Sedimentation Study In The Batu Merah River (Check Dam Rinjani) Ambon City

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Abstract. Batu Merah River is located in Ambon City, Maluku Province, which floods almost every year. The risk of flooding is increasing with the number of landslides found throughout the river area resulting in more and more sediment settling on the riverbed. The purpose of this study was to study sedimentation and changes in river morphology during the Rinjani Check Dam Upgrade construction. Analysis of flood discharge using the SCS method. Analysis of flood hydraulics for 25 years return period and sediment transport with daily discharge for 5 years using HEC-RAS 1D under existing and design conditions. Land erosion analysis using USLE method with Geographic Information System (GIS). The design flood discharge at the 25 years return period is 132.32 m3/s. From the results of sediment transport modelling, there is a 5.23% decrease in sedimentation volume from 1288 m3/year to 1220 m3/year, a 5.32% decrease in erosion volume from 1299 m3/year to 1230 m3/year and a decrease in average height of 20.71% from 0.31 m to 0.25 m and a decrease in the average depth of 14.82% from 0.71 m to 0.61 m. The results of the analysis of the erosion of the Batu Merah watershed showed an erosion rate of 1,197 tons/ha/year with a production of 46,186 tons/year.
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1. Introduction

The hydrological cycle describes natural phenomena that link erosion, sedimentation and runoff [1]. Land use that occurs in the watershed will affect the erosion that occurs. The decreasing forest area in the Watershed will cause the erosion that occurs in the watershed to be even greater. With increasing erosion that occurs in the watershed so that the sediment carried by the river will be even greater [2]. Flood is a condition where water cannot be accommodated in river channels or water flow is obstructed, so that water overflows and inundates the surrounding area (flood plain) [3]. The Batu Merah River is located in Ambon City, Maluku Province, where floods can occur almost every year and have the greatest flood impact compared to other areas in Ambon City. Floods that often occur in the Batu Merah River are because the capacity of the river channel is not able to accommodate the flood discharge so that the flood overflow causes disasters for the community. The risk due to flooding is increasing with the discovery of many landslides scattered throughout the river area resulting in more sediment settling on the riverbed which can accelerate the occurrence of riverbed aggradation and increase the peak of flooding [4]. The biggest flood that occurred in 2012 caused casualties and caused severe damage in Ambon City, especially the area around the Batu Merah River because along the left and right of the Batu Merah River there are densely populated residential areas. The government through the Maluku BWS has conducted an integrated study for flood and sediment control in the Batu Merah River, one of which is the construction of the Rinjani Upgrading Check Dam in the middle of the Batu Merah River.

In addition to controlling sediment, the Rinjani Upgrading Check Dam also functions as a retention pond that can temporarily accommodate flood discharges to protect downstream settlements. The purpose of this research is to study sedimentation and changes in river morphology due to flood and sediment control in the Batu Merah River, one of which is by increasing the structure of the Rinjani Check Dam.

2. Study Area

The research location is located in the Batu Merah watershed in the Ambon-Seram River Basin, in Sirimau District, Ambon City, Maluku Province. The upstream part of the Batu Merah River has a large potential for landslides and changes in land use and many new settlements. In the middle there is the Existing Rinjani Check dam which is already full of sediment, based on information the check dam was built by the local government in the 1990s whose condition is not maintained and is already full of sediment. In the lower reaches of the river there is quite a lot of sedimentation and densely populated settlements along and along the river border. The problems of sedimentation, bank erosion and garbage along the river from upstream to downstream have an impact on flood events in the middle and downstream parts of the Batu Merah watershed. Some photos of field documentation in the upstream, middle and lower reaches of the Batu Merah River (Figure 1) to illustrate the problems at the location are as follows (Figure 2):

Figure 1. Conditions for the upstream, middle stream and downstream of the Batu Merah River 2021

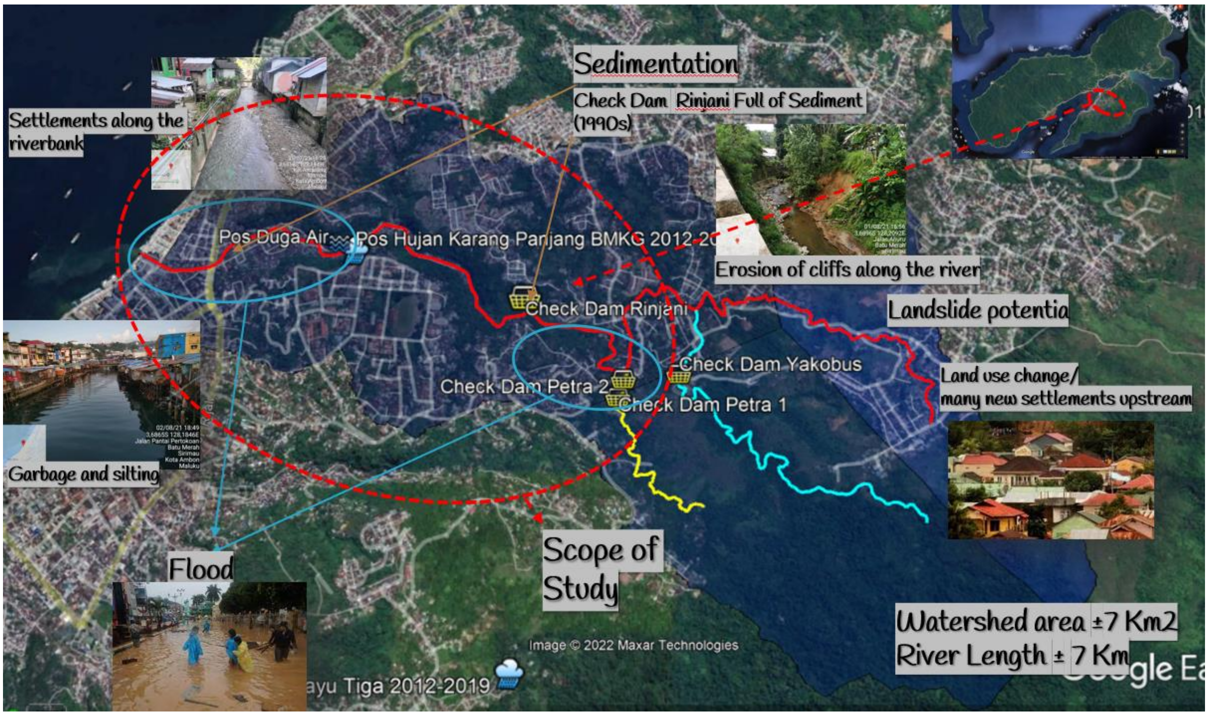

Figure 2. Batu Merah Watershed and problems

3. Material and Methods

The material in this study uses primary data and secondary data. Primary data in the form of grain size, specific gravity, and sediment concentration taken from the Batu Merah River. Secondary data were obtained from related agencies as well as from previous research. The hydrological analysis used data from three stations, namely Karang Panjang, Kayu Tiga and IAIN Rainfall Posts for 10 years from 2012 to 2021 (Table 1) by filling in the blank data using the square of the distance method.

Table 1. Annual maximum daily rainfall

Year	Karang Panjang Rainfall Max	Kayu Tiga Rainfall Max	IAIN Rainfall Max
2012	425.0	114.0	225.4
2013	315.0	209.7	263.0
2014	130.0	72.2	66.2
2015	147.0	79.6	85.1
2016	234.0	280.3	277.0
2017	202.0	245.0	203.3
2018	151.0	211.7	148.0
2019	144.0	69.1	101.1
2020	203.2	205.2	193.5
2021	194.1	199.1	170.5

In addition, daily discharge data for 5 years from 2012 to 2016, topographic data (Figure 3) from the Digital Elevation Model (DEM) and LIDAR (Light Detection and Ranging), land use from the Ministry of Environment and Forestry (Figure 4) is used. and soil data from the Harmonized World Soil Database (HWSD). The mean slope map provides information about the distribution of the slope across the basin and the slope map plays an important role besides flow direction and flow accumulation in hydrological modelling [5].

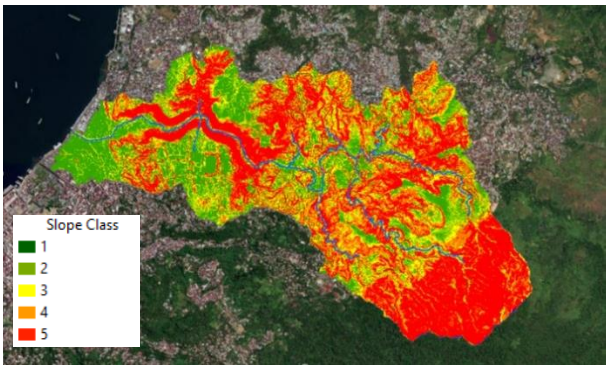

Figure 3. Slope map

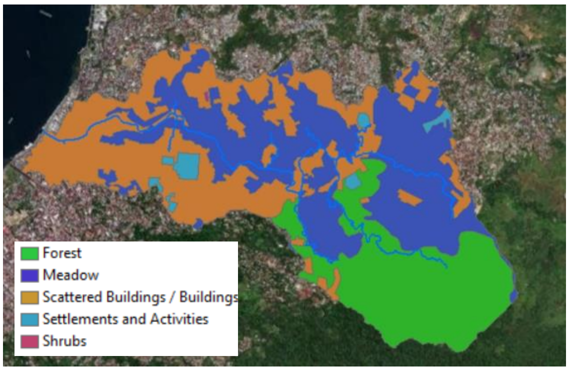

Figure 4. Land use map

Hydrological analysis consists of watershed delineation from topographic conditions and rainfall analysis using the Thiessen polygon method to obtain the area of influence of each rainfall post. Hydraulic analysis using HEC-RAS software with one-dimensional unsteady flow simulation flow conditions. One-dimensional hydraulic calculations are able to simulate unsteady flow through a full network of natural and artificial channels [6]. The conditions used in the upstream part of the model are flood discharge and tidal elevation in the downstream part of the model. Sediment transport modeling uses daily discharge input for 5 years and uses a sediment concentration rating curve. The modeling is carried out in 2 conditions, namely the existing condition and the design condition. As for the condition of the plan using a check dam type drip hole with 3 holes measuring 2x2m, 10m high, with dredging. Details of the building plans in this study can be seen in Figure 5.

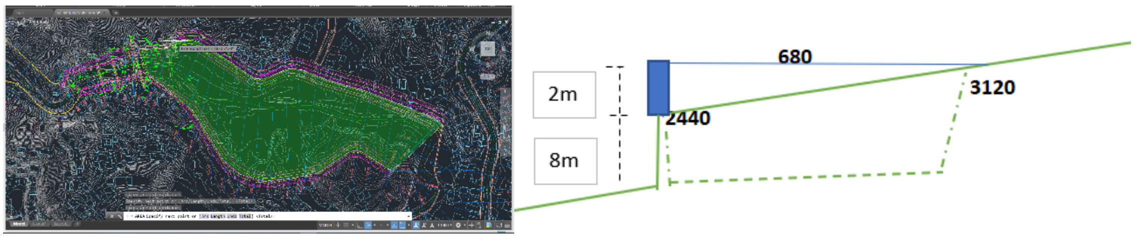

Figure 5. Building details check dam plan

Soil erosion analysis was carried out using the USLE (Universal Soil Loss Equation) method. A parametric model for predicting erosion of a plot of land has been developed by Wishcmeier and Smith (1978), USLE allows planners to estimate the average rate of erosion of a particular soil on a steep slope with a certain rainfall pattern for each type of crop and management action (conservation measures). land) that is possible or currently being used [7]. The flow chart of this research is described in Figure 6.

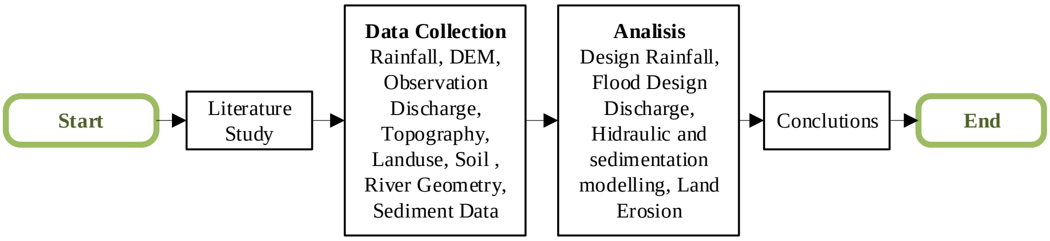

Figure 6. Flow chart of the study

4. Results and discussions

4.1. Watershed Property Analysis

Watershed property data were analyzed from LIDAR (Light Detection and Ranging) data using GIS software. The Batu Merah watershed was analyzed into four sub-watersheds and obtained characteristics such as Figure 7 and Table 2 as follows.

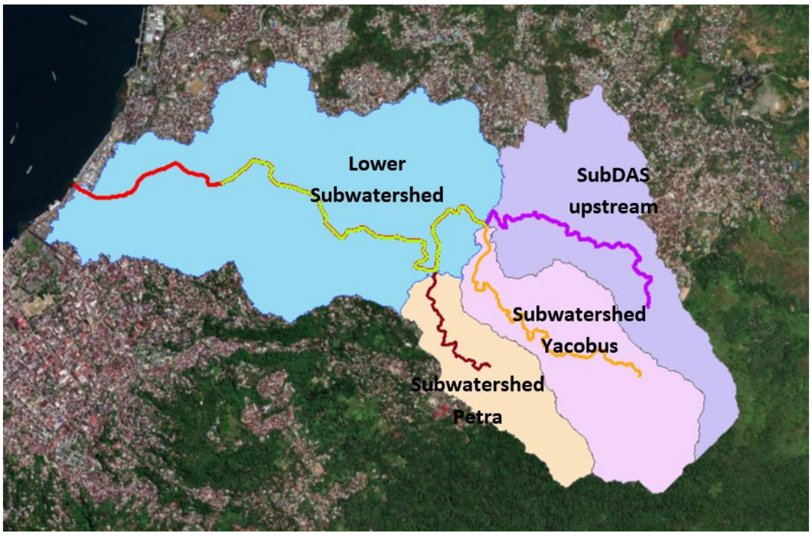

Figure 7. Map of Batu Merah Sub-watershed
Analysis result

Table 2. Characteristics of Batu Merah Sub-watershed

No	Sub-Watershed	Area (Km^2)	River Length (Km)
1	Sub-Watershed Downstream	3.18	4.2
2	Sub-Watershed Hulu Air Kuning	1.47	2.05
3	Sub-Watershed Yacobus	1.26	2.48
4	Sub-Watershed Petra	0.69	1.2

*Analysis result

4.2. Design rainfall analysis

Regional rainfall analysis used the Thiessen polygon method from 3 rainfall stations, namely Karang Panjang, Kayu Tiga and IAIN for 10 years (Figure 8) with a Thiessen coefficient as shown in Table 3. Analysis of the design rainfall distribution used several methods, namely Gumbel, Normal, Log distribution. Normal and Pearson logs and tested for distribution suitability with Smirnov Kolmogorov and Chi Square Test (Table 4).

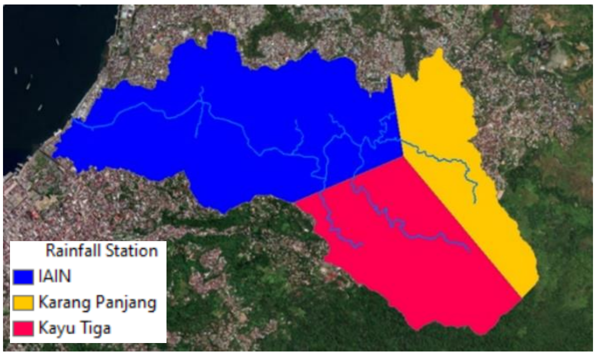

Figure 8. Thiessen polygon rainfall map

Table 3. Thiessen area coefficient

	Station Name	Watershed Area (km^2)	Weight (%)
1	Karang Panjang	3.436956	52.08%
2	Kayu Tiga	1.890952	28.65%
3	IAIN	1.271395	19.27%
	Total	6.599303	100.00%

Table 4. Frequency analysis

	Return Period (T) (Years)	Rain Distribution (mm) Polygon Thiesen			
		Normal	Gumbel	Log Normal	Log Pearson III
1	1.1	104.01	114.92	110.38	108.96
2	2	193.43	182.04	181.51	185.85
3	2.33	204.80	192.56	193.36	197.76
4	5	251.79	243.33	251.12	252.31
5	10	282.33	283.91	297.61	292.33
6	25	314.88	335.19	356.68	338.83
7	50	335.90	373.22	400.92	370.88
8	100	354.81	410.98	445.38	400.98
9	200	372.11	448.60	490.37	429.53
10	1000	407.78	535.74	597.98	491.14
Uji Smirnov-Kolmogorof		0.1413	0.1015	0.1509	0.1427
		0.4100	0.4100	0.4100	0.4100
		received	received	received	received
Uji Chi-Square		2.0000	3.0000	3.0000	4.0000
		5.9910	5.9910	5.9910	5.9910
		received	received	received	received

*Analysis result

4.3. Discharge design

The planned flood discharge analysis was carried out manually using the HSS SCS, Nakayasu and ITB methods with inputs namely watershed parameter data, planned return period rainfall data that had been distributed through hourly rains using the PSA 007 method. The results of the analysis of flood discharge plans for each return period The sub-watersheds can be seen in Table 5-8 below.

Table 5. Recapitulation of discharges for the Downstream Sub-Watershed

Tr	Nakayasu (Alpha=2.0)	SCS	ITB-1b	ITB-2b
2	67.35	36.23	36.82	58.17
5	92.94	50.53	51.38	80.32
10	106.34	58.01	59.00	91.92
25	120.61	65.99	67.12	104.27
50	129.83	71.14	72.37	112.25
100	138.12	75.78	77.08	119.43
200	145.71	80.02	81.40	126.00
1000	161.35	88.76	90.30	139.54

Table 6. Recapitulation of discharge for the Upstream Sub-Watershed

Tr	Nakayasu (Alpha=2.0)	SCS	ITB-1b	ITB-2b
2	25.48	18.42	18.25	20.67
5	34.57	25.18	24.97	28.05
10	39.32	28.72	28.48	31.91
25	44.39	32.49	32.23	36.03
50	47.67	34.92	34.64	38.69
100	50.61	37.11	36.82	41.08
200	53.31	39.12	38.81	43.27
1000	58.87	43.25	42.91	47.79

Table 7. Recapitulation of discharge for the Yacobus Sub-Watershed

Tr	Nakayasu (Alpha=2.0)	SCS	ITB-1b	ITB-2b
2	22.33	13.98	14.03	17.56
5	31.08	19.62	19.70	24.46
10	35.66	22.57	22.67	28.07
25	40.54	25.72	25.83	31.91
50	43.69	27.75	27.88	34.40
100	46.52	29.57	29.72	36.63
200	49.12	31.25	31.40	38.68
1000	54.46	34.69	34.87	42.89

Table 8. Recapitulation of discharge Petra Sub-Watershed

Tr	Nakayasu (Alpha=2.0)	SCS	ITB-1b	ITB-2b
2	7.80	8.62	8.51	7.36
5	10.90	12.17	12.01	10.27
10	12.52	14.03	13.84	11.80
25	14.25	16.01	15.79	13.42
50	15.37	17.29	17.05	14.47
100	16.37	18.44	18.19	15.42
200	17.29	19.49	19.23	16.28
1000	19.18	21.66	21.37	18.06

Analysis result

4.4. Hydrology data Calibration

Flood discharge calibration during discharge calibration is carried out by comparing the actual discharge data at the Water Level Recording post with the calculation of the instantaneous flood discharge on July 29, 2013 (Figure 9. and Table 9). From the HSS calibration, SCS was chosen as the design flood discharge to be used for hydraulic modeling. The results can be seen in Table 10.

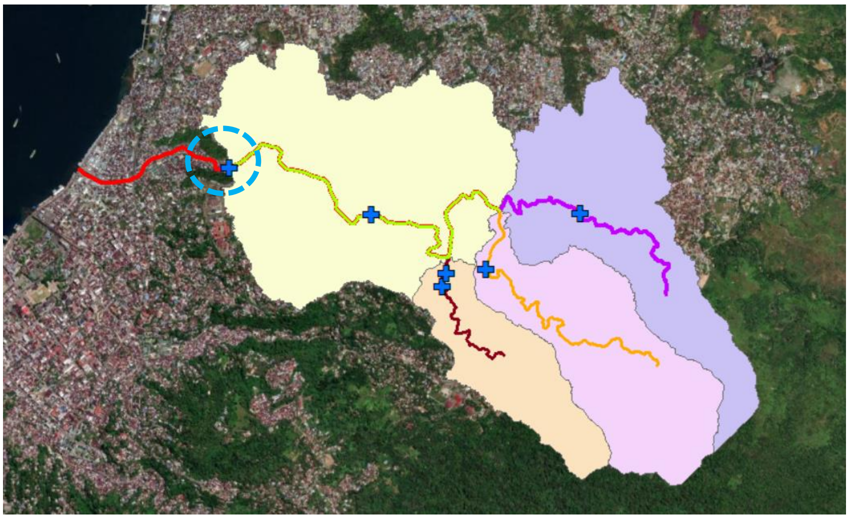

Figure 9. Post Water Level Recording

Table 9. Rainfall and Discharge Data July 29 2013

Date	Rainfall	Rainfall	Rainfall	Discharge
	Karang Panjang (mm)	Kayu Tiga (mm)	IAIN (mm)	m3/s
29-Jul-13	315	209.7	263.05	98.8

Table 10. Discharge Calculation Results July 29 2013 at the Water Level Recording Post

Hour	PDA	Hulu	Yacobus	Petra	Total
1	0.000	0	0.000	0	0.000
2	0.000	0	0.000	0	0.000
3	0.563	0.4088	0.169	0.20183	1.342
4	18.433	14.945	8.041	9.60551	51.024
5	43.830	26.359	18.140	11.0174	99.347
6	41.560	19.352	13.882	5.8187	80.613
7	25.771	10.459	7.902	2.47787	46.610
8	14.266	4.9795	3.889	0.94304	24.077
9	7.275	2.2398	1.899	0.35061	11.765
10	3.703	0.983	0.903	0.12216	5.711
11	1.877	0.4384	0.435	0.025	2.776
12	0.958	0.1013	0.206	0.00451	1.270
13	0.473	0.0228	0.045	0.00047	0.541
14	0.116	0.0038	0.009	0	0.129
15	0.029	0	0.001	0	0.030
16	0.005	0	0	0	0.005
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0

4.5. Hydraulic modelling analysis

Based on the Regulation of the Minister of Public Works and Housing of the Republic of Indonesia number 28/PRT/M/2015 concerning the determination of river and lake border lines, the embankment planning for the Provincial Capital requires that the embankment design be able to drain the planned discharge Q20 to Q50 [8]. Modeling is carried out in 2 conditions, namely existing and planned. Geometry Data used is based on 2019 measurement data. The first model for the existing condition uses the planned flood discharge as the boundary condition for the unsteady flow model.

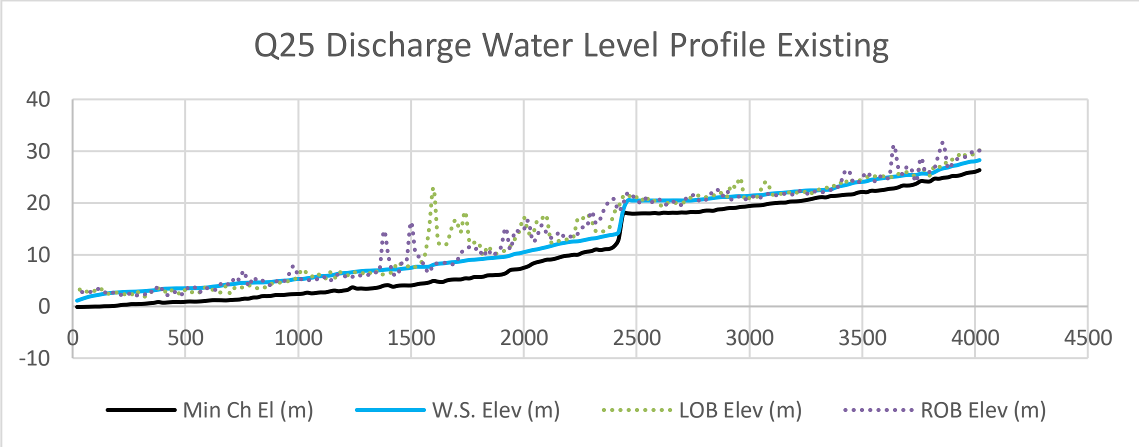

Figure 10. Existing Flood Modeling Results Q25

The flood discharges used in the upstream are the Upstream Sub-watersheds, Yacobus, Petra as a flow hydrograph and lateral flow. The middle section uses the discharge input from the Lower Sub-watershed as the lateral flow. Meanwhile, in the downstream part, tidal data is used as a boundary. Following are the results of the existing ID flood modeling in Figure 10 and the flood runoff can be seen in Table 11.

Table 11. Existing flood runoff

	W.S.Elv	LOB	ROB	left runoff	Right runoff
3100	21.8	21.71	21.66	-0.09	-0.14
3080	21.7	23.97	21.73	2.27	0.03
3060	21.54	23.47	21.36	1.93	-0.18
3040	21.49	21.38	20.82	-0.11	-0.67
3020	21.45	21.13	21.18	-0.32	-0.27
3000	21.36	20.95	21.23	-0.41	-0.13
300	2.91	2.29	2.27	-0.62	-0.64
280	2.86	3.07	2.13	0.21	-0.73
260	2.84	2.2	2.5	-0.64	-0.34
240	2.81	2.19	2.33	-0.62	-0.48
220	2.77	2.52	2.24	-0.25	-0.53
200	2.7	2.7	2.28	0	-0.42

*Analysis result

The second model uses a 10 m high checkdam building with dredging. This building is a drip hole type and has 3 holes 2 m in diameter. The results of the analysis can be seen in the following figure (Figure 11).

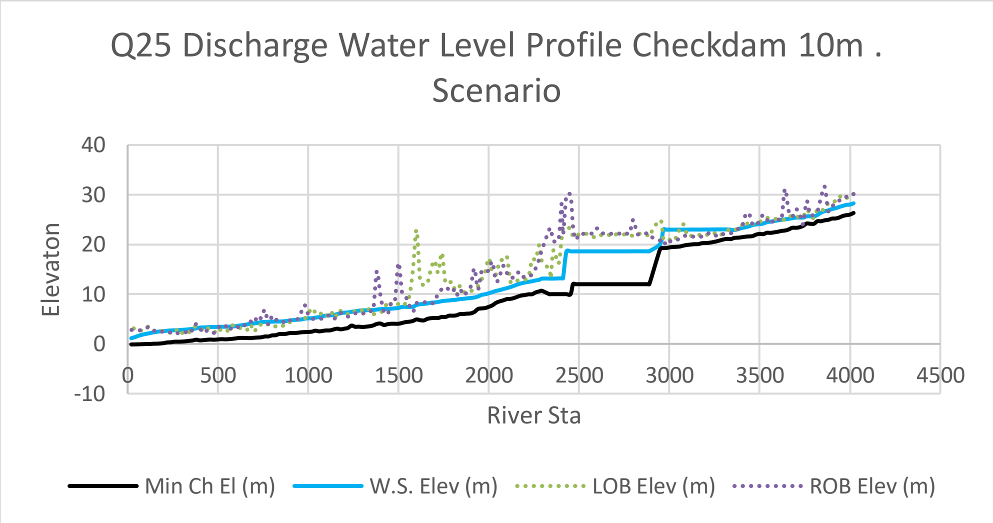

Figure 11. Flood Modeling Results with 10 meter Checkdam Q25 Analysis result

Based on the modeling analysis with flood discharge Q25, it was found that the speed decrease was 16.04% from 2.84m/s in the existing condition to 2.38 m/s in the design condition.

4.6. Sedimentation Transport Analysis

This study uses a quasi of unsteady sediment transport analysis module for simulated sediment transport. Sediment transport analysis is similar to hydraulic analysis, but the input data uses daily water discharge from 2012-2016. The other boundary conditions use the floating sediment rating curve. Sediment rank curves should be developed seasonally to evaluate the impact of seasonal differences in the dynamics of sediment source pathways [9].

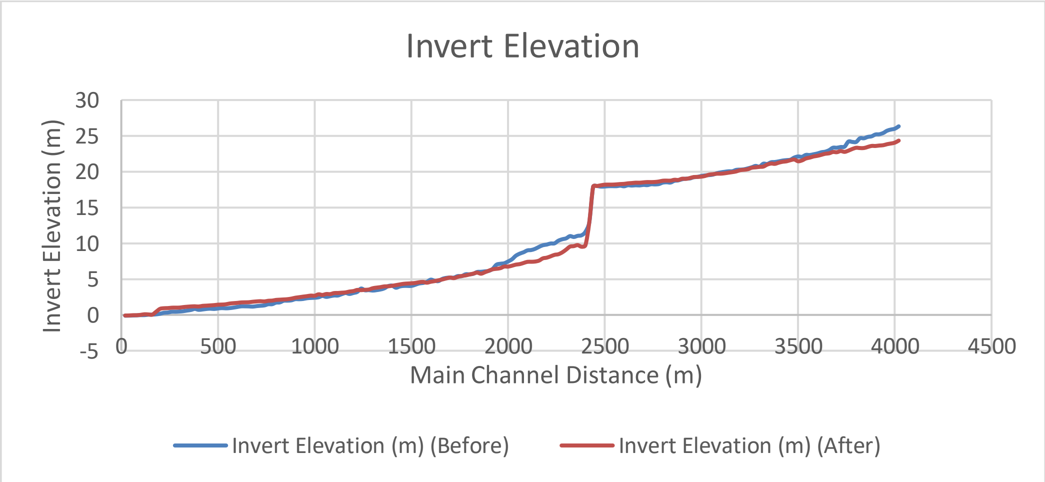

Figure 12. Changes in riverbed elevation existing condition

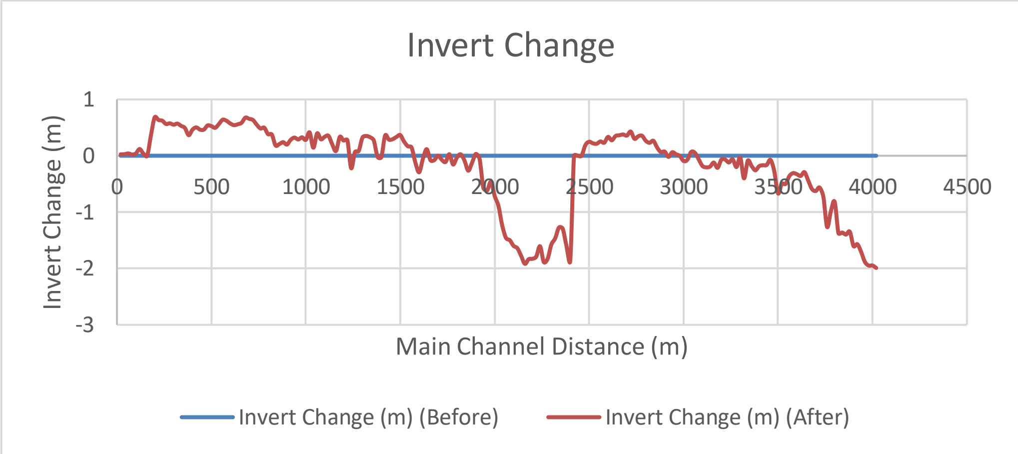

Figure 13. River degradation aggregation pattern design condition

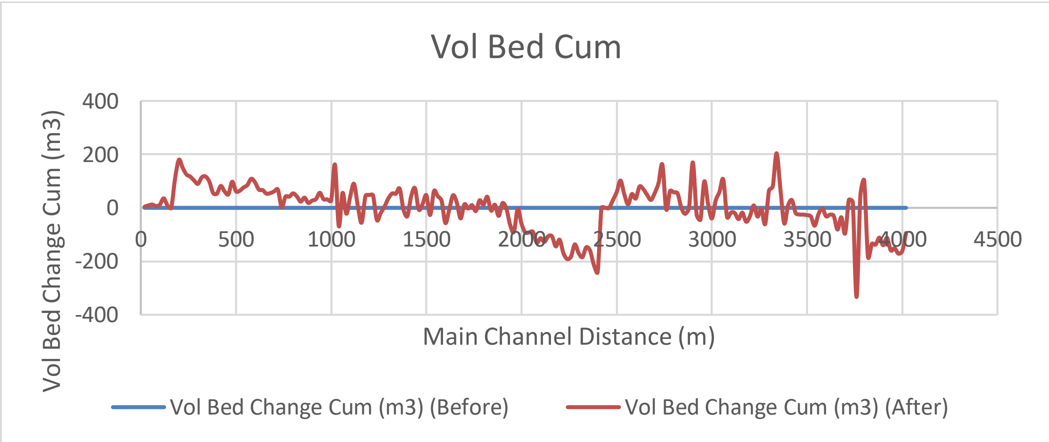

Figure 14. Aggregation volume of river degradation plan condition

The sediment transport modelling used the Ackers-White method because the granular material available from the laboratory test results was between 0.4mm for D10 and 6mm for D60. Based on the results of sediment transport modelling using the Ackers-White formula, it shows that in the existing conditions of the Batu Merah River for 5 years the average degradation occurs upstream and in the middle after the plunge due to the steep slope of the channel and the flow velocity that occurs in the middle of the river. Points increase, which results in scouring at the bottom of the channel. Meanwhile, towards the downstream direction, there is aggradation. 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 upstream. Sediment deposits result from a long and complex history of cycles of degradation and degradation associated with changes in environmental control properties that affect the sediment and water regime of the catchment [10].
Based on the results of sediment transport modelling (Figure 12-14) for 5 years under existing conditions, the sedimentation results obtained with a maximum height of 0.68 m and an average height of 0.31 m with a total sedimentation volume of 1288 m^3. While the results of erosion with a maximum erosion depth of 1.99 m and an average depth of 0.71 m with a maximum total erosion volume of 1299 m^3.For the check dam scenario with a height of 10 m and dredging from the modelling results, the changes in the shape of the longitudinal profile of the riverbed elevation occur as follows (Figure 15-17).

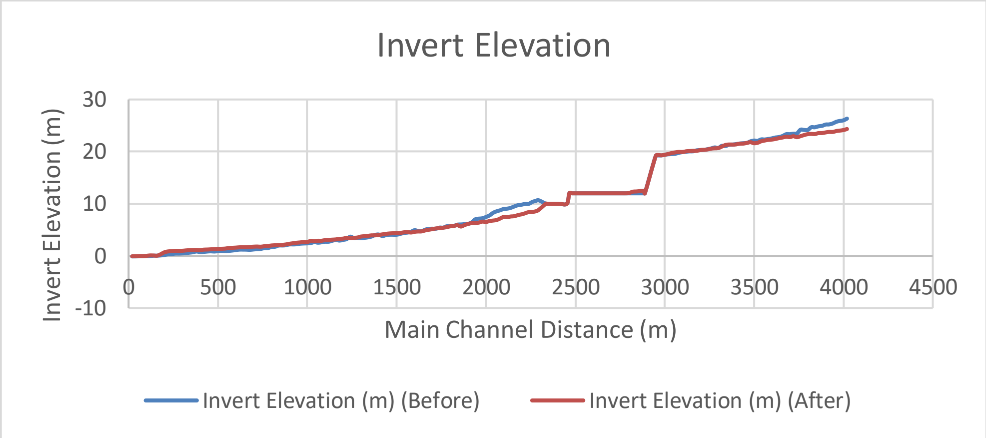

Figure 15. Changes in riverbed elevation with a checkdam of 10 meters and dredging. Analysis result

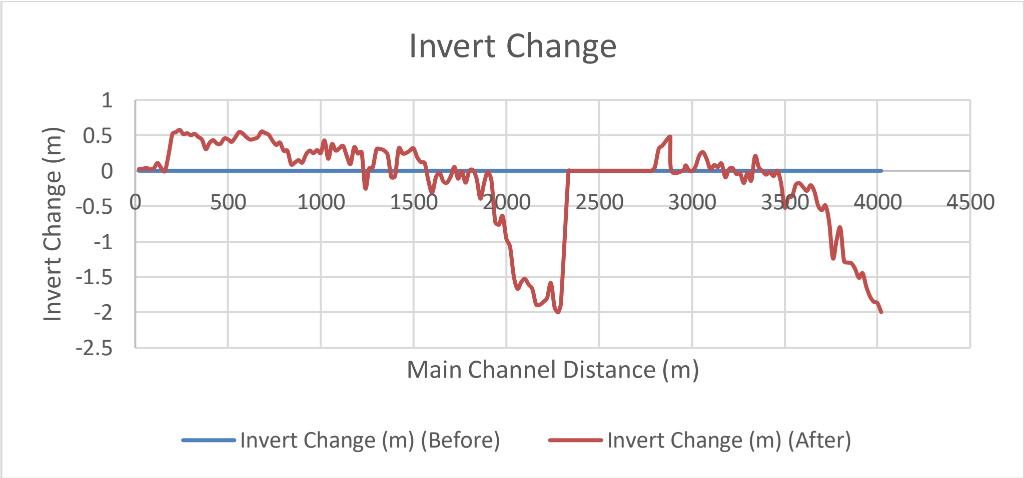

Figure 16. River degradation aggregation pattern with checkdam 10 meters dredging Analysis result

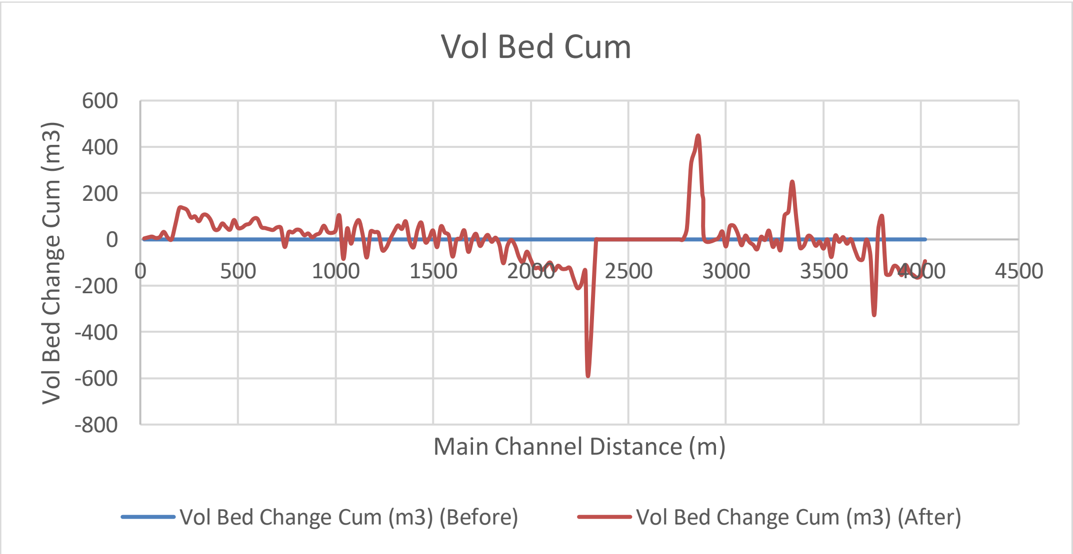

Figure 17. River degradation aggregation volume with checkdam 10 meters dredging Analysis result

Based on the results of sediment transport modeling for 5 years under checkdam scenario conditions with a height of 10 m, the sedimentation results with a maximum height of 0.57 m and an average height of 0.25 m with a total sedimentation volume of 1220 m^3. While the results of erosion with a maximum erosion depth of 1.99 m and an average depth of 0.60 m with a total erosion volume of 1230 m^3.

4.5 Land Erosion Analysis.

Soil erosion analysis was carried out using the USLE (Universal Soil Loss Equation) method. The data used in this analysis comes from secondary data which includes rainfall data, land use data, soil type data, and slope data. The data is then processed using GIS and displayed in the form of a spatial map (Table 12 and Figure 18).

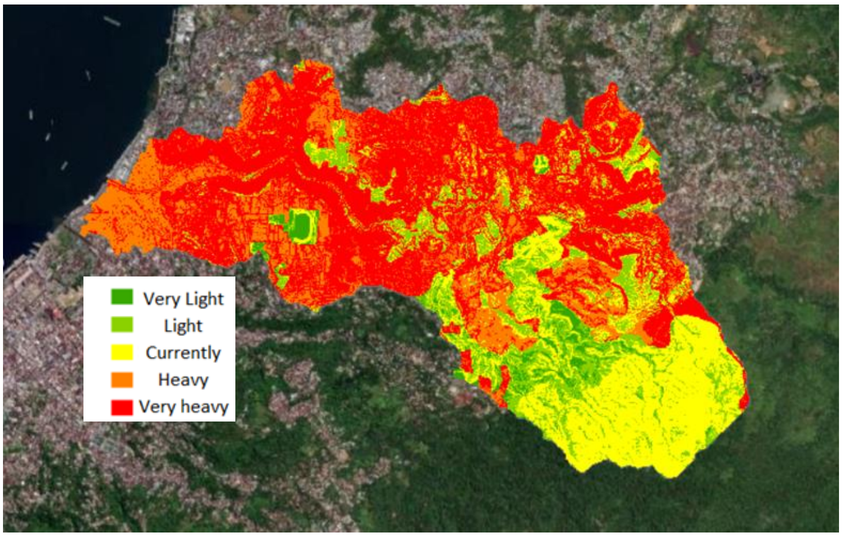

Figure 18. Map of Batu Merah Watershed erosion hazard class

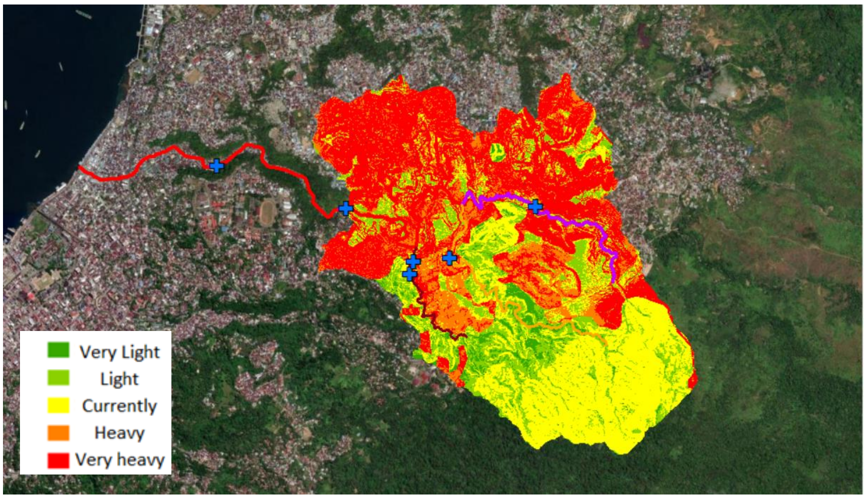

Figure 19. Map of Rinjani Sub-Watershed erosion hazard class Analysis Result

From the results of the overall watershed calculation, the erosion rate is 1,197 tons/ha/year. With the Sediment Delivery Ratio (Boyce) = 0.41 x A^-0.3 = 0.41 x (659.9)^-0.3 = 0.058 then the sediment production obtained is SY = EA x SDR x A = 1.197 x 0.058 x 659.9ha = 46,186 tons/year.

Table 12. Class of erosion hazard of Batu Merah Watershed

No	Class of Erosion Hazard	Area Km^2
1	Very Light	0.188702
2	Light	0.813231
3	Currently	1.351766
4	Heavy	1.267872
5	Very Heavy	2.943811

*Analysis result

Erosion calculations were also carried out in the Rinjani sub-watershed (Figure 19). From the calculation of the Rinjani sub-watershed, the erosion rate is 972 tons/ha/year. With the Sediment Delivery Ratio (Boyce) = 0.41 x A^-0.3 = 0.41x(548)^-0.3 = 0.065, the sediment production obtained is SY = EA x SDR x A = 972 x 0.065 x 548 ha = 29,044 tons/year.

5. Conclusions.

1. The return flood discharge used in the study is Q25 of 132.32 m^3/s. With the distribution of the Lower Sub-watershed of 65.99 m^3/s, the Air Kuning Sub-watershed of 32.49 m3/s, the Yacobus Sub-watershed of 25.72 m^3/s and the Petra Sub-watershed of 16.01 m^3/s.
2. In the analysis of land erosion using USLE (Universal Soil Loss Equation) Batu Merah watershed, the erosion rate was 1,197 tons/ha/year with sediment production of 46,186 tons/year. For the Rinjani sub-watershed, the erosion rate is 972 tons/ha/year with a sediment production of 29,044 tons/year.
3. From the results of the sediment transport modelling at Sta. 0 – Sta 4020 within a period of 5 years there is a decrease in sedimentation volume by 5.23% from 1288 m^3/year in the existing condition to 1220 m^3/year under the design conditions and a decrease in erosion volume by 5.32% from 1299 m^3/year in the existing condition to 1230 m^3 /year under plan conditions.
4. Changes in sedimentation height that occurred during 5 years at Sta. 0 – Sta 4020 experienced a decrease in average height of 20.71% from 0.31 m in the existing condition to 0.25 m in the design condition and the maximum sedimentation height by 15.4% from 0.68 m to 0.58 m.
5. Changes in the depth of erosion that occurred during 5 years at Sta. 0 – Sta 4020 experienced a decrease in the average depth of 14.82% from 0.71 m in the existing condition to 0.61 m in the design condition and the maximum erosion depth did not change by 2 m.
6. Changes in pace that occurred during the 5 years at Sta. 0 – Sta 4020 experienced a decrease in average speed of 8.74% from 0.45 m/s in the existing condition to 0.41 m/s in the design condition.
7. For further research, it is hoped that calibration can be carried out through measurements at the points of erosion and sedimentation. In terms of sampling the bottom and floating sediments, it can later represent optimal conditions, namely during the dry season and rainy season.

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