table 3** and **Table 4**.

4.2 Design discharge

The hydrological analysis is divided into two sub-watersheds are the downstream and AWLR. Maximum

rainfall design data was obtained from 3 rainfall stations for 14 years of data (2002-2014). The analysis uses SCS and Snyder with the hydraulic input data is 100-year return period. The analysis result shows that the flood discharge design of the 100-year return period from the SCS method in the AWLR sub-watershed is 124.6 m³/s and 107 m³/s from Snyder. Meanwhile, in downstream sub-watershed from the SCS method is 44.2 m³/s and 86.9 m³/s from Snyder. The diagram shows in **Figure 5**.

4.3 Hydrology data calibration

The calibration of return period flood discharge using bankfull capacity discharge. The bankfull discharge was defined as the discharge which filled the channel to the level of the floodplain (Andrews, 1980). The cross section used for calibration is Sta 194 in AWLR location with the natural channel condition. Manning's formula is widely used in hydrology, hydraulics, irrigation etc (Bonetti, 2017). The Manning value is

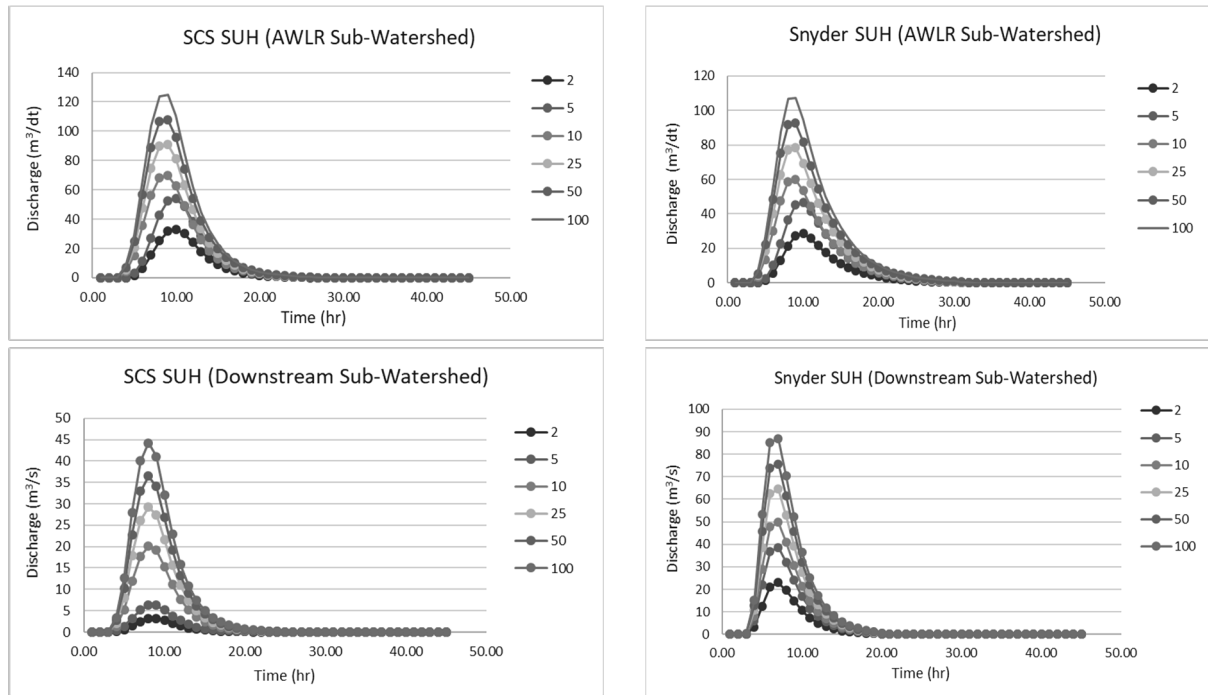


Figure 6. (a) SCS-SUH AWLR sub watershed (b) snyder SUH AWLR sub watershed (c) SCS-SUH downstream sub watershed (d) snyder SUH downstream sub watershed

0.07, which means the channel's type is mountainous river that consist of grave and big rocks (Nasional, at al., 2008). The condition is same with the existing condition. The equation to analyze the bankfull discharge formula be seen in the equation below:

$$Q = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} A = \frac{1}{0.07} \left(\frac{13.315}{11.257} \right)^{\frac{2}{3}} (0.024)^{\frac{1}{2}} = 32.958 \text{ m}^3/\text{s} \quad (1)$$

In this equation, Q is bankfull discharge (m^3/s), n is Manning's roughness parameter. R is hydraulic radius (m), S is bed slope and A is channel cross sectional area (m).

Based on the calculations with SCS and Snyder, it was found that the value close to the bankfull discharge is from the SCS method, which $33.1 \text{ m}^3/\text{s}$ (2-year return period). So that the method to analyze and for input data of flood discharge design is using SCS method with the time lag is 260 minutes (4.33 hours).

4.4 Hydraulic model analysis

The hydraulic analysis is carried out for runoff modeling in Bangga River in existing and sabo dam condition. The modeling is used HEC-RAS, which was made by the Hydrologic Engineering Center (HEC) from the US Army Corps of Engineers (USACE). Hydraulic models in HEC-RAS are typically calibrated against Manning's roughness (Environmental, 2016). The research uses is unsteady 1D with the cross-section data is from 2019th, containing of Sta 0 to Sta 194. The first modeling is existing condition was carried out on the main river, which downstream sub-watershed as the boundary of lateral inflow hydrograph. The normal depth is 0.0158. The second model is to add 3 sabo dams. The first type of sabo dam is a slit that take place on Sta 152.5. Second sabo is open type in Sta 118.25 and the third sabo is also

Table 5. Recapitulation of peak discharge

No	Return Period (th)	Peak Disharge (m^3/s)	
		SCS	Snyder
1	2	33,1	29
2	5	54,1	47
3	10	69,7	59
4	25	90,8	78
5	50	107,5	93
6	100	124,6	107

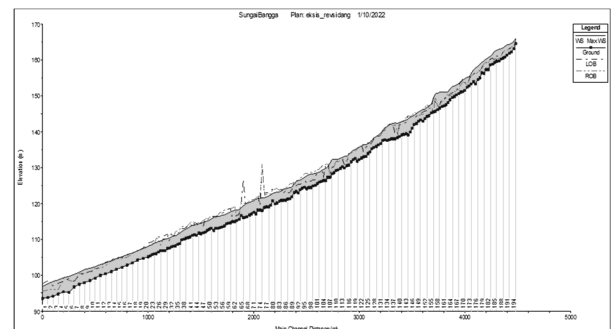


Figure 7. Long section in existing condition

open type on Sta 72.5 with 11 m height and 14.3 m width and there are 4 slits on 2 m of height. The top elevation of sabo is +161 m, and the open channel is on +150 m. The other sub dams is on +146.4 m. Sabo 2 is a conduit type sabo with a width of + 45.17 m and a height of + 11 m and has 5 holes in the body of the sabo with each diameter of 1 m. Likewise, sabo 3 has a height ranging from + 13.5 to 14.5 m with a total of 5 holes with a diameter of 1 m.

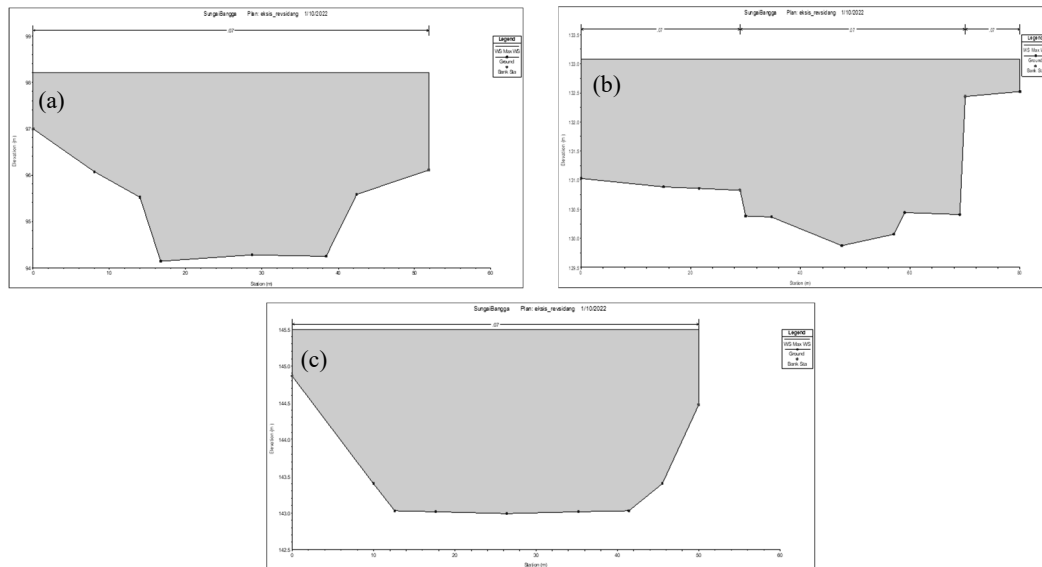


Figure 8. Cross section of existing (a) downstream (b) middle stream (c) upstream

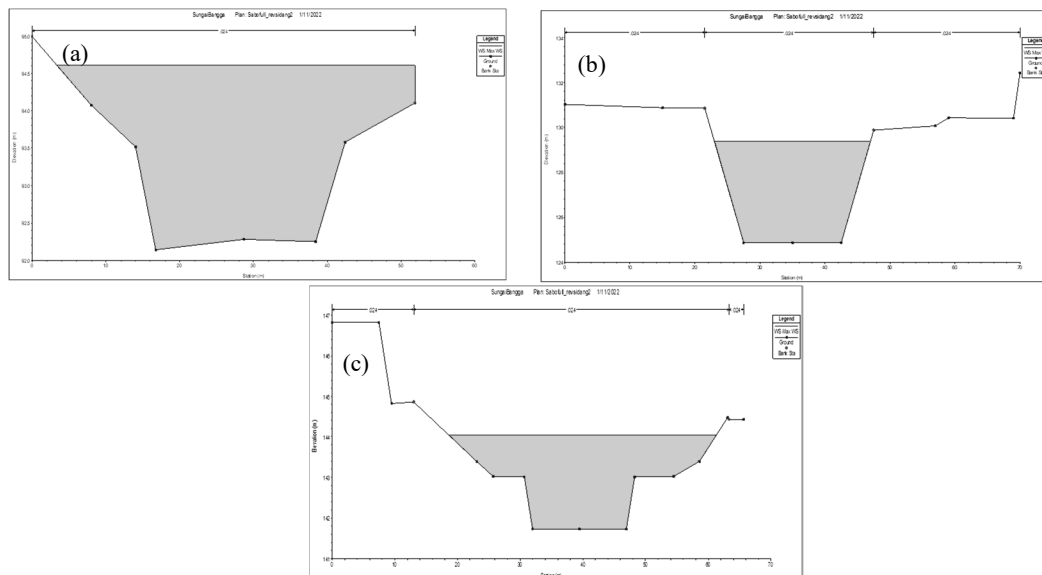


Figure 10. Cross section of after sabo (a) downstream (b) middle stream (c) upstream

The 100-year return period of modeling result shows that on existing condition, on Sta 2 (downstream) the runoff is 2.12 m. On the middle stream (Sta 113), the runoff is 2.25 m, and on the upstream is 0.62 m.

The runoff on Sta 2 is calibrated with historical data, which the flood of Bangga River was 2 to 3 m of height (Bonetti, et al., 2017). Meanwhile, the result of modeling by adding sabo dams shows that there is no runoff on Sta 2, Sta 113, and Sta 148. It means that the sabo dams can reduce the runoff in Bangga River by 100%.

4.5 Comparison of existing hydrograph and after sabo

According to the HEC-HMS simulation, it was found that the difference in peak discharge from the existing condition and after three sabo's bulding at 100 years return period. The peak discharge of the existing HSS

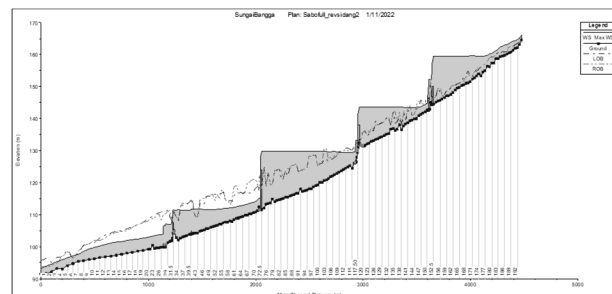


Figure 9. Long section in sabo condition

was 124.6 m³/s with a peak time (Tp) at 8 hours and HSS Sabo had a peak discharge of 93.8 m³/s with peak time at 12 hours. **Figure 9** it shown that the time lag is a four hours slowdown due to the sabo blocking the flow of flood discharge going downstream.

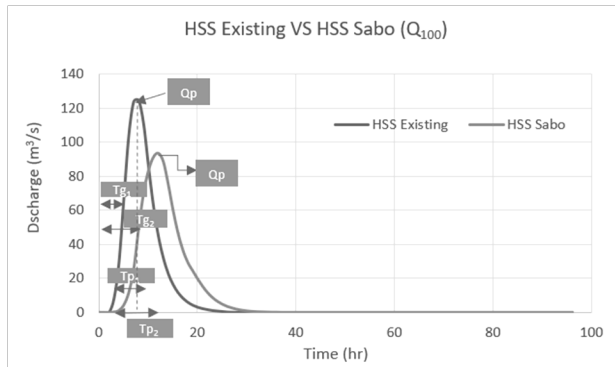


Figure 11. Graph of comparison of existing hydrograph and after Sabo

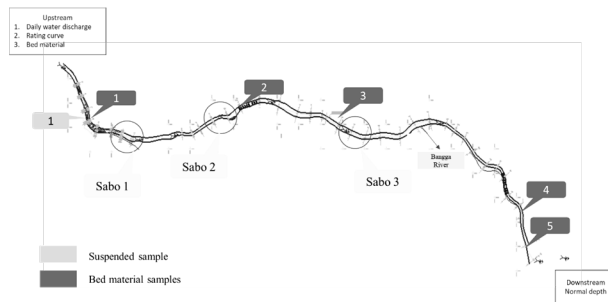


Figure 12. Sediment transport analysis modelling scheme

4.6 Sediment transport analysis

The concept of sediment transport capacity is commonly used in modelling sediment movement via overland flow and in channel transport models (Merritt, at al., 2003). This research employed the quasi unsteady sediment transport analysis module for sediment transport simulation (Environmental, 2016). Different processes of sediment transport can affect a single stream, depending on changes in sediment availability (i.e., sediment sources and their connectivity) and water runoff induced by a specific hydrological event (Brenna, at al., 2020). The sediment transport analysis is similar with the hydraulic analysis, but the input data is using daily discharge of 2006-2009.

The sediment data is the field data from 5 sampling points. Based on Laboratory analysis, the result of material are sand and silt. Sand or silt flows involving significant pore-pressures tend to occur in certain well-defined. These include submerged deposits of loose deltaic sand (Hung, at al., 2001). The other boundary condition is using floating sediment rating curve. Sediment rating curves should be develop on seasonal basis to evaluate impacts of seasonal differences in sediment source pathway dynamics (Pickering, Ford, 2021).

4.6.1 Existing condition analysis

The sediment transport modeling uses Engelund Hansen, MPM and Yang due to the existing granular material from Laboratory test results > 15 mm for d_{50} . The results of sediment transport modeling using Engelund Hansen formula show that the average degradation in the middle at Sta 76 is as high as 3.8 m due to the steep slope of the

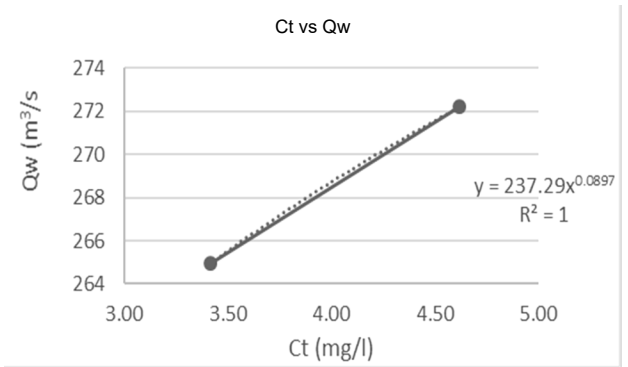


Figure 13. Graph of relationship between discharge and concentration in Bangga river

channel and the flow velocity that occurs in the middle of the river. The point increases, which results in scouring at the bottom of the channel. Meanwhile towards the downstream direction, there is an aggradation of 4.19 m at Sta 66. Aggradation occurs at a point where the slope is flatter than upstream so that the flow velocity is low and results in the deposition of particles carried from the upstream to Sta 66. Sedimentary deposits result from a long and complex history of aggradation and degradation cycles related to the changing nature of environmental controls affecting the sediment and water regimes of the catchment (Bertrand, at al., 2013).

According to **Table 6**, the amount of sediment from Sta 4 (downstream) is 409,709 ton/ 4years and from Sta 114 (middle stream, after sabo 1 and sabo 2) is 265,658 ton/ 4years. While on the upstream (Sta 185) is 27062 ton/ 4years

Table 6. Sediment total in existing condition

No	River Sta	Sediment Total (ton/ 4 years)
1	4	409,709
2	71	308,618
3	114	26,565
4	148	111,751
5	185	27,062

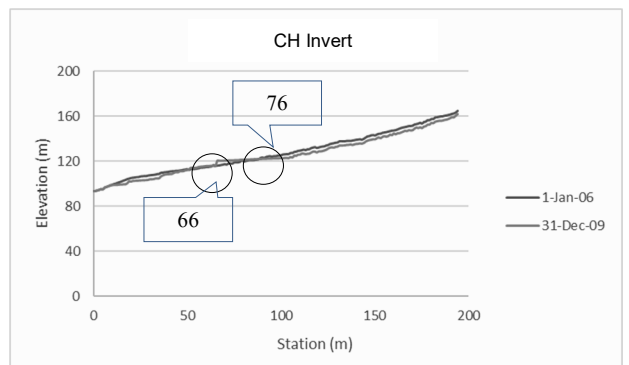


Figure 14. Invert elevation in existing condition

4.6.2 After sabo dams condition analysis

Based on the results of modeling using 3 (three) sabos using the Engelund-Hansen formula, it was found that the significant degradation occurred in the upstream part of the sabo as high as 3.8 m, namely at Sta 178. While the aggradation occurred before sabo 1 was 2.8 m high, sabo 2 was 1.39 m high and sabo 3 was as high as 0.084 m and the maximum aggradation is at Sta 80 which is 5 m high. In this zone, sediment originating from upstream in the presence of a structure across the river causes deposit to be retained and captured by the building and distributed downstream into scouring until it reaches a stable condition.

a. Engelund and Hansen

Engelund and Hansen formula selected for comparison developed based on flume data, using sediment size of bed material as input (WU, at al., 2008).

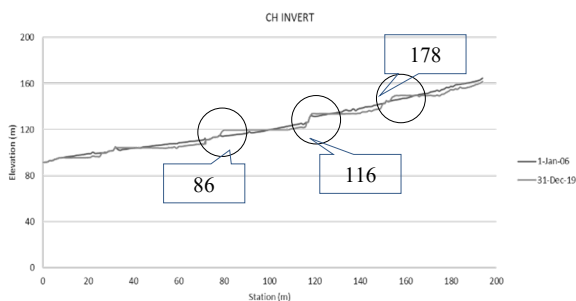


Figure 15. Invert elevation in Engelund-Hansen formula

Table 7. Sediment total in Engelund-Hansen

No	River Sta	Sediment Total (ton/ 4 years)
1	4	76,383
2	71	3,471
3	114	29,068
4	148	3,688
5	185	26,298

According to **Table 7**, the sediment from Sta 4 is 76,383 ton/ 4 years (409,709 ton/ 4years before). So the sabo dam can reduce the sediment transport is 81%. Meanwhile, on Sta 114 the sediment reduced by 89%, and on Sta 185 is 3%.

b. Meyer Peter Muller (MPM)

MPM was found to perform reasonably well by Gomez and Church [22]. A total sediment transport curve was constructed for each gaging station by adding measured instantaneous suspended sediment discharge to bedload sediment discharge computed by MPM [12]. The formula analysis shows that the maximum degradation is at Sta 178 as high as 3.99 m. Meanwhile, the largest aggradation is at Sta 86 is 3.85 m.

Based on **Table 8**, the results of total sediment at Sta 4 downstream was 31,816 tons / 4 years, in sta 114 (middle stream) is 8,465 tons/4 years, and in Sta 185

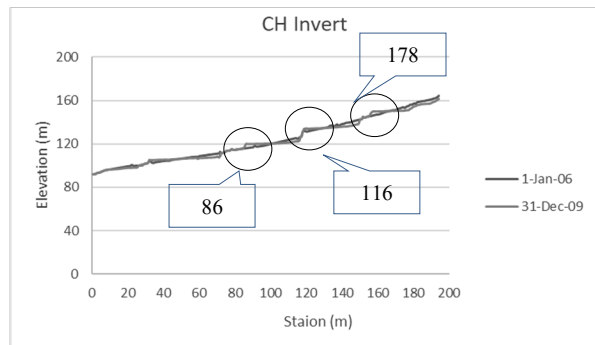


Figure 16. Invert elevation in Meyer Peter Muller formula

Table 8. Sediment total in Meyer-Peter Muller

No	River Sta	Sediment Total (ton/ 4 years)
1	4	31,816
2	71	1,620
3	114	8,465
4	148	3,661
5	185	27,668

(upstream) is 27,688 tons/4 years. While in MPM simulation, the reduction of the total sediment at Sta 4 by 92%, Sta 114 by 98%, and Sta 185 by 3%.

c. Yang

Yang's formula were selected for comparison using sediment size and suspended load as input [21]. Based on the analysis results, the formula shows the maximum degradation is at Sta 178 as high as 3.99 m. Meanwhile, the largest aggradation is at Sta 86, which is 3.85 m.

According to **Table 9**, the results of total sediment at Sta 4 (downstream) was 33,461 tons / 4 years and 114 (middle stream and coincided with the location of the

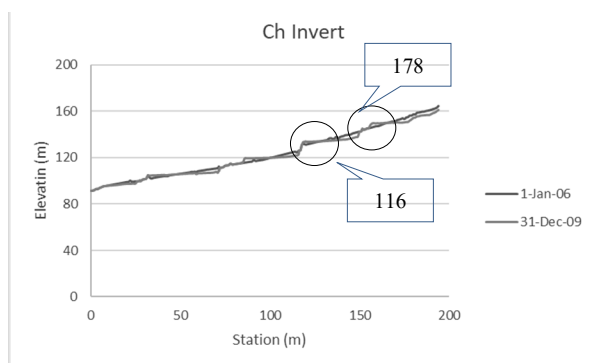


Figure 17. Invert elevation in Yang formula

Table 9. Sediment total in Yang

No	River Sta	Sediment Total (ton/ 4 years)
1	4	31,816
2	71	1,620
3	114	8,465
4	148	3,661
5	185	27,668

Table 10. Sediment transport simulation

Average Region	Engelund Hansen			Meyer Peter Muller			Yang		
	Max Degradation	Max Aggradation	Total Sediment	Max Degradation	Max Aggradation	Total Sediment	Max Degradation	Max Aggradation	Total Sediment
	(m)	(m)	(ton/ 4 years)	(m)	(m)	(ton/ 4 years)	(m)	(m)	(ton/ 4 years)
Upstream	-3.99	3.89	26298	-4.00	3.66	27669	-4.00	3.54	23339
Middle Stream	-3.79	5.25	29069	-4.00	3.85	8465	-3.99	4.02	10483
Down Stream	-3.58	2.25	76383	2.75	-2.63	31816	-2.73	2.75	33461

point after the placement of sabo one and sabo 2). is 10,483 tons/4 years, and 185 (upstream) is 23,339 tons/4 years. So, this formula can reduce sediment total at Sta 4 by 91.8%, Sta 96.1%, and at Sta 185 by 13.8%. This simulation was carried out using the same river geometry as hydraulic analysis and using 3 (three) transport functions, namely Engelund Hansen, Meyer Peter Muller, and Yang formulas. The summary of the analysis will present in the following table:

The table shows the river's degradation and aggradation in river morphology using the Yang and MPM equations has relatively the same results for all parts of the river. Yang's formula is more significant to reduce sediment total, in the upstream are able to reduce total sediment by upstream 13%, middle stream 96.1% and downstream 91.8%.

5. Conclusion

The conclusions of this research are:

1. Bankfull discharge of the Bangga River is 32.95 m³/s and equivalent to a 2-year return discharge using the HSS SCS method, which is 33.1 m³/s.
2. The results of the HEC-RAS 1D simulation, which uses two conditions existing and after the sabo dam's was built, show that the water surface is stood at 2.1 m depth before the constructed sabo dam. However, the simulation indicates low discharge (runoff) after the constructed sabo dam.
3. Based on the results of sediment transport modeling with three methods, namely Engelund Hansen, Meyer Peter Muller, and Yang, which is the most optimal using the Yang formula with the percentage of total sediment reduction in the upstream area of 13%, middle stream 96.1% and upstream 91.8%.
4. For the further research, can be modelling by HEC-RAS 2D so the area and distribution mapped of sediments or in supporting this research approaching the situation in the field, can be tested hydraulic model. And it is necessary to carry out operations and maintenance of sediments to maintain the sustainability of the sabo dam's structure.

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