EFFECT OF SAND MINING ACTIVITY ON THE SEDIMENT CONTROL SYSTEM (A CASE STUDY OF SOMBE-LEWARA RIVER, DONGGALA, INDONESIA)

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ABSTRACT

Sombe-Lewara River is a tributary of Palu River which lies at the most downstream part of Palu River which has 112.38 Km^2 of catchment area and 28.11 Km of river length. Sombe-Lewara River comprises three reaches, i.e. Sombe River, Lewara River, and Sombe-Lewara River. In order to control the debris flow disaster, six sediment control structures have been built in Sombe River and another two were built in Lewara River. The sand mining activity in Sombe-Lewara River has caused river degradation and to some extent damaged sediment control structures. In order to prevent the river from further degradation and decrease in environment condition, a proper sediment management is therefore considered necessary. This paper illustrates the sediment balance analysis which applies the empirical formula of sediment supply at the upstream of sediment control structure and storage characteristics of sediment control structures, the initiation of debris flow occurrence and the sediment volume controlled by sediment control structures. The sediment balance was studied based on the sediment flow within the period of 2000 through 2009, at the existing infrastructures and the further development of sediment control structures. The results show that at 10 mm rainfall depth over the catchment, the average annual sediment supply at Somber River and Lewara River was found to be approximately 240,195 m^3 and 112,500 m^3 respectively. Within the above period, the sediment volume passing through control point 1 was approximately 105,890 m^3. Furthermore, the sand mining activity at Sombe-Lewara River has caused severe river degradation and damage on the existing sediment control structures.

Keywords: Sediment balance, sediment control structures, sand mining.

1 INTRODUCTION

A river is a natural stream which may contribute both benefit and loss to the community at its surrounding. In line with the rapid infrastructure development, a river may be a source of materials which support the infrastructure development. This also happens in Sombe-Lewara River, Palu, Indonesia. The improper sand mining activity in Sombe-Lewara River has caused destruction of the sediment control structures in the form of broken sub-dam as the results of intensive scouring near the sub-dam, the failure of the Nunu Bridge abutment, and the failure of the river bank protection. The lack of coordination among several institutions, i.e. Balai Wilayah Sungai III Sulawesi Tengah which has the authority to sustain the sediment control structure and the local governments of Donggala District, Sigi Biromaru District, and Palu City, which have the authority to control the sand mining activity at Sombe River, Lewara River, and Sombe-Lewara River, seems to be a complex situation that contributes factors affecting the problem of river environment degradation. An assessment regarding the sediment balance in Sombe-Lewara River is important to be conducted to obtain the effect of sand mining activity on the dynamics of the riverbed variation. The results of the investigation are anticipated to enlighten on how to improve the sediment management system in such that the negative impact is minimized.

Sombe-Lewara River with the catchment area of approximately 112.38 Km^2 has two sub-catchment areas, i.e. Lewara Sub-catchment and Sombe Sub-catchment (Directorate General of Water Resources, 2006). Lewara Sub-catchment is approximately 55.71 km^2, with the river length and slope inclination of approximately 12.81 Km and 0.087. Sombe Sub-catchment is approximately 56.67 Km^2, with length of 10.65 Km and average river slope of 0.075. Both rivers meet at a location at the elevation of + 95m, then flows down as Sombe-Lewara River, which is 4.85 Km long and 0.026 slope inclination, until finally meets Palu River (see Figure 1). It is seen from Figure 1 that six sediment control structures were built in Sombe River, two at Lewara River, and six at Sombe-Lewara River. Additional three sediment control structures are planned to be constructed at Sombe-Lewara River. An evaluation on the sediment balance of Sombe-Lewara River was carried out by considering both the existing river condition (with current structures) and the river condition with additional structures; the resulted performance of riverbed dynamics was then compared.

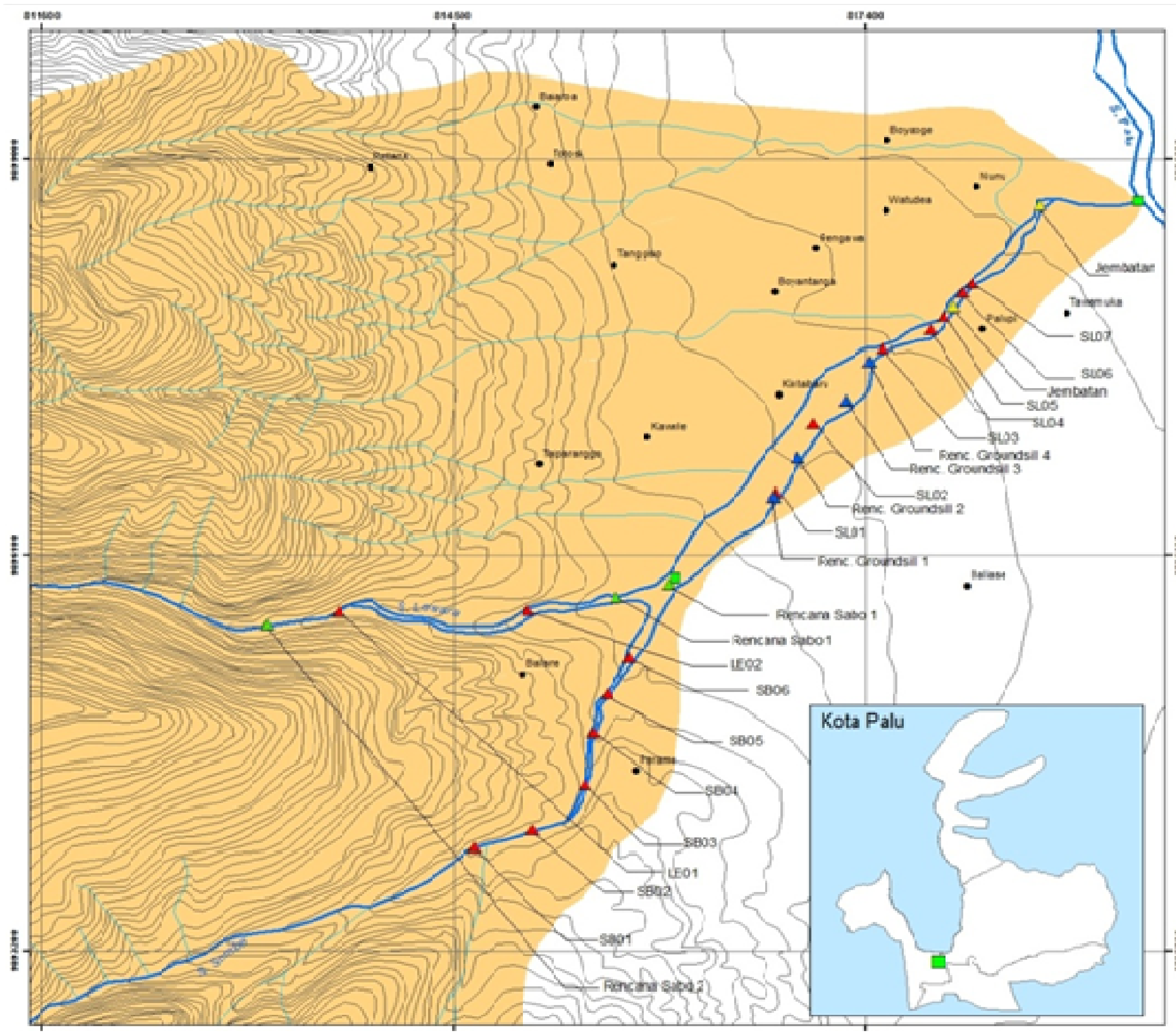

Figure 1. Situation map of Sombe-Lewara River

The analysis of sediment balance was carried out based on the following equation (Shimoda, 1995) in Sudiarti (2001); the sketch is shown in Figure 2.

(1)

where:

V_E : sediment overflowing the structure (m^3)
V_S : sediment entering upstream of structure (m^3)
V_H : sediment trapped at upstream of structure (m^3)
V_C : sediment controlled at upstream of structure (m^3)
V_{se} : dead storage of structure (m^3)

Depending upon the dynamic storage capacity of a structure which is a function of the dead storage volume (V_{se}), the sediment control volume (V_C), the sediment volume trapped or accumulated at the upstream of structure (V_H), the sediment supply from upstream (V_s), and the intensity of the sand mining activity, the sediment overflowing the structure (V_E) could be positive or zero. The very intensive sand mining activity is in such that the volume is much larger than the sediment supply. In such a case, the sediment overflow could be relatively small or even zero

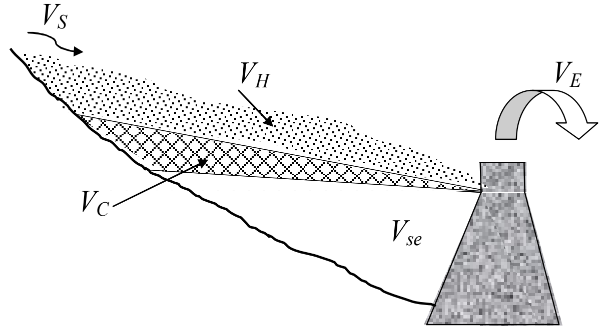

Figure 2. Sketch of sediment balance at a structure

MASS ROUTING OF SEDIMENT FLOW

1.1 Empirical Formula of Sediment Supply

The catchment area of Sombe-Lewara River comprises a non-volcanic formation; therefore, the sediment source of this river may consist of landslides and riverbed erosions. The sediment volume estimation in one particular control point may be estimated based on the empirical equation according to Takahashi (1991) and Mizuyama (1997) in Rachmat (2009);

$$V_s = \frac{R_{24} A 10^3}{1-\lambda} \frac{C_d}{1-C_d} f_r \tag{2}$$

where;

- V_S : sediment input (m^3)
- A : catchment area (Km^2)
- R_{24} : considered daily rainfall (mm)
- C_d : debris flow concentration
- λ : void ratio
- f_r : run off correction factor as a function size of catchment area and sediment characteristics.

1.2 Types of Sediment Flow in Steep Channel

Since the slope of riverbed varies in nature, the types of sediment flow in river may be distinguished as follows;

a) Debris flow, occurs when the river bed slope is greater than or equal to the critical slope of the debris flow equation as written in the following empirical equation (Takahashi, 1978);

$$\tan\theta_d = \frac{C_*(\sigma-\rho)}{C_*(\sigma-\rho)+\rho(1+\frac{1}{K})}\tan\phi \tag{3}$$

where;

- θ : river bed slope
- θ_d : critical slope of debris flow
- ϕ : internal friction angle (^{0})
- σ : mass density of debris flow (ton/m^3)
- ρ : mass density of water (1.0 – 1.2 ton/m^3)
- C_* : sediment concentration at river bed
- K : empirical constant (0.85-1.00)

b) Hyperconcentrated flow of sediment which occurs when the riverbed slope is smaller than the critical slope of the debris flow equation, but greater than or equal to the critical slope of hyperconcentrated sediment flow equation ($\tan\theta_h \le \tan\theta \le \tan\theta_d$).

$$\tan\theta_h = \frac{C_*(\sigma-\rho)}{C_*(\sigma-\rho)+\rho(1+\frac{h_0}{K})}\tan\phi \tag{4}$$

Where $\tan\theta_h$ is the critical slope for the hyperconcentrated flow.

c) Individual sediment flow, occurs when the riverbed slope is much less than the critical slope for hyperconcentrated flow or the acting shear stress is greater than the critical shear stress ($\tan\theta_d \le \tan\theta_h$ or $\tau_* > \tau_{*c}$); the relevant equation is written as follows;

$$\tau_* = \frac{U_*^{\ 2}}{(\sigma-\rho)gd} \tag{5}$$

$$U_* = \sqrt{ghI} \tag{6}$$

where;

- d : sediment diameter (m)
- g : acceleration due to gravity (m/sec^2)
- I : riverbed slope ($\tan\theta$)
- θ : inclination angle of riverbed (^{0})
- σ : mass density of sediment
- ρ : mass density of water
- τ_* : shear stress (N/m^2)
- τ_{*c} : critical shear stress (N/m^2)
- C_* : sediment concentration at bed

A relatively complicated equation model such as rheological model (Chen, 1988) offered different approach utilized in debris flow-related studies

1.3 Sediment Concentration in the flow

The sediment concentration in the flow (C_d) for debris flow and hyperconcentrated flow may be estimated based on Equation (7) from Takahashi (1991) and Equation (8) from Mizuyama (1995) respectively.

$$C_d = \frac{\rho\tan\theta}{(\sigma-\rho)(\tan\phi-\tan\theta)} \tag{7}$$

$$C_d = \frac{11.85\tan^2\theta}{1+11.85\tan^2\theta} \tag{8}$$

where;

- C_d : sediment concentration in the flow
- ρ : mass density of water (ton/m^3)
- σ : mass density of sediment (ton/m^3)
- ϕ : internal friction angle (^{0})
- θ : slope of riverbed

1.4 Control Capacity of Sediment Control Structure

The estimation of sediment balance due to the presence of sediment control structures and the sand mining activity may be affected by the types of sediment control structures. For the close type sediment control structure, the control capacity (V_c) may be estimated based on the following equations with the sketch is shown in Figure 3;

$$V_c = V_{tot} - V_{ds} \tag{9}$$

$$V_{tot} = (A_1 + A_2)B \tag{10}$$

where;

$$A_1 = \tfrac{1}{2} HL_1 \text{ and } A_2 = \tfrac{1}{2} HL_2 - A_1$$

$$V_{ds} = \tfrac{1}{2} HBL_1 \tag{11}$$

where;

$$L_1 = \frac{H}{I_0 - I_s} \tag{12}$$

A_1, A_2 : area at upstream of structure (m^2)
B : river width (m)
H : height of structure (m)
I_o : original slope of riverbed
I_d : dynamic slope, (2/3 I_o – 3/4 I_o)
I_s : static slope (1/2 I_o)
V_C : control capacity (m^3)

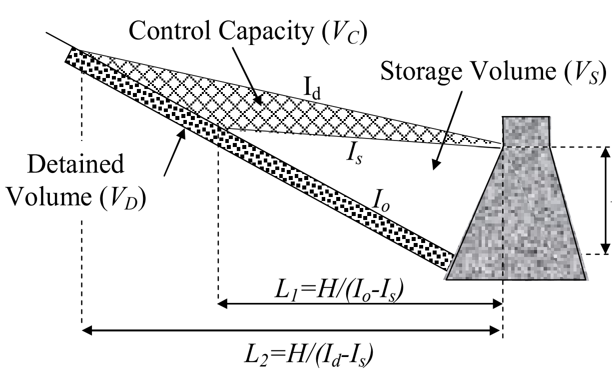

Figure 3. Control capacity (V_C) of a structure

1.5 Natural and Human Interfered Sediment Balance

It is seen from Figure 3 that a detained volume (V_D) is taken into account; hence, Equation (1) is then modified into the following equations:

$$V_E = V_S - (V_D + V_C + V_{ds}) \tag{13}$$

and

$$V_E{}' = V_E - V_{sm} \tag{14}$$

where;

V_E : overflowing sediment before sand mining (m^3)
V_E' : overflowing sediment after sand mining (m^3)
V_S : sediment entering the structure (m^3)
V_C : control volume (m^3)
V_{ds} : dead storage of sediment control structure (m^3)
V_{sm} : sand mining volume (m^3)
V_D : detained volume (m^3)

2 APPROACHES OF ANALYSIS

For the case of Sombe-Lewara River, the sediment balance analysis was carried out by applying the primary data obtained from direct field measurement and observation. These data comprise sand mining activity, sediment source potentiality, and geometry of sediment control structures. Secondary data such as river geometry (topography) and daily rainfall were also collected accordingly. The analysis of sediment balance was carried out in the following approaches;

1) Identification of types of sediment flow applying Equation (1), (2), and (3).
2) Determination of sediment concentration within the flow applying the empirical formula of debris flow and/or hyperconcentrated flow.
3) Identification of sediment source potentiality in Sombe-Lewara River from either riverbed erosion or bank failure.
4) Analysis of sediment supply entering the structures (V_s) applying Equation (2) at various assumptions of rainfall depth.
5) Analysis of control capacity (V_c) of sediment control structures as sketched in Figure 3.
6) Analysis of sand mining volume in Sombe River and Lewara River
7) Analysis of sediment balance at one particular control point, i.e. near the downstream of the tributary of Sombe and Lewara River.

The location of sediment control structures at Sombe River (SB.01 through SB.06) and Lewara River (LE.01 and LE.02) is shown in Figure 4, with CP is the control point for the sand mining location under investigation.

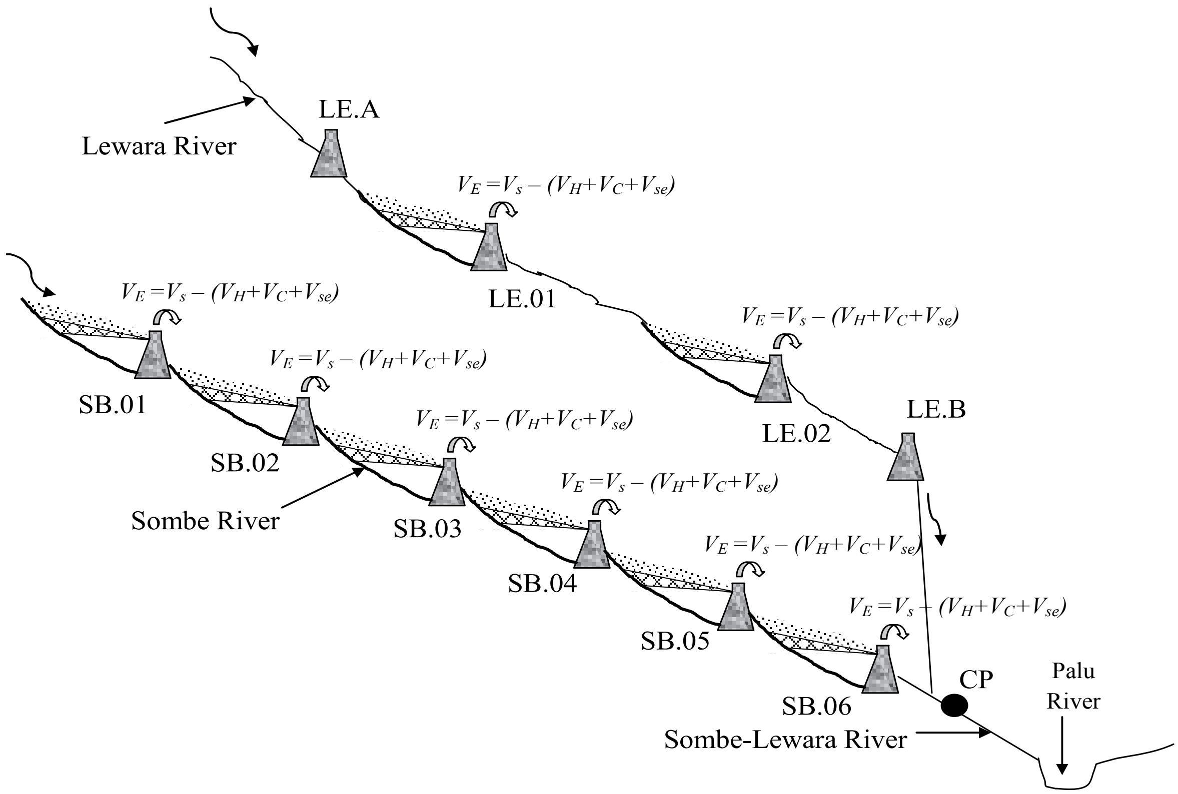

Figure 4. Sketch of location of sediment control structures in Sombe and Lewara River

3 SEDIMENT BALANCE ANALYSIS

It was found that the tan θ_d at various river reaches was generally greater than the slope of the corresponding riverbed. Therefore, the sediment flow type at three reaches (Sombe, Lewara, and Sombe-Lewara River) is generally a hyperconcentrated flow type. The sediment concentration in the flow *(C_d)* was then calculated based on Equation (8) of Mizuyama formula, and the result of calculation of C_d for all sediment control structures at Sombe-Lewara River is presented in Table 1.

The sediment source of Sombe-Lewara River is highly affected by the physiographical condition of the catchment which is dominated by the steep torrential channel with slope ranges from 25% to 45%. The presence of Palu Koro (a fracture zone of Palu) at the upstream of Sombe-Lewara River indicates that a landslide is potential to occur. Additionally, the geological condition of Sombe-Lewara River that consists of conglomerate material or loose sand has made the wet perimeter of the river easily unstable and have a very high porosity. Figure 5 and Figure 6 show the apparent condition of the sediment source of Sombe-Lewara River. It is seen from the above figures that both bank failure and riverbed erosion may occur intensively.

Table 1. Value of C_d at Sombe-Lewara River

Structure	Type	θ	C_d
SB.01	Closed	0.08	0.14
SB.02	Closed	0.05	0.05
SB.03	Closed	0.06	0.07
SB.04	Closed	0.05	0.05
SB.05	Closed	0.04	0.04
SB.06	Closed	0.05	0.07
LE.A	Closed	0.09	0.19
LE.01	Closed	0.09	0.18
LE.02	Closed	0.07	0.10
LE.B	Closed	0.04	0.04

Figure 5. Upstream topography of Lewara River

Figure 6. Deposition at Lewara River

It was found from the field investigation that the unstable sediment formation (i.e. the sediment potential to be easily eroded and became a source of material entering the river) was 278,226 m^3 and 165,247 m^3 for Somber River and Lewara River respectively. These numbers should have not been exceeded by the sand mining activity nearby. Regarding the sediment entering the sediment control structures (V_s), an estimation applying the four different daily rainfall assumptions (i.e. 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, and 80 mm) during 2000 until 2009 shows that a greater value of daily rainfall generally contributes smaller V_s (see Figure 7). This is considered logical since the smaller rainfall is normally more frequent to occur, and therefore the number of sediment being supplied is greater.

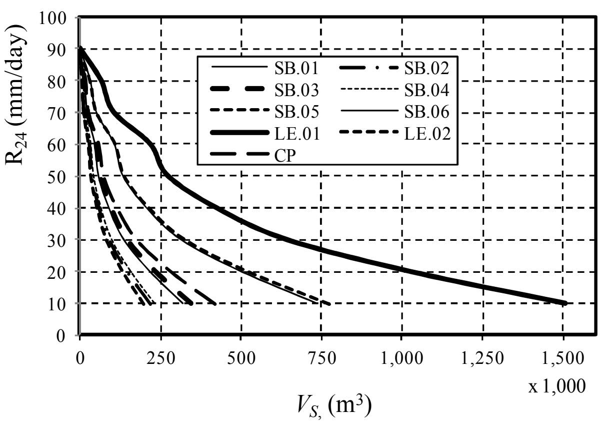

Figure 7. Sediment entering structures (V_S)

The current condition of the sediment capacity (V_C) of sediment control structures are generally already filled up by sediment (V_{ds} = 0). Considering the geometry of the sediment control structures and application of the formula of Equation (9), the control capacity of all sediment control structure is shown in Table 2.

Table 2. Value of V_C at Sombe-Lewara River

Structure	$I_{(1997)}$	$I_{(2010)}$	V_c (m^3)
SB.01	0.06	0.06	2,592
SB.02	0.06	0.05	2,552
SB.03	0.06	0.06	8,333
SB.04	0.06	0.05	5,193
SB.05	0.06	0.04	7,291
SB.06	0.06	0.05	3,572
LE.A	0.09	0.09	4,287
LE.01	0.09	0.07	5,714
LE.02	0.09	0.07	7,714
LE.B	0.04	0.04	12,325
CP	0.05	0.05	59,573

As mentioned in the previous section, the sediment balance analysis is aimed at obtaining information on the amount of sediment overflowing the sediment control structures (V_E), particularly at the control structure downstream of the tributary between the Sombe River and Lewara River. The results are shown in Figure 8.

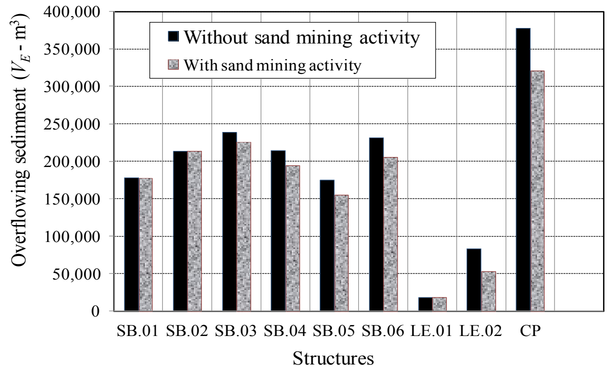

Figure 8. Sediment overflowing structures (V_E)

4 CONCLUSIONS AND RECOMMENDATIONS

The sediment balance is one of many aspects that should be considered in the integrated sediment management. The sediment balance in Sombe-Lewara River was estimated taking into account the four different assumptions of daily rainfall triggering the hyper concentrated flow entering the sediment control structures. The results of simulation show that among the eight rainfalls under investigation, the 10 mm assumption produces a better agreement with the actual occurrence. At this situation, the sediment entering the upstream of SB.01 was 277,736 m^3, whereas at the upstream of LE.01 was 162,713 m^3. The followings are possible considerations that may be taken into account for further sediment management at Sombe-Lewara River, assuming that that all sediment control structures in Sombe and Lewara River are in full condition. Sediment balance with eight sediment control structures (six structures at Sombe River and two structures at Lewara River) contributes the control of sediment at 29,536 m^3 and 13,428 m^3 for Sombe River and Lewara River respectively. The above systems also produce 91,061 m^3 and 70,222 m^3 of overflowing sediment from Lewara River and Sombe River, which made approximately 161,284 m^3 of sediment at the control point under investigation. Based on the field survey, sand mining activity at the control point is slightly less than the overflowing sediment, i.e. 137,700 m^3 or 85.38%. Additionally, the overflowing sediment at control point was reduced due to the sand mining activity in SB.03, SB.04, and SB.06 with 56,400 m^3. This condition has made the overflowing sediment from the control point become 104,884 m^3. Therefore, the overflowing sediment volume is less than the sand mining volume at the control point under investigation. Such situation may have caused degradation downstream of the control point of Sombe-Lewara River.

At the condition where another two sediment control structures are planned to be built along the Lewara River (i.e. LE.A and LE.B), the control capacity of sediment control structures at Lewara River would become 30,042 m^3, much higher than that of the existing ones (i.e. 13,428 m^3). The sediment supply volume of LE.B would be 12.82% of the total capacity of LE.B at 43,141 m^3. At this situation, there is no overflowing sediment from the control point under investigation since the overflowing sediment at 91,061 m^3 only filled the sediment in CP at 70.70%.

It was found that the average sand mining during May 2010 at Sombe-Lewara River was 137,700 m^3 or approximately 459 m^3/day, or approximately 90 trucks per day. If additional two sediment control structures are built in Lewara River, overflowing sediment in Sombe-Lewara River will not occur, which means that the sand mining activity should be ceased, or degradation may occur otherwise. The excessive sediment mining in Sombe-Lewara River has made severe scouring near downstream of SL.03, bank failure and scour around bridge abutment of Nunu/Jati Bridge.

It is recommended that the additional sediment control structures which are planned to be built in Sombe and/or Lewara River should consider the sediment mining activity that may develop. A sufficient and reliable plan on sediment management should be further studied provided with some obligations on the locations, allowable amount sand mining, and good governance on the whole implementation of the regulation. In order to avail a proper (reliable and implementable) sediment management, a participatory study on sediment management applying both technical and non-technical (such as socio-engineering) approaches might have a promissing prospect.

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REFERENCES

Chen, C. (1988). “Generalized viscoplastic modelling of debris flow.” *Journal of Hydraulic Division,* ASCE, 114 (3), 237-258

Directorate General of Water Resources. (2009). *Overall Plan of Sombe-Lewara River, Central Sulawesi Province*. Ministry of Publics Works, Government of Indonesia.

Rachmat, A., Legono, D., and Haryono, K. (2008). “Sediment Management at Gendol River at Post 2006 Mt. Merapi Eruption.” *Master Thesis – Universitas Gadjah Mada*, Yogyakarta, Indonesia.

Sudiarti, S.U. (2006). “Management of Boyong River (Natural and Human Interfere Sediment Migration).” *Master Thesis – Universitas Gadjah Mada*, Yogyakarta, Indonesia.

Takahashi, T. (1978). “Mechanical characteristics of debris flow.” *Journal of Hydraulic Division*, ASCE, 104, 1153-1169

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