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Transport Sediment Analysis Using Bed-load: Case Study Bilibili Reservoir

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Abstract This study conducted to analyze transport sediment using bed-load in the Bilibili reservoir case, South Sulawesi, Indonesia. The laboratory test has done to determine the basic characteristics of samples consisting of sediment concentration tests and specific gravity tests. Furthermore, the data analysis using Van Rijn formulation to calculate bed sediment discharge (Q_b) and flow rate (Q), and analysis result found the relationship between bed sediment discharge and flow rate expressed in equation $y = 12.314x + 1.4292$ where $y = x$. $Q_b = Q$. Therefore, the existing sediment transport amount of the Bilibili reservoir for 2014 to 2018 is 1.102 million tons, 1.426 million tons, 0.737 million tons, 1.277 million tons, and 0.895 million tons, respectively. Besides, total sediment is 216,9261.2 tons/year equivalent to 6,142 m³/year, and the percentage of bed sediment transport to total sediment is 70.5%. The analysis results also indicate an increase in bed sediment discharge due to an increase in river water discharge. The condition explains that increasing the flow rate causes the amount of transported sediment to increase.

Keywords Flow Rate, Bed Transport Sediment, Bed-load, Water Discharge

1. Introduction

The reservoir is water management to collect water flows in a watershed system network built by making a dam in the downstream. In addition, to collect transported water and soil erosion in the river upstream, the reservoir also serves to prevent flooding and erosion in the downstream [1,2].

Sediment potential due to massive landslides will flow downstream if the intensity of the rain is high and that it is prone to debris flow with high concentrations [3-5]. The condition caused by that Jeneberang river continues to

drain sediment during floods and settles along the river channel to the Bilibili reservoir [6]. As a result of a considerable volume of Bawakaraeng mountain caldera collapse, approximately 201 million m³ sediment flows along the Jeneberang River and into various existing water structures, such as sabo dam increased rapidly [6]. The landslide eroded and damaged the existing sabo dam and sand pocket and would increase sedimentation in the Bili-Bili Reservoir, thereby causing the reservoir siltation, which will ultimately reduce the operational life of reservoir and threaten reservoir functions sustainability.

The study on sediment transport, especially bed-load measurements, has been carried out and reported well as described below. The use of geophones to measure sediment bed-load found that there is a linear relationship between the amount of impulse and charge mass passing through the sensor. This finding is used to calibrate the geophone signal to determine the bed-load transport velocity [7-9]. Measurement of bed-load transport speed using bathymetry data with sequential time is as accurate as using measurements using amplitude and speed. However, it is necessary to consider waveform deformation due to unstable flow properties and three-dimensional bathymetry surfaces [10].

Furthermore, the study to develop a bed-load transport concept in a number flow and sediment conditions, especially the coastal marine environment, has found the new formulation of bed-load transport. They were using 150 laboratory experiments results and more than 75 measurements of bed-load transportation conducted to validate and limitation of the bed-load transport model [11]. The prediction of bed roughness and bed-load transport in steady river flow is extended to coastal flow, applying an interweave approach and propose simplified bed-load transport formulas [12].

Meanwhile, bed-load transport analysis is fundamental in sediment potential monitoring in a reservoir. Besides, to overcome the problem of landslides, improvements, and

additions, the sediment control structure such as the Sabo dam, check dam, consolidation dam, and sandbags carried out. Therefore, the study conducted to analyze the transport of sediments entering the Bilibili Reservoir using bed-load analysis.

2. Literature Review

2.1. Watershed Management

The watershed concept is the basis of all hydrological planning. Since large watersheds are composed of smaller watersheds, and these smaller watersheds are also composed of smaller watersheds. Generally, a watershed defined as an area bounded by natural boundaries, such as ridges or mountains, or artificial boundaries as roads or embankments where rainfall falling in the area contributes to the control points (outlets). The watershed is an area bounded by topographic separators that receive rainwater, store and drain into rivers, and so on into lakes or the sea [13,14].

Therefore, watershed management efforts are a form of regional development that places the watershed as a management unit, trying to use natural resources in a watershed rationally to achieve optimum production goals in unlimited time so that the distribution of flow evenly distributed throughout the year [15,16] - rivers functions as collecting rainfall in the watershed and flow it to the sea. The function of the river also for agriculture, flood control, freshwater, and water power [17,18].

Watershed management is a regional development form that places the watershed as its development unit. Three main aspects are always a concern in watershed management: water amount (water yield), supply time (water regime), and sediment. A watershed can see as a hydrological system influenced by the precipitation variable as input into the system. Besides, the watershed has a specific character and is closely related to its primary elements, such as soil type, topography, geology, geomorphology, vegetation, and land use. Watershed characteristics in catching rainfall effect evapotranspiration rate, infiltration, percolation, surface flow, groundwater content, and river flow.

In river channel maintenance at downstream, generally, sedimentation occurs. As a result of deposition, the wet cross-sectional area reduced. If sedimentation occurs in a part of a river, then the dredging part of the river needs to be carried out dredging so that the drainage capacity does not decrease [19,20]. The quite prominent area of riverbank needs to be compressed so that no crossing occurs during a flood that can threaten the stability of both the embankment and riverbank.

2.2. River Flow Discharge

River flow is the volume of water that flows through the

river's cross-section at a particular area with the velocity that affects each other, especially rainfall and physical properties [21,22]. River flow data is the most important information for water resources management, while flow rate is water flow (in water volume) that passes through a cross-section in time unit. River discharge is obtained after measuring water velocity using a device such as a current meter or buoy to find out the river flow velocity data. The factors that influence discharge and characteristics are grouped into [23]; 1) factors influence the total runoff volume include climate factors, precipitation, and evaporation; 2) Watershed factors consist of watershed size, topography, soil type, vegetation, drainage water (river sequence) and drainage runoff; and 3) human factors include agricultural techniques and urbanization.

The river discharge needed in studies to determine the flow volume caused by river structures implementation by humans, then further, because the discharge amount is equal to the wet cross-section area multiplied by the current velocity, then its measurement directed against these two factors.

2.3. Sediment

Sediment is the result of erosion, either in surface erosion, ditch erosion, or soil erosion. Sediment generally settles at foothills, flooded areas, waterways, rivers, and reservoirs. The sediment yield is a sediment amount derived from erosion in the catchment area measured at a certain period and place. The sediment yields usually obtained from dissolved sediment measurements in rivers (suspended sediment). In other words, sediments are fragments, minerals, or organic materials that transferred from various sources and deposited by air, wind, ice, or water, and also included deposited from material floating in the water or the chemical solutions forms [24].

Each river carries several suspended sediments and moves solid materials along the riverbed as bed loads. Because the specific gravity of soil material is approximately 2.65 g/cc, floating sediment particles tend to settle at groove bottom. However, the upward current in the turbulent flow prevents gravitational precipitation. If the water-containing sediment reaches a reservoir, the velocity and turbulence will significantly reduce. Floating sediment loads in rivers are cured by taking water samples, filtering them to separate the sediment, drying it, and weighing the filtered material—sediment loads expressed in parts per million (ppm). Sediments aerated in a river valley in the rainfall event can be deposited in the river channel and stay there until the next rainfall pushes it downstream. Certain parts of the river basin may be more sensitive to erosion than other parts so that a higher sediment load expected if rainfall concentrated in such areas.

The sedimentation process consists of process erosion, transportation, deposition, and compaction. The process is very complex, starting from the rainfall, which produces

kinetic energy, which is the initial erosion process. The fine-grained soil will roll along with the flow, and some left above while the other part enters the flow channel into a sediment transport. The soil ability erodes not only on particle sizes but also on the physical properties of organic and non-organic materials bound together with the particles. If the eroded soil particles from the bottom and cliff are eroded, the sediment will move continuously into the sediment transport. Sediment transport can be measured at an estimated water post location so that sediment yield can calculate from a watershed [25-27].

The riverbed is composed of sediment transport material carried by river flow that can transport back in high flow velocity. The huge sediment transport volume depends on flow velocity change, seasons change, and velocity change influenced by human activities. Sediment load is the total sediment transported by river flow at a particular measurement location expressed in weight per time (tons/day or kg/sec) or volume units (m³/day).

Based on the transportation method, sediment loads classified into two: bed-load sediment and suspended load sediment. Bed-load is part of a sediment load that moves along the riverbed by rolling, jumping, or shifting. In contrast, the suspended load is part of the sediment load that moves floated in the flow and interacts very little with the river bed because it always pushed upward by flow turbulence. The bed-load is rougher than the suspended load. Moreover, based on sediment particle size, the sediment load divided into two: bed-material load and fine-material load. The bed materials are sediment at the riverbed, have a coarse particle size, and tend to settle on flow conditions. Whereas fine material load is a sediment load with fine size, not from a riverbed, and tends to settle [28]. Sediment load types, as represented in Fig. 1 [29,30].

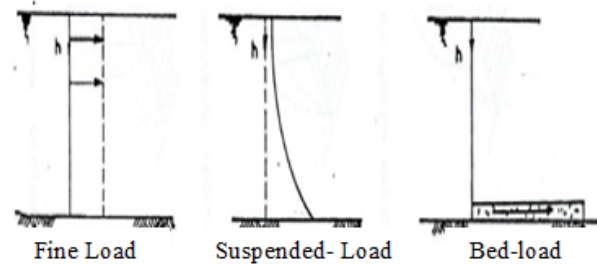


Figure 1. Sediment classification

3. Methodology of Research

3.1. Sediment Sampling

The present study was conducted in Bilibili watershed Jeneberang river South Sulawesi Province, Indonesia, and the sampling location as presented in Fig. 2. Sediment sampling conducted shortly after discharge measurement in a river. The sampling is useful to determine bed sediment concentration and bed sediment volume per unit time transported during measurement. The measurement location must qualify as a bed sediment concentration location, including 1) The flow is not abundant, the straight river channel along more than 3 x the width of the flow when flooded and easily reached. 2) Free from backflow, flowing. 3) Sediment concentrations mixed at the measurement cross-section width. 4) Flow without turbulence so that the sediment is mixed though turbulence is not high. When high turbulence, it is not appropriate as a location for discharge measurements. 5) There is a cable car or other measurement during floods. 6) The shape of the river cross-section is regular, not rocky, has no floodplains, and there is no narrowing of the channel or a meaningful widening of the channel.



Figure 2. Sampling location of Bilibili watershed sediments

One of the two methods of measurement of sediment concentration can be point integration and depth integration. The point integration method is the point of sampling to obtain distribution data of sediment concentration suspension versus depth. The integration method is required when the desired depth analysis of hydrologic concerning sediment suspension watershed. In Indonesia generally uses depth integration methods. River cross-section divided into several vertical paths (vertical distance from the riverbed to water-wet surface cross-section) as seen in Fig. 3.

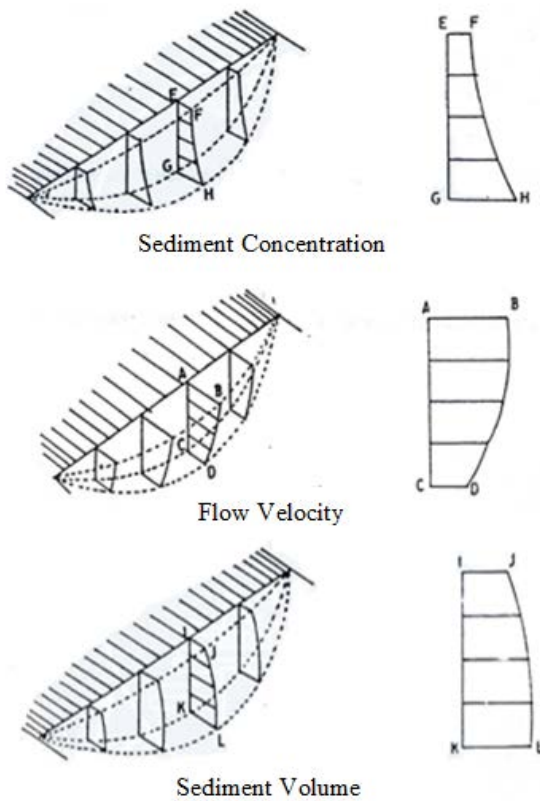


Figure 3. Sketch of vertical flow curve, sediment concentration and sediment volume

Furthermore, the sample from a sampling site conducts a laboratory test to determine bed sediment concentration and dry specific gravity. Bed sediment samples analyzed in the laboratory directly, after being deposited for 1-2 days, the concentration of sediment determined by weighing dried sediment content and dividing by sediment volume into units: mg/l, or g / l, or g / m³, or kg / m³, or parts per million, or stated in%. There are two methods typically used to determine sediment concentration: the precipitation method and filtration method. Precipitation method is a sediment concentration test using gravimetry and is a simple method—the provisions of this test based on Indonesian Standard (SNI 03-3961-1995).

The test analysis conduct starts from depositing the sediment level then drying in an oven. While filtering method conducts if sediment particles will not be analyzed. Specific gravity is a ratio between sediment weight with

distilled water at a volume and the same temperature. The determination of specific gravity performed by measuring the weight and volume of sediment using the Picnometer tool based on SNI 03-4 145-1996.

3.2. Data Analysis

Bed-load transport sediment accurately analyzes with two dimensionless parameters [31]: particle parameter (P) and critical mobility parameter (C). Particle parameter determined using Equation 1.

$$D_* = D_{50} \left[\frac{(s-1)g}{\nu^2} \right]^{1/3} \quad (1)$$

Where: D₅₀ = average particle size, S = particle density (ρ_s / ρ), ρ_s = particle density, ρ = water density, g = acceleration due to gravity, ν = kinematic viscosity (μ/ρ), and μ = dynamic viscosity.

Meanwhile, critical mobility parameter determined using Equation 2.

$$\theta_{cr} = \frac{(u_{*,cr})^2}{(s-1)gD_{50}} \text{ or } u_{*,cr} = [\theta_{cr}(s-1)gD_{50}]^{0.5} \quad (2)$$

Where θ_{cr} is obtained with calculated from the equation:

$$\begin{aligned} \theta_{cr} &= 0.24(D_*)^{-1} && \text{If } D_* \leq 4 \\ \theta_{cr} &= 0.14(D_*)^{-0.64} && \text{If } 4 < D_* \leq 10 \\ \theta_{cr} &= 0.04(D_*)^{-0.10} && \text{If } 10 < D_* \leq 20 \\ \theta_{cr} &= 0.013(D_*)^{0.29} && \text{If } 20 < D_* \leq 150 \\ \theta_{cr} &= 0.055 && \text{If } D_* > 150 \end{aligned}$$

Chezy Coefisien:

$$C' = 18 \log \left(\frac{12R_b}{3D_{90}} \right) \quad (3)$$

For wide channel the assumption: R_b = d (depth of flow), Grain-shear velocity:

$$u'_* = \frac{g^{0.5} \bar{u}}{C'} \quad (4)$$

Transport stage parameter:

$$T = \frac{(u'_*)^2 - (u_{*,cr})^2}{(u_{*,cr})^2} \quad (5)$$

Sediment discharge per meter wide of river:

$$q_b = 0.053 \frac{T^{2.1}}{D_*^{0.3}} [(s-1)g]^{0.5} D_{50}^{1.5} \quad (6)$$

Bed sediment discharges that flow through the river cross section as follows.

$$Q_b = q_b \cdot b \quad (7)$$

With : b = average river width



Figure 4. Sediment laboratory test: a) air-dried sediment, b) specific gravity test, c) sieve analysis, and d) hydrometer test

4. Result and Analysis

4.1. Bed Sediment Laboratory Test

The testing of sediment characteristics conducted the Soil Mechanics Laboratory to classify sediment type can be seen in Fig. 4. Sediment samples of this study obtained from the Jeneberang river. The result of a specific gravity test can be seen in Table 1. Meanwhile, the filtration analysis is shown in Table 2.

Table 1. Specific Gravity of Samples

Sample Code	Specific gravity
Sample 1	2.70
Sample 2	2.67
Sample 3	2.74
Average	2.70

Based on Table 1 the specific gravity obtained, the sediments of Jeneberang river consist of silty sand.

Table 2. Filter Analysis Test Result

No.Filter	Escaped percent			Average Passing Percent
	Sample 1	Sample 2	Sample 3	
4.75	97.16	91.33	92.52	93.67
2.36	96.39	89.19	91.37	92.32
1.19	95.39	87.91	90.24	91.18
0.59	93.14	85.43	88.15	88.90
0.425	92.77	84.97	87.57	88.44
0.27	74.53	75.58	77.40	75.83
0.25	50.63	58.72	63.46	57.60
0.14	18.61	19.62	30.79	23.01
0.07	12.87	9.66	21.83	14.79

The sediment diameter determination through analysis experiment conducted in a laboratory to find grain diameter values D_{50} and D_{90} ; the value of D_{50} is 0.218mm and D_{90} is 0.875mm, as seen in Fig. 5.

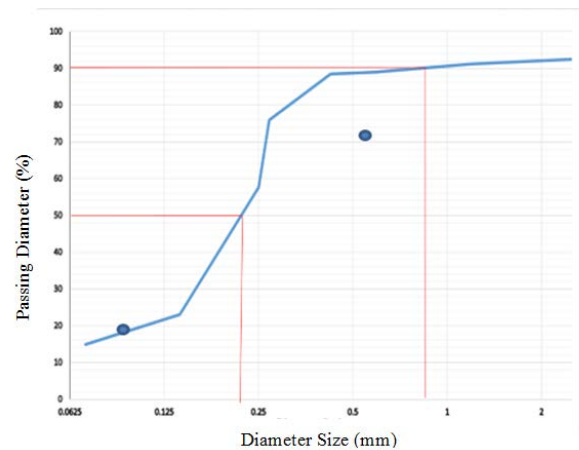


Figure 5. Relationship between passing material and diameter size

4.2. Flow Velocity

Assuming the flow is uniform, the cross-section width knew from the measured result, further cross-section depth known as a calculated result in Table 3. Furthermore, the flow velocity calculated results, as represented in Table 4.

4.3. Bed Sediment Discharge

Bed sediment discharge calculated using Van Rijn formulation in Equation 1, 2, 3, and 4. Based on previous data analysis as in Table1-4 and Fig. 5, The flow rate and bed sediment discharge result analysis represented in Table 5.

Table 3. Calculation of the Stream Depth by Trial And Error

Q	b	d	A	P	R	$AR^{2/3}$	$(n^2Q)/\sqrt{s}$	Correction
(m ³ /s)	(m)	(m)	(m) ²	(m)	(m)	(m)	(m)	
547.01	126	1.843	232.22	129.7	1.791	342.424	342.523	0.099
429.07	126	1.591	200.47	129.2	1.552	268.699	268.672	0.027
334.37	126	1.368	172.37	128.7	1.339	209.392	209.377	0.016
247.51	126	1.140	143.64	128.3	1.120	154.889	154.982	0.093
122.15	126	0.745	93.87	127.5	0.736	76.541	76.489	0.052
88.27	126	0.612	77.112	127.2	0.606	55.228	55.275	0.047
61.02	126	0.491	61.866	127	0.487	38.305	38.207	0.098
46.82	126	0.418	52.668	126.8	0.415	29.315	29.317	0.002
11.72	126	0.182	22.932	126.4	0.181	7.351	7.336	0.015

Table 4. Calculation of Average Flow Velocity

Q	d (h)	b	S	A	P	R	U	Qs
(m ³ /s)	(m)	(m)		(m) ²	(m)	(m)	(m/s)	(m ³ /s)
547.01	1.843	129.375	0.003124	238.4381	133.061	1.792	2.356	561.775
429.07	1.591	128.334	0.003124	204.1794	131.516	1.553	2.141	437.191
334.37	1.368	127.515	0.003124	174.4405	130.251	1.339	1.940	338.476
247.51	1.140	126.623	0.003124	144.3502	128.903	1.120	1.722	248.594
122.15	0.745	125.571	0.003124	93.5504	127.061	0.736	1.302	121.816
61.02	0.491	125.109	0.003124	61.4285	126.091	0.487	0.989	60.739
46.82	0.418	124.977	0.003124	52.2404	125.813	0.415	0.889	46.433
11.72	0.182	124.548	0.003124	22.6677	129.912	0.181	0.512	11.603

Table 5. Calculation Results of Flow Rate (Q) and Bed Sediment Discharge (Q_B)

Q	d (h)	b	U	D50	D90	D*	qcr	u*cr	C'	U*'	T	φ	Q _B	
(m ³ /s)	(m)	(m)	(m/s)	(mm)	(mm)		(m) ²	(m)	(m)	(m/s)			Kg/s	(m ³ /s)
547.01	1.843	129.375	2.356	0.000218	0.000875	6.002	0.044	0.013	70.660	0.104	66.309	0.002725	953.241	83260.05
429.07	1.591	128.334	2.141	0.000218	0.000875	6.002	0.044	0.013	69.511	0.096	56.447	0.001943	660.801	57093.21
334.37	1.368	127.515	1.940	0.000218	0.000875	6.002	0.044	0.013	68.330	0.089	47.819	0.001372	463.454	40042.42
247.51	1.140	126.623	1.722	0.000218	0.000875	6.002	0.044	0.013	66.905	0.081	39.113	0.000899	301.762	26072.23
122.15	0.745	125.571	1.302	0.000218	0.000875	6.002	0.044	0.013	63.580	0.064	24.394	0.000334	111.040	9593.85
61.02	0.491	125.109	0.989	0.000218	0.000875	6.002	0.044	0.013	60.320	0.051	15.267	0.000125	41.350	3572.63
46.82	0.418	124.977	0.889	0.000218	0.000875	6.002	0.044	0.013	59.062	0.047	12.711	0.000085	28.114	2429.09
11.72	0.182	124.548	0.512	0.000218	0.000875	6.002	0.044	0.013	52.562	0.031	4.742	0.000011	3.533	305.23

Furthermore, calculation results plotted on logarithmic paper in Fig. 6, and a combined sedimentary curve was obtained for all daily discharge samples, and bed sediment equation (bad load) was obtained $X = Q$ and coefficient $Y = Q_b.R^2 =$ correlation curve sediment observations for several sediment samples. Figure 6 shows the relationship between bed sediment discharge (Q_b) and flow rate (Q) determined as in Equation 5.

$$Q_b = 12,314 \times Q^{1.4294} \quad (5)$$

Where: Q_b = base sediment discharge (ton/day), and Q = flow rate (m^3/sec).

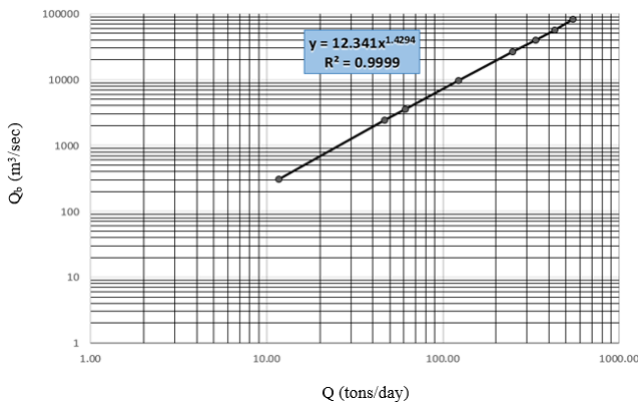


Figure 6. The relationship between flow rate (Q) and bed sediment discharge (Q_b)

Based on Equation 5, the daily bed sediment discharge known, further the calculation results represented in Table 6.

Table 6. Calculation Results of Bed Sediment Discharge (Q_b) Daily

Year	Month	Date	Q (m3/s)	Qb (tonnes/ day)
2014	January	1	194.92	23146.4
		2	123.01	11987.5
		3	63.22	4628.8
		4	85.89	7173.9
		5	42.20	2597.6
		.	.	.
		.	.	.
		.	.	.
2018	December	28	25.30	1250.22
		29	25.31	1251.16
		30	27.23	1388.68
		31	27.44	1404.11

Based on the results of laboratory tests for sediment grain size and analysis that has been carried out, it is known that Bilibili sediment is dominated by silt and fine sand. This result is the following research conducted by Maddi et al. [25] and Lukman et al. [26]. In some areas in eastern Indonesia, the average sediment transport is dominated by fine silt-sand. The research conducted by Nugroho and Basit [32] and Crabbe and Smith in Wakatobi Island, Indonesia [33]. Therefore, based on the results of sediment analysis using bedload to obtain the amount of sediment currently present in the Bilibili dam, this study strongly supports several previous studies that have been carried out at the location by Maddi et al. [25], and Lukman et al. [26]. Besides, this research by the results agreed with a study conducted by Otun and Adeogun [34] on Kubanni Reservoir, Zaria, Nigeria, and concluded that the control of sedimentation in Kubanni Reservoir requires a radical approach than ever before. Furthermore, the equation obtained for the relationship between sediment discharge and flow rate can quickly determine the amount of sediment in the future. The study results greatly help the dam manager decide the number of deposits so that it can be easier to anticipate in the worst conditions, for example, in the rainy season. High rainfall intensity causes high eroded sediment flow from the headwaters and affects the amount of sedimentation. Therefore, this study's results can be used as a guide for managers in preparing future dam management plans.

5. Conclusions

Transport sediment analysis using bed-load conducted and found the relationship between bed sediment discharge and flow rate expressed in equation $y = 12.314x^{1.4292}$ where $y = x.Q_b = Q$. Therefore, the existing sediment transport amount of the Bilibili reservoir for 2014 to 2018 is 1.102 million tons, 1.426 million tons, 0.737 million tons, 1.277 million tons, and 0.895 million tons, respectively.

The previous study results conducted by Wahana Krida Konsulindo found total sediment volume was 5.437 million m^3 while the present study found 216,9261.2 tons/year equivalent to 6,142 m^3 /year. Moreover, the percentage of bed sediment transport to total sediment is 70.5%.

The analysis results also indicate that the increase in bed sediment discharge is due to an increase in river water discharge. The condition explains that increasing the flow rate can cause the amount of transported sediment to increase.

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