Journal of Engineering and Applied Sciences 12 (4): 981-987, 2017
ISSN: 1816-949X

Estimating Volume of Settled Sediment Base on Flood Discharge Plan in T-Year Period Bili-Bili Reservoir

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Abstract: Bili-Bili reservoir is a procurement to overcome the crisis of drinking water, electricity, irrigation and the flooding. Every second, these sediments increasing, piling and lifting up the base in reservoir. The problem that must be concerned nowadays is 75 million m^3 wash-load that has stacked in the bottom of the reservoir and almost reaches intake drain. This study aims to estimate the volume of settled sediment flood discharge plan based on the T-year period using rainfall data obtained from rain stations which influenced the location of research, namely; Senre station, Pamukkulu station and Malino stasion, from 1996-2015. The results of this study indicate that the relationship between suspended load (Q_{sm}) and water discharge (Q_w) obtained by curve equation of sediment; i.e, $y = 0{,}0822x^{0.8558}$ with a correlation coefficient (R) = 1.0, this indicates the relationship between suspended load (Q_{sm}) and water discharge (Q_w) has directed positive relationship is perfect which is among $0.6<R<1.0$. Based on the above curve equation sediment, sediment discharge obtained drift (Q_{sm}) amounting to 37,044.12 tons/day and bed load base on (Q_{sd}) obtained 37,044.12×20% = 7,408.82 tons/day, the total amount of bed load obtained 44,452.94 tons/day. So the volume of settled sediment is obtained at 44,452.94 tons/day = 16,225,323.1 m^3 by flood discharge of 2,341.110 m^3/sec in a period of 10 years. For the condition settles volume of sediment suspended load based on data obtained during the 8 years of the Central River Region Pompengan Jeneberang (CRRPJ) in 2012 as many as 1,317,413.68 m^3 while the estimation results obtained by this research as many as 16,225,323.1 m^3. It shows an increase in volume of settled sediment to the Bili-Bili reservoir in the form of sediment transport from 2012-2015 as many 14,907,909.42 m^3.

Key words: Sediment volume, flood discharge plan, T-year period, Bili-Bili reservoir, Indonesia

INTRODUCTION

Bili-Bili reservoir is the largest one in the province of South Sulawesi located in Gowa regency, about 30 km to the East of Makassar and launched in 1999. The reservoir has the broad of 40,428 ha was built by borrowing funds abroad amount to Rp. 780 billion with the cooperation of the Japan International Cooperation Agency (JICA). Bili-Bili reservoir becomes a source of raw water for Local Drinking Water Company (LDWC) Gowa regency and Makassar city helpful as Jeneberang River flood control of the discharge of 2,200-1,200 m^3/sec. It also serves as Hydroelectric Power Plant (HePP) with a high capacity falls of water = 16.3 m. However, if it rains, then former landslides at the foot of Mount Bawakaraeng flowing debris flow entered Bili-Bili dam up the raw water becomes turbid.

Problems related to sediment transport of substances such as phosphorus, heavy metals and pesticides that have a negative impact. One of the efforts is to conduct periodic dewatering sludge through the power intake which is located at the bottom of the dam. However, if no efforts to prevent sedimentation in a comprehensive manner, the efforts that have been made might not be able to run optimally.

Every second, sediment soil material continues to grow, stack and elevate the base of the reservoir. Data sediment/sludge fine until today had been reached 75 million m^3 and had been stacked at the bottom of the reservoir and almost reaches intake drain. The condition shows the potential to be clogged drain at a later date. As we know that the intake drainage into the estuary of the raw water treatment activities taps, turbines, power generations and irrigations. If the intake tract is covered with fine sediment (wash-load) it is assured that the acitivities concerning lives of millions of citizens would be disrupted. It could be said that the condition of Bili-Bili reservoir has been changed completely from reservoir which holds water. into the reservoir which accommodate mud, rocks and other avalanche materials. So, it cannot be

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expected a lot more for functions of Bili-Bili reservoir that is destined for irrigation and clean water. As evidence when the rainy season the community meets water crisis. because of turbidity of water and the level of threshold value (Fattinaware, 2010). The problem encounters with many sediments were deposited in reservoirs such as Tatipata *et al*. (2015):

- Influencing the storage capacity of the reservoir
- The entry of sediment into the power plant, so it would affect the turbine performance
- Potential abrasion on the building process
- The reducing supply of irrigation with the influx of sediment transport into irrigation canals

With the influx of sediment in the reservoir will result in sedimentation and silting up, so it will affect the capacity of the reservoir in supplying water, both for the purpose of drinking and irrigation. Based on the foregoing, the authors would like to examine further the title of the writing of "Estimating volume of settled sediment base on flood discharge plan in T-year period Bili-Bili reservoir". This study aims to estimate the volume of sediment that settles based on the flood discharge plan in T-year period by using formulas, among others to find out:

- Rainfall area
- Rainfall plan
- Flood discharge plan
- Total of sediment discharge
- The volume of sediment that settles based on flood discharge plan

MATERIALS AND METHODS

Bili-Bili reservoir is located about 30 kilometers to the east Makasar or exactly in watershed Jeneberang downstream, Bili-Bili Village, Ditrict Parangloe, Regency of Gowa, South Sulawesi as shown in Fig. 1. The data used in this study are as follows:

- Regional topographic maps river flow Jeneberang
- Rainfall data which affecting Jeneberang upstream watershed year 1996-2015
- Reservoir inflow discharge Bili-Bili data from 2004-2012
- Suspended load data for 8 years
- Data of results of sediments test laboratory result Bili-Bili reservoir
- Data of technical Bili-Bili reservoir

The first analysis isused to determine of regional rainfall. In this study, uses Thiessen polygon method. Results Thiessen polygon method is more accurate than the method Arithmetic mean. This method is suitable for the area with spacious 500-5000 km^2 and the number of rain stations limited when it compared with the region wide (Suripin, 2013):

$$p=\frac{A_1P_1+A_2P_2+......+A_nP_n}{A_1+A_2+......A_n} \tag{1}$$

Where:

p = Average rainfall
$p_1, p_2, ..., p_n$ = Rainfall observation 1, 2, 3...., n
$A_1, A_2, ..., A_n$ = The area which representing the observation 1, 2, 3...., n

To calculate the frequency distribution of rainfall used Log Pearson Type 3 distribution with consideration that this method is feasible and can be used for all sorts of data distribution. The parameters necessary statistics are; average price (Log X_{rt}), Standard deviation (Sd), Coefficient skewnes (Cs) and Kurtosis Coefficient (Ck). Log Pearson Type 3 distribution is the result of the transformation of Pearson Type 3 distribution by replacing the data into a logarithmic value. Equation Log Pearson Type 3 distribution can be written as following:

$$\log x_t = \log Xrt + (GxS) \tag{2}$$

Where:

$\log x_t$ = Number of rainfalls based on T-year period (mm)
$\log X_{rt}$ = Average logaritma value of X data (mm)
G = Frequency factor
S = Standar deviation of X data

Based on the calculation of rainfall distribution plan using the Log Pearson Type 3, then it is tested. The test is intended to determine the truth of rainfall frequency distribution analysis. The method used in this test is a test of Chi-square and Kolmogorov-Smirnov test method as following. Testing probability distribution by the χ^2-test method can be calculated using the equation, as following:

$$\chi^2=\sum_{i=1}^{n}\left(\frac{(O_f-E_f)^2}{E_f}\right) \tag{3}$$

Where:

χ^2 = Parameter of Chi-square
E_j = Observed frequency
O_j = Expected frequency

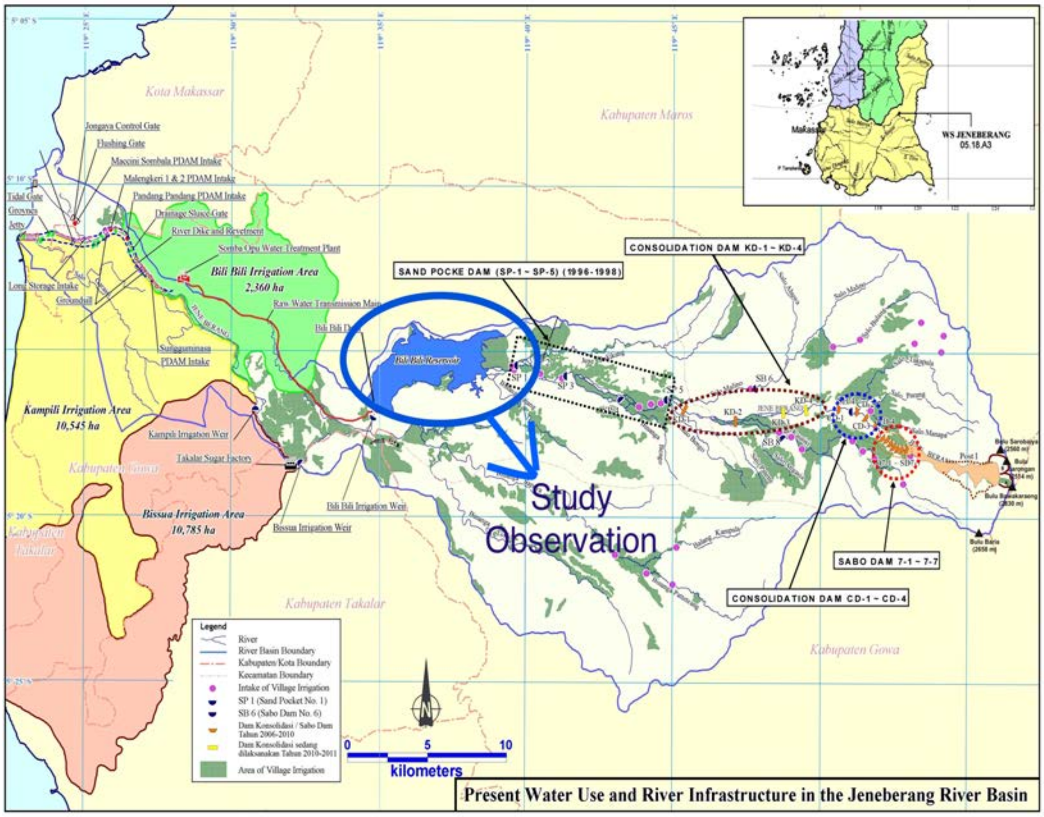

Fig. 1: Map of Bili-Bili reservoir

Testing probability distribution with the Kolmogorov-Smirnov test method can be calculated by using the equation, as following:

$$P(X_i) = \frac{n+1}{i} \tag{4}$$

Where:

$P(X_i)$ = Emperical opportunities
n = Number of events
I = The serial number of data

In the rain-flow analysis, to estimate the flood discharge it's required to enter into a rain plan watershed system. Rain plan in the form of rain in the depths of a point or rain hietograf plan that is the distribution of the rainfall as a function of time during heavy rain. There are several methods used to determine the distribution of rainfall, they are; Tadashi Tanimoto method, Mononobe method and Alternating block method.

In this study, the method used to calculate the intensity of the rain is Mononobe by using Intensity Duration Frequency curve (IDF) as following. The intensity of rain is the height of rainfall that occurs in a period where the water is concentrated (Sriyono, 2012) by denoting with the letter I in mm/hour. Duration is the length of the rain occurs. High rainfall intensity generally lasts short duration and covers an area is not extensive. Rain which covers the broad area, seldom occurs with high intensity but it can continue with longer duration. According to Sriyono (2012) rainfall (mm/hour) can be derived from the data of daily rainfall (mm) empirically by Mononobe method as following:

$$I_t = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}} \tag{5}$$

Where:

I_t = Rainfall intensity (mm h^{-1})
T = Lenght rainfall (h)
R_{24}= Maximum rainfall for 24 h (mm)

Synthetic Unit Hydrograph Nakayasu is developed by several rivers in Japan. Synthetic forms of hydrograph Unit Nakayasu as shown in the equation as following:

$$Q_p = \frac{1}{3.6}\left(\frac{AR_e}{0.3T_p + T_{0.3}}\right) \tag{6}$$

Table 1: Borlan and Maddock's percentage load

Conc. of measured Susp. sediment	Type of material forming the channel	Texture of the suspended materal	Unmeasured load (%)
Small: <500 ppm	Sand Gravel dan rock	Similiar to bed material,	50
		cly siilt, small amount of sand	5
Moderate: 1000-7500 ppm	Sand Gravel dan rock	Similiar to bed material,	10-20
		clay, silt, 25% sand or less	5-10
Big: Over 7500 ppm	Sand Gravel dan rock	Similiar to bed material,	10-20
		clay, silt, 25% sand or less	2-8

Borland and Maddock in Balitbang PU (1989) in Aisyah (2012)

Where:

Q_p = Flood peak flow rate (m^3/sec)
A = Wide of watershed (km^2)
R_e = Effective rainfall (1 mm)
T_p = Time interval from the begining of the rain untill the flood's peak unit (hour)
$T_{0,3}$ = Time required by a decrease of peak discharge up to 30% of peak discharge (h)

To get the volume of settled sediment in a reservoir, sediment curve equation used in data processing suspended load. Assuming that the concentrations of suspended load (C_s) evenly on all parts of the cross section of the dam/river, then floated sediment discharge (Q_{sm}) can be obtained as a result of the multiplication between sediment concentration (C_s) and discharge (Q_w) which can be formulated as following:

$$Q_{sm} = 0{,}0864 \times C_s \times Q_w \quad (7)$$

Where:

Q_{sm} = Suspended load discharge (ton day^{-1})
C_s = Suspended load concentration (mg L^{-1})
Q_w = Water discharge (m^3/sec)

From the above calculation, then made suspended load curve which is a regression line between suspended load and water discharge by following equation (Asiyah, 2012):

$$Q_{sm} = aQwb \quad (8)$$

Where:

Q_{sm} = Suspended load (ton day^{-1})
Q_w = Water discharge (m^3/sec)
a, b = Constants

Sediments disharge (Q_{sd}) was estimated based on the Table Borland and Maddock where the tables provide data on the relationship between the concentration of suspended load, the material type and the percentage of basic bed load and suspended load as shown in Table 1.

RESULTS AND DISCUSSION

Calculation of the rain area is based on rainfall data at average a maximum of 3 stations rain as shown in Table 2, the Senre, Malino and Pamukkulu using polygons Thiessen, then gained extensive rain region affect the location research, as shown in Table 3.

Table 2: Average rainfall maximum

	Maximum daily rainfall annually stations based on rain			
	Senre (%)	Malino (%)	Pamukkul (%)	
Years	0.19	0.49	0.32	Number
1996	27.50	59.90	0.00	87.41
1997	13.17	91,.07	0.00	104.24
1998	12.78	49.19	0.00	61.97
1999	20.92	90.10	23.95	134.96
2000	37.38	57.47	30.97	125.82
2001	23.82	53.57	31.93	109.33
2002	35.45	60.88	28.74	125.06
2003	26.73	79.38	44.70	150.81
2004	24.21	66.72	18.84	109.77
2005	21.31	39.94	33.84	95.09
2006	58.69	68.18	7.34	134.21
2007	43.58	65.75	38.31	147.64
2008	36.80	36.53	38.31	111.64
2009	34.86	45.29	27.78	107.94
2010	23.82	46.75	30.33	100.91
2011	17.43	64.77	16.28	98.49
2012	22.86	75.00	11.49	109.35
2013	39.32	133.93	6.39	179.64
2014	22.27	47.73	30.33	100.33
2015	21.69	70.62	36.08	128.39

Table 3: Broad area of rain each station

Station	Extensive rain influential area (km^2)	Percentage of area influential region (%)
Senre	12,460	19
Malino	31,330	49
Pamukkulu	20,540	32
Number	64,330	100

Calculation of rainfall plan by using the frequency distribution of Log Pearson Type 3 obtained the results as shown in Table 4, as following: statistical parameters are required in the calculation of rainfall by the Log Pearson Type III method on the location of the study, obtained as following; Total average = 116.5, SD = 25.71, coefficient of Skewnes = 0.47, coefficient of Kurtosis = 4.49, No. of events = 20.

Based on the results of rainfall plans by using Log Pearson Type 3 method, then tested by Chi-squared and Smirnov-Kolgomorov method as shown in Table 5. The result of the calculation of daily rainfall intensity using the

Table 4: The results of calculations by the method of precipitation plan Log Pearson Type 3

T-T year period	G	Log	XtXt
2	0.0641	2.061	115.070
5	0.8559	2.139	137.785
10	1.2178	2.175	149.607
25	1.5717	2.210	162.147
50	1.7839	2.231	170.160
100	1.9639	2.249	77.277
200	2.1192	2.264	183.650
1000	2.4169	2.293	196.515

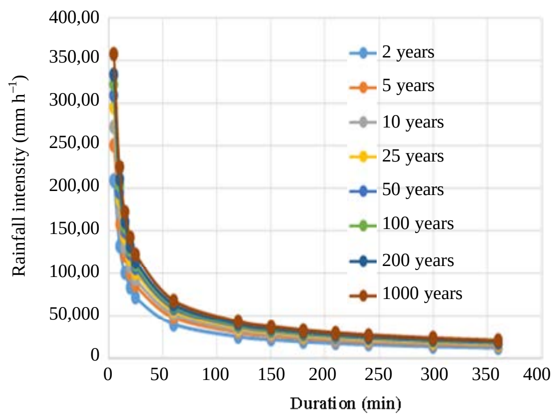

Fig. 2: Graph of Intensity Duration Frequency (IDF)

intensity of Intensity Duration Frequency (IDF) curve obtained rainfall intensity on a T-year period using Mononobe method, as shown in Table 6 and Fig. 2.

The result of the calculation of flood discharge with hydrograph of Nakayasu synthetic unit based on a period T-year, 2, 5, 10, 25, 50, 100, 200 and 1000, is obtained as shown in Table 7 and Fig. 3. The results of the calculations suspended load (Q_{sm}) based on sediment equation curve as shown in Fig. 4 is obtained for 37,044.12 tons/day as following: Bed load (Q_{sd}) was estimated based on Borland and Maddock Table (Table 3). Based on the percentage of bottom sediments by Borland and Maddock Table, shows that concentrations of suspended load (Cs) in reservoir Bili-Bili <7500 ppm with bed load percentage among 10-20%, the amount of bottom sediment discharge is obtained as following:

$$\begin{aligned} Qsd &= 20\% \times Qsm\ hit \\ &= 20\% \times 37{,}044.12\ ton\ day^{-1} \\ &= 7{,}408.82\ ton\ day^{-1} \end{aligned}$$

$$\begin{aligned} S_{total} &= Q_{sm} + Q_{sd} \\ &= 37{,}044.\ 12 + 7{,}408.82 \\ &= 44{,}452.94\ ton\ day^{-1} \\ &= 16{,}225{,}323.1\ m^3\ year^{-1} \end{aligned}$$

Table 5: Distribution fitting test results

Distribution	Chi-square test: Chi-Kuadrat	Chi-square test: Chi-Kuadrat critics	Smirnov-Kolgomorov test (Max. delta value)
Log pearson 3	2.0	5.991	0.485
Gumbel	53.5	5.991	0.122

D critics = 0.29

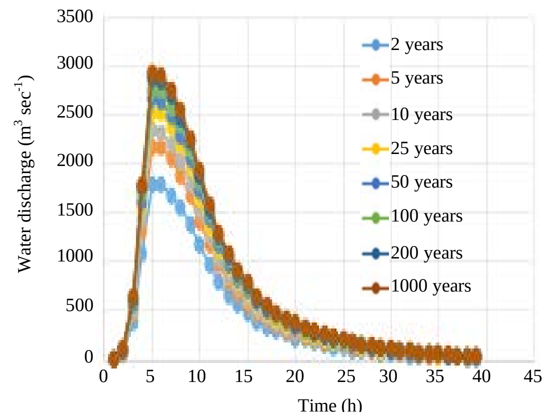

Fig. 3: Graph of nakayasu hydrograph based on years period

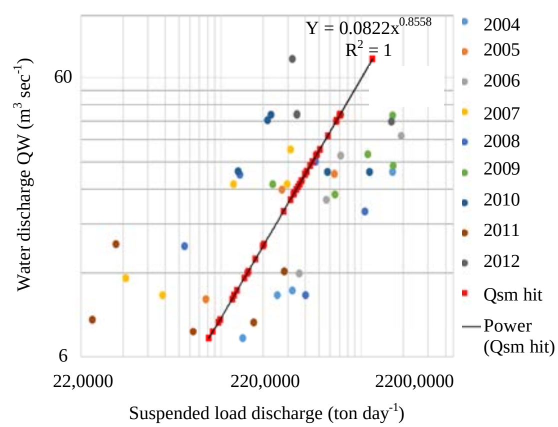

Fig. 4: Graph of the relationship between suspended load and water discharge by sediment curve

The results of the analysis of the maximum average precipitation as shown in Table 2 are obtained for 150.81 mm in 2003 based on the extensive rains which affected to the research area sites, namely; Malino station by 49% as shown in Table 3. It shows that the Malino station is used as a reference for analyzing the frequency distribution of rainfall. The results of rainfall using frequency distribution Log Pearson Type 3 is obtained as shown in Table 4. After the results obtained by the method of precipitation plan Log Pearson Type 3,

Table 6: Results intensity rainfall

Duration (t)			Rainfall intensity (mm h^{-1}) on T-year period						
Minute	2	5	10	25	50	100	200	1000
5	209.108	250.371	271.854	294.641	309.208	322.134	333.715	357.091000
10	131.730	157.724	171.257	185.612	194.789	202.931	210.227	224.953150
	100.529	120.366	130.694	141.649	148.652	154.866	160.433	171.672200
	82.985	99.360	107.885	116.928	122.709	127.839	132.435	141.712000
25	71.514	85.626	92.973	100.766	105.748	110.168	114.129	122.123600
	39.895	47.767	51.866	56.213	58.992	61.458	63.668	68.128000
120	25.132	30.092	32.673	35.412	37.163	38.716	40.108	42.918000
150	21.658	25.932	28.157	30.517	32.026	33.365	34.564	36.986000
180	19.179	22.964	24.934	27.025	28.361	29.546	30.608	32.752000
210	17.306	20.721	22.499	24.385	25.591	26.661	27.619	29.554000
240	15.832	8.956	20.583	22.308	23.411	24.390	25.267	27.037000
300	13.644	16.336	17.738	19.225	20.175	21.019	21.774	23.299000
360	12.082	14.466	15.708	17.024	17.866	18.613	19.282	20.633000

Table 7: The calculation of flood discharge plan based on a year-period

T-year period	Flood discharge plan (Qr) (m^3/sec)
2	1,800.770
5	2,182.710
10	2,341.110
25	2,537.340
50	2,662.790
100	2,774.100
200	2,873.830
1000	3,075.140

then the distribution test using Chi-square test and Kolmogorov-Smirnov test as shown in Table 5. Based on result of uji Chi Kuadrat obtained with a = 5% and DK = 2, then obtained $\chi^2_{cr} = 5.991$. So $\chi^2_{hit} < \chi^2_{cr}$, 1<5.991, This indicates that the Log Pearson Type 3 distribution is acceptable. Kolmogorov-Smirnov test results obtained from the calculation of the biggest differences from biggest difference D_{max} = 12.203%. From the table, the critical price Kolmogorov-Smirnov obtained D_{cr} price = 29% as $D_{max}<D_{cr}$, the deviation is still within the limits of the test, it means that the distribution of rainfall observations in accordance with the distribution model teoritis. Based on the results daily rainfall intensity curve using the intensity of Intesnsity Duration Frequency (IDF) is obtained as shown in Table 6 and Fig. 2. It shows an increase in the intensity of rainfall each T-year period where the intensity is highest rainfall occurs in the period T_{1000}, namely; 357.091 mm h^{-1}. Based on the sediment obtained by curvilinear relationship between suspended load (Q_{sm}) and water discharge (Q_w), namely: $y = 0.0822x^{0.8558}$ with a correlation coefficient (R) = 1.0, this indicates that the relationship between suspended load (Q_{sm}) and water discharge (Q_w) has a direct positive relationship is perfect which is among 0.6 <R <1.0 (Soewarno, 1995), the obtained suspended load (Q_{sm}) of 37,044.12 tons day^{-1} and bed load (Q_{sd}) obtained at 37,044.12×20% = 7,408.82 tons day^{-1}, the total amount of sediment discharge (S_{total}) obtained at 44,452.94 ton day^{-1}. So, the volume of sediment that settles obtained at 44,452.94 ton day^{-1} = 16,225,323.1 m^3/year by plannig flood discharge of 2,341.110 m^3/sec in 10 years of year. To condition the sediment that settles volume based on secondary data obtained from the Central River Region Pompengan Jeneberang (CRRPJ) in 2012 as many as 1,317,413.68 m^3 while the estimation results obtained by this research as many as 16,225,323.1 m^3. This shows an increase in volume of sediment to settle to the Bili-Bili reservoir in the form of sediment transport from 2012-2015 as many as 14,907,909.42 m^3.

CONCLUSION

Based on the results obtained as described in the discussions above the conclusion can be drawn as followings. Based on sediment curve that is the relationship between sediment discharge (Q_s) and the flood discharge (Q_r) based on 10 years of period. The result of model correlation equation, namely $y = 0.0822x^{0,8558}$ with a correlation coefficient (R) = 1.0. The volume of sediment that settles based on measuring which conducted by the Central River Region Pompengan Jeneberang (CRRPJ) in 2012 as many as 1,317,413.68 m^3, while the estimation results obtained by this research as many as 16,225,323.1 m^3. Any increase in the volume of sediment to settle to the Bili-Bili reservoir of the year 2012-2015 as many as 14,907,909.42 m^3.

ACKNOWLEDGEMENTS

Behalf of the authors would like to thank you for Central River Region Pompengan Jeneberang (CRRPJ) which has given data in order to this research. We also would like to thank you for head of State Polytechnc of Ujung Pandang who supported us, so this research could be completed properly.

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