SEDIMENT RELATED-DISASTER DUE TO INTENSE RAINFALL IN MT. BAWAKARAENG CALDERA, SOUTH SULAWASI, INDONESIA

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INTRODUCTION

The large-scale landslide occurred on March 26, 2004 at Mt. Bawakaraeng Caldera is considered as one of the worst events in Indonesia. The volume of the landslide was about 232 million m^3. The landslide was caused by the collapse of the walls of the caldera leading to a flow of a large amount of debris. Two collapsed areas were found at the source section of the landslide: one occurred near Mt. Bawakaraeng which was collapsed with a width of 500 m; the other one was a large collapse at the ridge of Mt. Sarongan, which occurred in a horseshoe shaped with horizontal length of about 1,300 m. Collapsed caldera-wall brought tremendous damage to the area, accounting for death of 32 local people, loss of 635 livestock and destruction of many houses and an elementary school. After the collapse, several ponds and gullies developed on the debris. The river discharge containing a high density of sediment has been flowing into the Bili-Bili reservoir and it is anticipated that its service duration has been shortened and the water quality of municipal water supply has been deteriorated (Hasnawir et al., 2006).

The huge mass of debris yielded from the large-scale landslide at Mt Bawakaraeng traveled about 7 km down from the upper reach of the Jeneberang River with 500 m to 800 m in width. On the other hand, the debris deposit has a total volume of 272 million m^3 on the upper reach of the Jeneberang River and 160 million m^3 deposited within the caldera. In the rainy season, there could be a great possibility of strong erosion and huge sediment transportation with debris flows (Tsuchiya et al., 2004). Therefore this paper is developed to estimate the velocity of landslide and debris-flow as well as sediment produced due to intense rainfall.

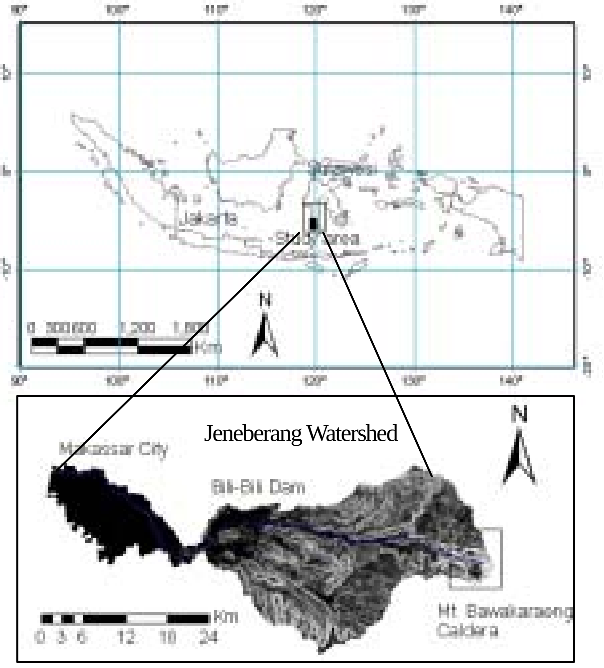

Fig. 1 Location map of the study area in Jeneberang Watershed, South Sulawesi, Indonesia.

GENERAL FEATURES OF THE SITE

Mt. Bawakaraeng is located 90 km away from Makassar, South Sulawesi and the elevation is 2,830 m above sea level. The vegetation of the mountainous area is composed of natural forest and forest plantation dominated by *Pinus merkusii*. The morphology of Mt. Bawakaraeng is characterized by high relief, extreme slope, high degree of weathering as well as erosion activities such as soil movement and landslide. Mt. Bawakaraeng was developed as a result of volcanic activities during the Pleistocene period. It is composed of andesite rocks such as breccia, pyroclasts, tuff and interstratified lavas (Sukamto and Supriatna, 1982). As most of these rocks especially pyroclastic ones have not been compacted, they can be easily decomposed, eroded and slid. Moreover, the rocks consist of lava layers, overlain by ash-build up forming slopes. The contact between layers is considered as the vulnerable part to be eroded. Location map of the study area is shown in Fig. 1.

Generally, the high intensity rainfall occurs from December to March in the study area. The monthly average rainfall is shown in Fig. 2.

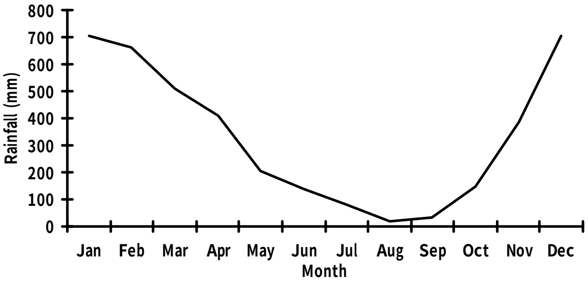

Fig. 2 The monthly average rainfall at the study area (source: monthly rainfall data from 1975 to 2005 in Malino station, 10 km away from Mt. Bawakaraeng Caldera).

VELOCITY AND AMOUNT OF SEDIMENT PRODUCE

The slope gradient is 40° and 17° at the head and toe parts respectively. The longitudinal profile along the course of mass flow is shown in Fig. 3. The transportation of sediment lies within the range of 8,000 m from the source. In order the flow velocity to estimate, the energy line starting from the head of the landslide to the end of sediment where the transportation had been stopped, the velocity was considered to be zero. The following equation was used to compute the flow velocity of landslide.

$$V = \sqrt{2g\Delta h} \qquad (1)$$

where, V is estimated mean velocity (m/sec), g is acceleration due to gravity (m/sec^2) and Δh is height of sliding mass from energy line (m).

The maximum estimated velocity was 75 m/sec. The mean velocity was 59 m/sec. This velocity has caused death of 32 people and destruction 14 houses. Therefore, the landslide at Mt. Bawakaraeng Caldera can be categorized under landslide velocity class 7, as shown by Tables 1 and 2 (Cruden and Vernes, 1996).

According to the people living around Mt. Bawakaraeng, a loud noise was heard before a mass movement had arrived at the settlement area located 7 km away from the caldera.

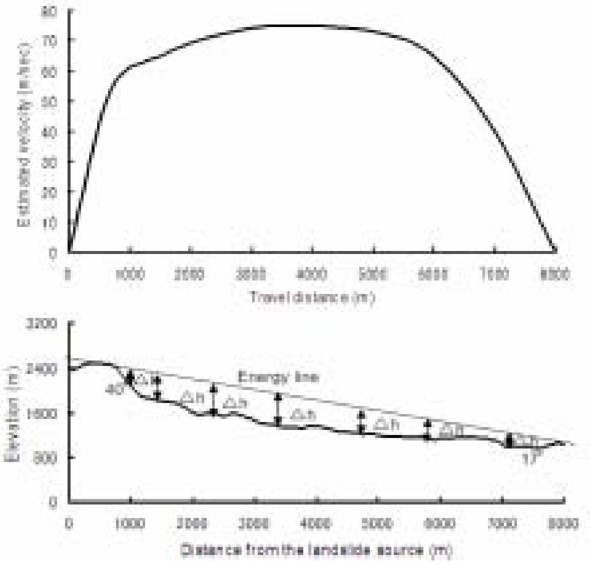

Fig. 3 Longitudinal profile and estimated velocity

Similarly, the debris deposited had been formed large-scale debris which was discharged into the Jeneberang River at a burst on February 16, 2007. The mean velocity of the debris-flow is 32 m/sec. The volume of the debris-flow was estimated about 7.8 million m^3. The velocity of debris-flow became 10 m/sec below 1 km downstream of the Sabo Dam No.7-1. There are three dams named Sabo dam No.7-1 to Sabo dam No. 7-3 for mitigation of sediment disaster. Photographs of Sabo Dam No.7-1 before and during debris-flow are shown in Fig. 4 and Fig. 5 represents the orographic clouds inducing intense rain in South Sulawesi which caused debris-flow on February 16, 2007.

Beside the huge debris-flow after landslide in March 2004, other minor scale debris-flows occurred 10 times in Mt. Bawakaraeng Caldera till December 2007.

IMPACTS AFTER THE LANDSLIDE

After the landslide at Bawakaraeng Caldera in March 2004, the headwaters of the Jeneberang River were covered by sediment. There were tremendous suspended sediments in the river. The sediment had the width of about 1 - 3 km. The length was not less than 30 km and the depth was

40 - 200 m. During the dry season, the sediment does not disturb the river flow. However, when there is heavy rain, water erodes the sediment into the Jeneberang River until the entrance of the Bili-Bili Dam and the water treatment company Somba Opu. This company belongs to the local government (PDAM), supplies water from the Jeneberang River to two districts (municipalities), Gowa and Makassar. This is the worst disaster ever happened in the history of the drinking water company in Makassar. Fig. 6 shows the relationship between turbidity and rainfall pattern from January 2003 to July 2004. Before the landslide occurred, the turbidity of Jeneberang River that entered Sombu Opu reached only 0 - 50 NTU (Nephelometric Turbidity Units) with a maximum value of 100 NTU at times. But after landslide the value sometimes exceeds 6000 NTU. However, with an NTU value of 6,000, 1 out of 2 liters of a sample is mud. This result is obtained after adding double chemical additives, Poly aluminum chlorite (PAC), in order to clean the water from the mud. Hence, the fish habitat of the Jeneberang River was affected; in general, the river ecosystem was destroyed. The landslide also caused intense sedimentation of the Bili-Bili dam, reducing the lifetime and function of the dam.

Table 1 Definition of class probable destruction significance of landslides of different velocity classes (Cruden and Vernes 1996).

Landslide velocity class	Probable destructive significance
7	Catastrophe of major violence; buildings destroyed by Impact of displaced material; many deaths; escape unlikely
6	Some lives lost; velocity too great to permit all persons to escape
5	Escape evacuation possible; structures, possessions, and equipment destroyed
4	Some temporary possible and insensitive structures can be temporarily maintained
3	Remedial construction can be undertaken during movement; insensitive structures can be maintenance work if total movement is not large during a particular acceleration phase
2	Some permanent structures undamaged by movement
1	Imperceptible without instrument; construction possible with precautions

Table 2 Comparison of landslide velocity (Cruden and Vernes, 1996).

Landslide velocity class	Landslide name or location	Reference	Estimated landslide velocity (m/sec)	Death	Remark
7	Elm	Heim,1932	70	115	
7	Goldau	Heim, 1932	70	457	
7	Mt. Bawakaraeng	Hasnawir et al.,2006	59	32	House destroyed
7	Jupille	Bishop, 1973	31	11	House destroyed
7	Frank	Mc Connel and Brock, 1904	28	70	
7	Vaiont	Mueller, 1964	25	1,900	
7	Ikuta	Engineering News Record, 1971	18	15	Equipment destroyed
7	St. Jean Vianney	Tavenas et al., 1971	7	14	Buildings damaged
6	Aberfan	Bishop, 1973	4.5	144	Buildings damaged
5	Panama Canal	Cross, 1924	0.017		Equipment trapped, people escaped
4	Handlova	Zaruba and Mencl, 1969	6.9×10^{-5}		150 houses destroyed, complete evacuation
3	Schuders	Huder, 1976	3.17×10^{-7}		Road maintained with difficulty
3	Wind Mountain	Palmer, 1977	3.17×10^{-7}		Read and railway require frequent maintenance, building adjusted periodically
2	Lugnes	Huder, 1976	1.17×10^{-8}		Six village on slope unditurbed
2	Little Smoky	Thomson and Hayley, 1975	7.93×10^{-9}		Bridge protected by slip joint
2	Klosters	Haefeli, 1965	6.34×10^{-10}		Tunnel maintained, bridge protected by slip joint
2	Ft.Peck Spillway	Wilson, 1970	6.34×10^{-10}		Movements unacceptable slope flattened

MITIGATIVE MEASURE ADOPTED ON SITE

The high magnitude and resulting consequences of damage from debris-flows by landslide and debris-flow in March 2004, indicates that the mitigation is necessary to minimize the future losses of lives and property damages from events of similar or greater magnitude. The selection and design of appropriate mitigation measures depend upon the rate of recurrence of events, their magnitudes, economics, feasibility and acceptability of preventing damage and casualties.

Approaches to debris-flow hazard mitigation can be generally separated into two categories, one involves the construction of some type of physical structures and next involves measures for debris-flow hazard mitigation include removing or converting existing development, discouraging development and regulating development (Erley and Kockelman, 1981).

To reduce the subsequent sediment-related disaster in study area, a pilot project under the cooperation of Japanese and Indonesian governments have been conducted for hazard mitigation. For debris basins surrounded by residential development, the capability to remove material may be necessary on a 24-hr basis during storms and three Sabo Dams out of seven planned are constructed so far in Mt. Bawakareang Caldera area (Fig. 7, 8 and 9).

Before debris-flow(upper), During debris-flow(lower)

Fig. 4 Sabo Dam No.7-1 before and during debris-flow (event with this debris-flow is only one, since series of Sabo Dams have been constructed).

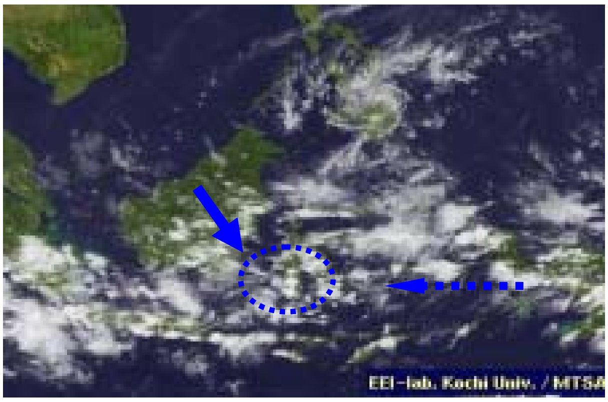

Fig. 5 The orographic clouds inducing intense rain in Southern Sulawesi on February 16, 2007 (with upper air eastward advection).

Monitoring, warning and evacuation can also be considered as hazard mitigation. A cooperative effort of Japanese and Indonesian government is functioned to monitor the debris-flow and rainfall pattern to provide warning mechanism. However, accurate identification of the rainfall conditions of sediment-related disasters is needed to provide forecasts and warnings.

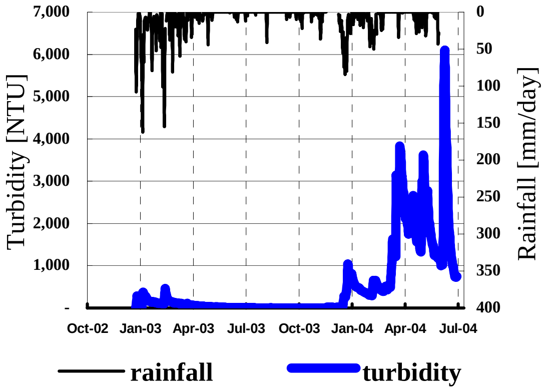

Fig. 6 Turbidity of Bili-Bili Dam Reservoir and daily rainfall condition in January 2003 to July 2004 (Ministry of Public Works, 2005)

APPLYING THRESHOLDS TO WARNING

One of the first warning systems was developed by the USGS in the San Francisco Bay area. The landslip warning system is based on short-term rainfall forecast and it is composed of 86 rain gauges. Conventionally, critical precipitation indicates the amount of rainfall from the time (zero point) in which a sharp increase in rainfall intensity is observed and the triggering of the (first) landslide (Aleotti, 2004); or maximum cumulative rainfall, or combination of cumulative rain and antecedent rain (Hirano, 1995; Kubota, 1995). Duration of the critical rainfall event, as expressed in hours, is the time that elapses from the beginning of critical precipitation to activate landslides.

In this study, hourly rainfall data was used to measure critical precipitation for the previous days. Based on the formula determined by Hirano (1992), the formulas are obtained for the critical line as following.

$$Pdc = Cd / Pa, \quad \text{and} \quad Pic = Ci / Pa . \qquad (2)$$

where, Cd corresponds to “C” for daily rain Pd, Ci is “C” for rain intensity Pi. For a torrent, Cd takes a value of 12000 and Ci is 9000 at the study area. The obtainable results using this equation are shown on Fig. 10 and Fig. 11 respectively.

The maximum rainfall intensity of 70 mm/hr in March 2004 led to landslide after three days. Fig. 10 illustrates when rainfall condition exceeds the critical line, disastrous sediment may be induced.

Fig. 7 Downstream view of concrete Sabo Dam No 7-1 in Jeneberang River, 7 km far from Mt. Bawakaraeng (photograph by Hazama, 2007).

Fig. 8 Downstream view of concrete Sabo Dam No 7-2 in Jeneberang River (photograph by Hazama, 2007).

Fig. 9 Upstream view of concrete Sabo Dam No 7-3 in Jeneberang River (photograph by Hazama, 2007).

However, when rainfall condition below the critical line, a minor sediment flow may be occurred as illustrated clearly by Fig. 11.

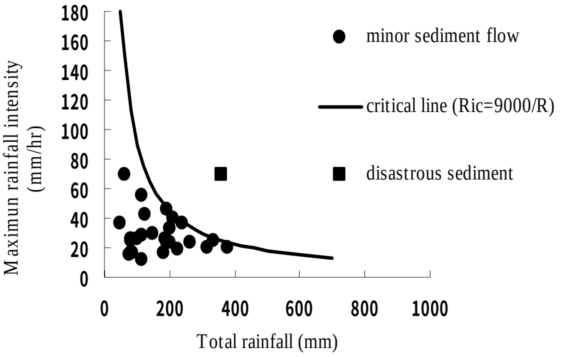

Fig. 10 Relationship between the maximum rainfall intensity and the total rainfall (rain-gauge in Malino station , 10 km from Mt. Bawakaraeng Caldera, rainfall data from 1999 to 2004, large-scale landslide in March 26, 2004 with maximum intensity 70 mm/hr with volume about 232 million m^3).

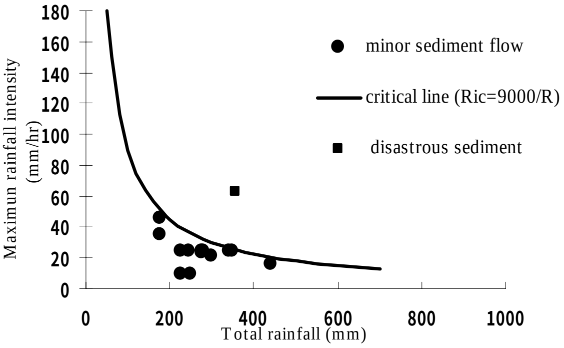

Fig. 11 Relationship between the maximum rainfall intensity and the total rainfall (rain-gauge in Lengkese Village, entrance to Mt. Bawakaraeng Caldera, rainfall data from 2005 to 2007, large scale debris-flow on February 16, 2007 with maximum intensity 40 mm/hr with volume about 7.8 million m^3).

In this case there was an intense debris-flow due to rainfall and a huge amount of sediment deposited during the March 2004 landslide. Debris-flow is likely to occur in many cases even if the rainfall intensity is below the critical line.

CONCLUSIONS

1. The velocity of the landslide and debris-flow in Mt. Bawakaraeng Caldera is categorized as rapid velocity (Cruden and Vernes 1996). The

volumes of large-scale landslide and debris-flow produced are respectively 232 million m^3 and 7.8 million m^3.

2. The maximum intensity on March 2004 was 70 mm/hr while on February 2007, it was 40 mm/hr. The landslide and debris-flow were mainly triggered by intense rainfall. The rainfall data show that higher rainfall intensity is prone to yield disastrous sediments.
3. Under a joint Japanese - Indonesian government cooperation project, three Sabo dams out of seven planned are constructed to reduce sediment related disaster. Therefore, the remaining four dams should be constructed as soon as possible to reduce further effects of sediment-related disaster. In addition, continuous monitoring, warning and evacuation system should be implemented for hazard mitigation.

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