Effect of Debris Flows Post the 2010 Eruption of Mount Merapi on Environment and Socio-Economic Condition in Progo River and Its Tributaries

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The 2010 eruption of Mount Merapi resulted in huge sediment that flows through tributaries as debris flows which had caused morphological change. Its impacts affected on environment and socio-economic condition of inhabitant. It is important to study the effect of debris flow post the 2010 eruption of Mount Merapi on environment and socio-economic inhabitant. The study aims to investigate morphological condition, damage due to debris flow and its impact on inhabitant life as well as environmental change. The study locations were the lower of Pabelan River, the lower of Putih River and Progo River. The Rosgen method was used to determine the morphological characteristic. To calculate sediment transport, Einstein method was used. River bank erosion and number of infrastructure collapse were used to investigate damage due to debris flows. Number of inhabitant evacuated and sand mining activity were parameters to investigate the impact of Merapi eruption on inhabitant life. To identify environmental change, the porosity of riverbed material was used. The result showed that the morphology type of river has been changed significantly. Volume of sediment transport increased after the eruption. River bank collapse was mayor damage through along the river. Some bridges were not function along Progo tributaries, especially along Pabelan River. Thousands of inhabitants along Putih River were evacuated, because their villages buried by sediment and damaged due to river bank erosion. Sand mining activities became intensive in Pabelan River and lower reach of Progo River. From the environment view, porosity of riverbed material commonly decreased in the Progo River and its tributaries.

Key words: Merapi eruption, morphology, porosity, transport sediment, sand mining

1. BACKGROUND

Mount Merapi is one of the most dangerous volcanoes in Indonesia. During its eruption, pyroclastic flows through in almost rivers that originate at Mount Merapi as Apu River, Trising River, Senowo River, Batang River, Woro River, Gendol River and others. Mount Merapi danger is not only primary hazards, as lava and hot clouds, but also secondary hazards as debris flow. In the rainy season, volcanic material flows rapidly and spreads through tributaries as debris flow that has a huge destructive force resulting in damage of infrastructure and loss of human life.

After its eruption in 2010, the land surface conditions have hardened so when rain took place, the impact will be greater. The condition aggravated by a green cover on the slopes of Mount Merapi has been largely destroyed by the eruption of Mount Merapi in 2010. And also, the shallow river channel due to sedimentation will facilitate debris flows. Damage due to debris is not only a change in Progo River and its tributaries, but also the social conditions of inhabitants along the rivers. Therefore, it is necessary to carry out the impact of debris flow post the 2010 eruption of Mount Merapi at Progo River and its tributaries from environment and socio-economic aspects.

2. THE 2010 ERUPTION OF MOUNT MERAPI

The 2010 eruption of Mount Merapi is the biggest eruptions compared to its eruptions in history, especially the eruption in 1872. One of indicators used to determine an index of eruption is amount of volcanic material that has been leveled. In the 1872 eruption, the amount of volcanic material brought up by the eruption during its process was about 100 million m^3. Meanwhile, the amount of volcanic material has spewed from Mount Merapi since October 2010 to present is estimated at around 150 million m^3.

The volcanic material brought by debris flow reached nearly 50 million m^3, 100 million m^3 as remaining material that become a threat in every heavy rain. The material flows through tributaries that have originate in Mount Merapi as Pabelan, Putih, Blongkeng and Krasak Rivers. The tributaries flow into Progo Rivers that has downstream in Trisik Beach, Kulon Progo Regency.

The amount of volcanic material carried by debris flow through tributaries of Progo River is estimated at 30.8 million m^3, with of 20.8 million m^3 in Pabelan River, 8.2 million m^3 in Putih River and 10.8 million m^3 in Krasak River. It means that Krasak, Pabelan and Putih Rivers potentially affected by debris flows again.

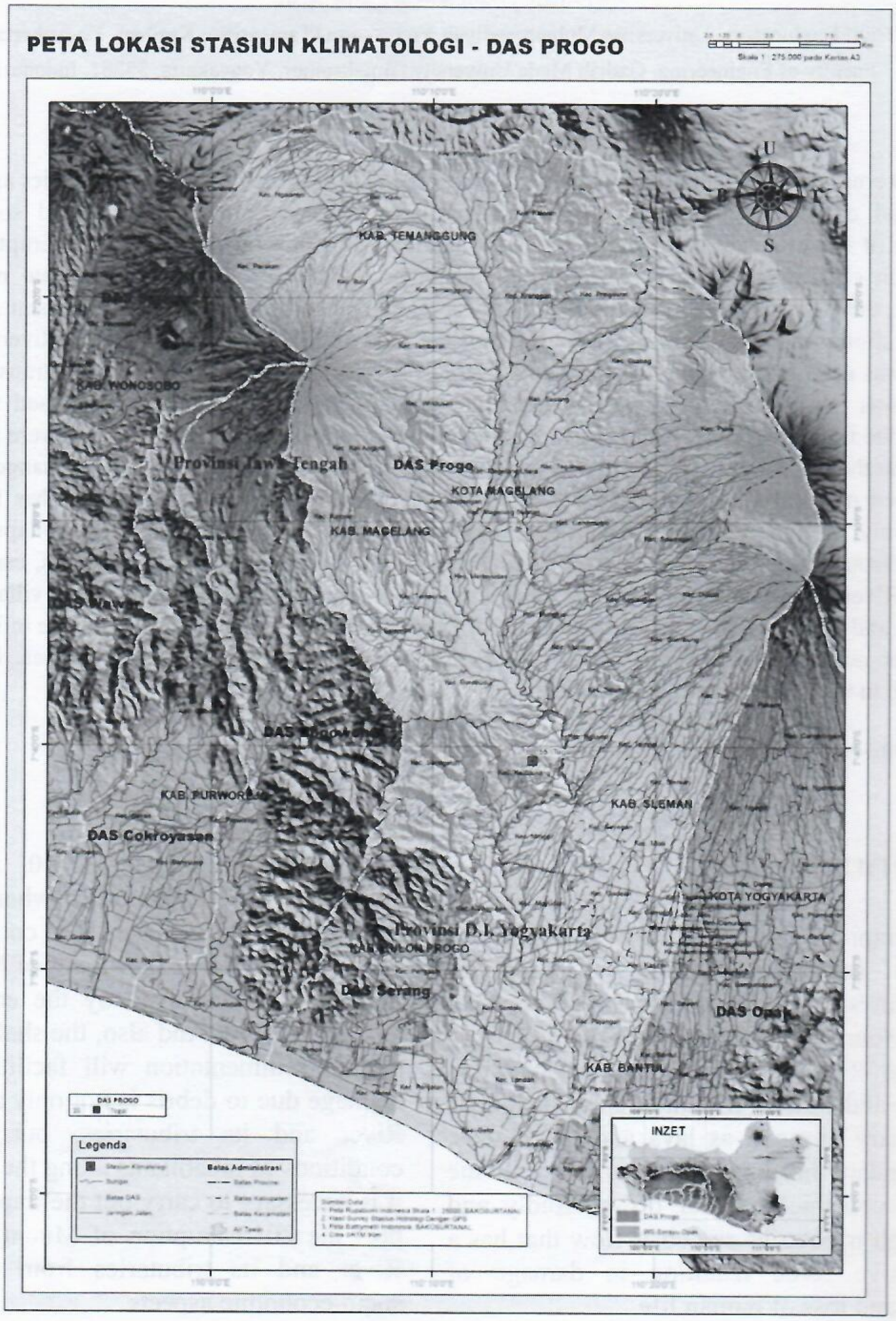

Figure 1. Basin area of Progo River and its tributaries [http://www.bbws-so.net]

3. PROGO RIVERS AND ITS TRIBUTARIES

Progo River originates in Temanggung Regency and flows through Magelang Regency (in Central Java Province) and Sleman, Kulon Progo and Bantul Regencies (in Yogyakarta Special Province). In Magelang, Pabelan and Putih Rivers join into Progo River, while Krasak River joins into Progo River in Sleman Regency. Progo River is a river with a pattern of radial flow, with a basin area of 2380 km^2 and a river length of 140 km. Progo River is widely used by inhabitants in its surrounding for irrigation, tourism, sand mining and others. **Fig. 1** shows basin area of Progo River and its tributaries.

4. ENVIRONMENTAL AND SOCIO-ECONOMICAL ASPECTS

4.1 Environmental aspect

River environmental aspect used in this study is morphological, porosity and sediment transport parameters.

4.1.1 Morphology

River morphology is the study of river condition changes. For specific description, river morphology is a matter that concerns in a geometry change (shape and size), type and behavior of river with all aspects of the changes in the dimensions of space and time. Thus concerning the dynamic aspect of river and its environment is interconnected.

To determine river morphology, it must be known a number of characteristic factors of river. The data required is a flow width (W_{bkf}), flow depth (d_{bkf}), flood flow width (W_{fpa}), a maximum depth of flow (d_{mbkf}), river slope and river bed material (d_{50}). **Fig. 2** shows the main parameter to determine river morphology types using [*Rosgen*, 1996] method.

4.1.2 Porosity

According to [*Sulaiman*, 2008], to calculate a value of riverbed sediment porosity is done with the following steps. First, the bed material on each point representing top, middle and bottom material is sieved to obtain grain size distribution. Furthermore, a type of sediment distribution is determined based on the value of γ and β parameters, which is calculated by the following equations:

$$\gamma = \frac{\log d_{max} - \log d_{50}}{\log d_{max} - \log d_{min}} \quad (1)$$

$$\beta = \frac{\log d_{max} - \log d_{peak}}{\log d_{max} - \log d_{min}} \quad (2)$$

where:

γ dan β = geometrical parameter
d_{max} = maximum diameter
d_{min} = minimum diameter
d_{peak} = peak diameter
d_{50} = diameter of 50 % from sample sieved

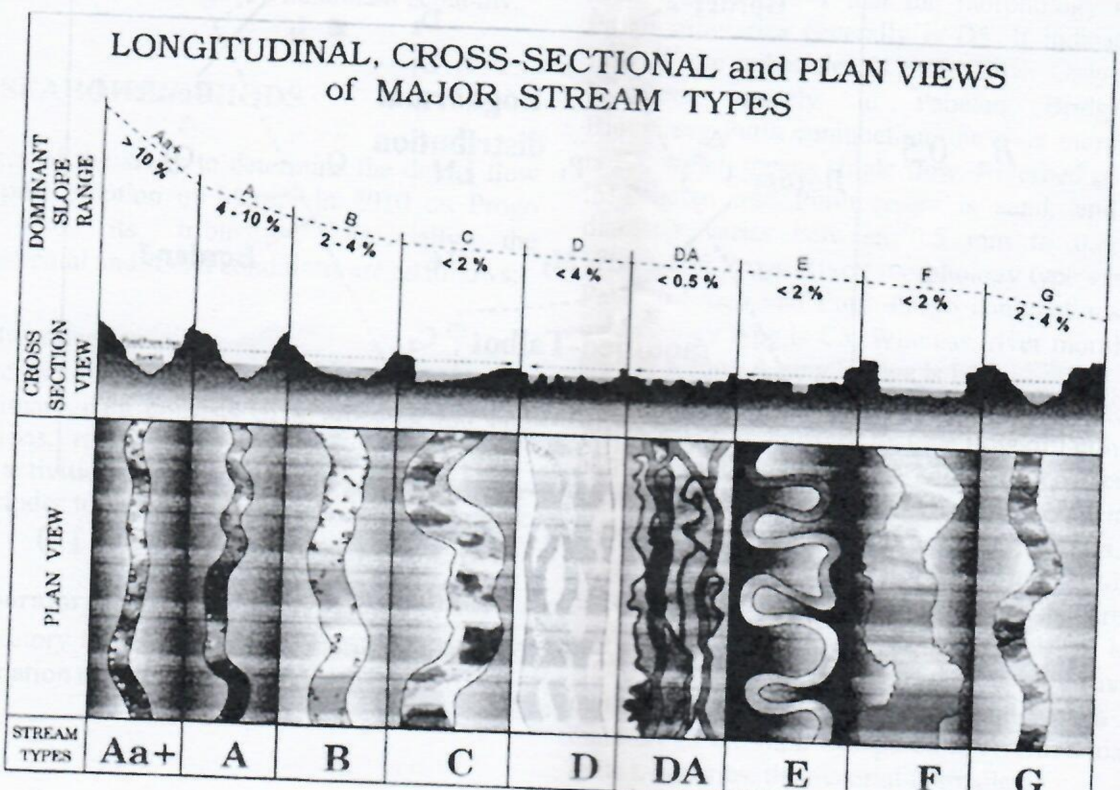

Figure 2. The main parameters of river morphology [*Rosgen*, 1996]

Once the values of γ and β are known, the type of grain size distribution can be found using the diagram proposed by [*Sulaiman*, 2008], as shown in **Fig 3**.

Furthermore, the porosity values can be calculated with the following equation:

4.1.2.1 Lognormal distribution

$$\sigma_1{}^2 = \sum_{j=1}^{N} (Ind_j - Ind)^2 P_{sj} \quad (3)$$

where:

$$\gamma = (0.1561) if\ 1.5 < \sigma \quad (3a)$$

$$\gamma = (0.0465\sigma) + (0.2258)\ if\ 1.25 < \sigma < 1.5 \quad (3b)$$

$$\gamma = (-0.141\sigma) + (0.3445) if\ 1.0 < \sigma < 1.25 \quad (3c)$$

$$\gamma = (-0.105\sigma) + (0.3088)\ if\ 0.75 < \sigma < 1.0 \quad (3d)$$

$$\gamma = (-0.1871\sigma) + (0.3698)\ \ if\ 0.5 < \sigma < 0.75 \quad (3e)$$

where:

σ = deviation standard
d = grain size diameter
j = grain size class
p_{sj} = proportion of class j
γ = porosity

4.1.2.2 M Tallbot distribution

$$n_T(x\%) = \frac{In(f(D_{x\%}))}{In\left(\dfrac{\log D_{x\%} - \log D_{\min}}{\log D_{\max} - \log D_{\min}}\right)} \quad (4)$$

$$n_T = \frac{n_T(16\%) + n_T(25\%) + (50\%) + n_T(75\%) + n_T(85\%)}{5} \quad (4a)$$

$$100 \le d_{max}/d_{min},\ \gamma = 0.0125\ n_T + 0.3 \quad (4b)$$

$$d_{max}/d_{min} \ge 1000,\ \gamma = 0.0125 n_T + 0.15 \quad (4c)$$

where:

$f(D)$ = cumulative percentage of grain size
n_T = Talbot number

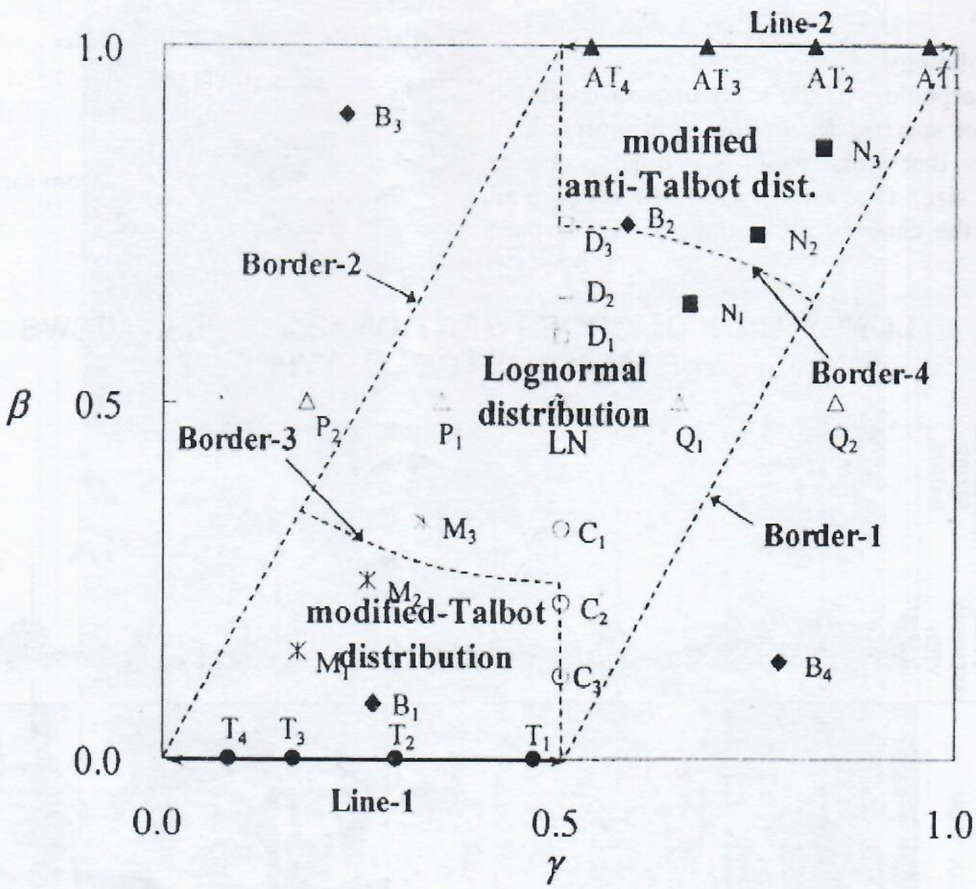

Figure 3. Diagram to determine type of grain size distribution [*Sulaiman*, 2008]

4.1.3 Sediment transport

Sediment transport is an event when material transported by river flow. Shape, size and weight of material particle will determine the amount of sediment transport. There are many formulas to calculate the amount of sediment transport, one of them is using Einstein formula [*Kironoto*, 1997].

Einstein set the basic sediment transport equation as the equation that connects bed material and local flow. The equation describes an equilibrium state of the bed granular exchange between first bed layer and second bed layer. Einstein used d_{35} as a transport parameter, whereas for roughness used d_{65}. To determine sediment transport using the Einstein formula, the necessary data are: the flow discharge (Q), the width of the channel/river (B), the slope of the river (S), gradation of grain size from sieving analysis and viscosity of water (v).

4.2. Socio-economical aspects

Socio-economical parameters used in this study are infrastructures damage; inhabitant evacuated and sand mining activities. Debris flows will give negative impacts in social condition as well as positive impacts. The negative impacts that often occurred are river bank collapse due to erosion along the river. Damage in a river bank, it will cause the social problem, such as the loss of agricultural land, houses damaged and others. Nevertheless, debris flows also brought positive impacts, such as the material could be used as resources, so that mining activities can improve inhabitant economy.

5. RESEARCH METHODS

Stages of the study to determine the debris flow effect post eruption of Merapi in 2010 on Progo River and its tributaries, especially the environmental and social conditions are as follows:

5.1 Data collection

The data collected is primary and secondary data. The primary data consists of a cross-section and dimensions, river slope, sediment samples, sand mining activities and riverbank collapses. Secondary data includes topographic maps and social economic data.

5.2 Laboratory test

Laboratory testing is used to determine the grain size gradation of riverbed material sample.

5.3 Analysis data

Based on the data from the field survey and the laboratory test, river morphology, porosity and sediment transport were analyzed. In addition, also land degradation/river bank collapse and sand mining activities were analyzed.

5.4 Discussion and conclusion

Based on the analysis data, then discussion of the results and conclusion were carried out. The parameters used to determine effects of debris flow due to the eruption of Merapi in 2010 on environmental conditions is river morphology, porosity of riverbed sediment and sediment transport. River morphology determination method used [*Rosgen*, 1996], sediment porosity using the formula of [*Sulaiman*, 2008] and to determine the amount of sediment transport with Einstein's formula. The parameters used to determine on social conditions are inhabitant evacuated, infrastructure damage and sand mining activities. Location of the study were conducted in three locations, namely in Putih River, Pabelan River and Progo River.

6. RESULT AND DISCUSSION

6.1 River morphology

Based on [*Rosgen,* 1996] method, morphology types of the rivers are shown in **Table 1**. It can be seen from **Table 1** that the morphology type in Progo tributaries generally is D5. It indicates that flow in the tributaries is multi flow. Only in two locations, namely in Pabelan Bridge and Blongkeng-Putih conjunction, the river morphology is E5, which means single flow. Riverbed materials in Pabelan and Putih rivers is sand, and mean diameter varies between 0.5 mm to 0.88 mm. Whereas in Progo River, morphology type varies. In Pabelan-Progo and Putih-Progo conjunctions, river morphology type is C5. Whereas, river morphology type in Kebun Agung Bridge is F5.

Slope of Pabelan River is smaller than slope of White River. It indicates that the flow of Putih River has capability to transport sediment coarser than flow of Pabelan River. In Progo River, especially in Pabelan-Progo and Putih-Progo conjunctions, river slope is stepper than in Kebun Agung Bridge (> 1.4). It describes that the two points are areas of sediment transport. Whereas in point of Kebun Agung Bridge is a deposition area. Riverbed material of Progo River is fine sand with a mean diameter of 0.3 mm. Compared to riverbed material in its tributaries, the material is smaller.

Table 1 Morphplogy type of river

Location	*Parameter*				
	ER	W/R	Slope (%)	d50	Type
Putih River					
Sirahan I	10.70	20	0.571	0.88	D5
Sirahan II	9.11	16.88			
Blongkeng-putih	20.63	7.55	1.512	0.83	E5
Putih-progo I	20.64	15	1.374	0.85	D5
Putih-progo II	29.72	10.14			
Pabelan River					
Pabelan 1 Bridge	13.30	7.804	0.445	0.60	E5
Srowol 1 Bridge	16.134	12.526	0.748	0.50	D5
Srowol 2 Bridge	25.772	9.313			
Srowol 3 Bridge	7.266	45.957			
Pabelan-Progo 1	11.953	12.333	0.56	0.88	D5
Pabelan-Progo 2	9.938	5.817			
Progo River					
Pabelan-Progo 1	19.57	11	1.41	0.3	D5
Pabelan-Progo 2	3.35	72.73			
Putih-Progo	3.73	23.91	2.1	0.25	C5
Kebon Agung Bridge	1.26	261	0.84	0.38	F5

6.2 Porosity of sediment

Based on the results, the value of γ and ß parameters are shown in **Table 2**. **Table 2** shows that for Putih River, the type of grain size is Log Normal with porosity values varying from 0.21 to 0.28. For Pabelan River, a type of grain size in the upstream area is Talbot with porosity of 0.29. In the downstream area of Pabelan River, type grain size is log normal with a porosity value of 0.15.

In Progo River, the grain type is Talbot with a porosity value of 0.29. From **Tables 1** and **2**, also show that the porosity value of riverbed sediment in Progo River is greater than in tributaries. In addition, the mean diameter of the riverbed material in Progo River is smaller than in its tributaries. Compared to conditions before the eruption of Merapi in 2010, there has been a change in morphology, especially on river width in Progo River as well as its tributaries.

Table 2. Grain size type and porosity

Location	*Parameter*			
	γ	β	Type	λ
Putih River				
Sirahan I Sirahan II	0.164	0.5637	LN	0.284
Blongkeng-putih	0.557	0.4399	LN	0.210
Putih-Progo I Putih-Progo II	0.148	0.5637	LN	0.214
Pabelan River				
Jembatan Pabelan 1	0.476	0.0996	T	0.290
Jembatan Srowol 1 Jembatan Srowol 2	0.432	0.0996	T	0.291
Jembatan Srowol 3 Pabelan-Progo 1 Pabelan-Progo 2	0.558	0.5639	LN	0.156
Progo River				
Pabelan-Progo 1 Pabelan-Progo 2	0.104	0.1886	T	0.291
Putih-Progo	0.194	0.1886	T	0.292
Jembatan Kebon Agung	0.328	0.1886	T	0.290

6.3 Sediment transport

Based on calculations using Einstein formula, sediment transport for each location is shown in **Table 3**. Sediment transport at upstream location in Putih River has a smaller value than in the downstream location. This condition indicates that there is potential erosion occurs.

Sediment transport the location in Pabelan River shows the same relative value. This indicates that there is no erosion or deposition. Material transported in the River Pabelan, generally derives from Mount Merapi. In Progo River, sediment transport in the upstream location is greater than the downstream. This illustrates that deposition occurs in the middle and lower reaches.

Table 3. Sediment transport

Location	Q (m^3/s)	Qsed (ton/day)
Putih River		
Sirahan I	0.036	0.0027857
Sirahan II	0.194	0.0147729
Blongkeng-putih	0.858	1.177
Putih-progo I	0.949	0.6590209
Putih-progo II	0.647	0.3522725
Pabelan River		
Jembatan Pabelan 1	5.429	4.171
Jembatan Srowol 1	2.614	2.648
Jembatan Srowol 2	1.791	1.741
Jembatan Srowol 3	2.339	0.988
Pabelan-Progo 1	4.094	3.213
Pabelan-Progo 2	1.798	0.665
Progo River		
Pabelan-Progo 1	7.05	4.69
Pabelan-Progo 2	25.94	24.30
Putih-Progo	26.38	10.78
Jembatan Kebon Agung	34.81	22.24

6.4 Socio-economic aspects

The number of social economical effect is shown in **Table 4**. From **Table 4** illustrates that the losses due to debris flow in 2010/1 greater than in 2012/3. It also shows that the intensity of debris flow in 2010/1 was also higher compared to 2012/3. However, it still must be taken an attention for the possibility of debris flow events in the future, because the material from the eruption is still quite a lot in slope of Mount Merapi. **Fig. 4** shows a map of the disaster due to debris flow in Progo River and its tributaries.

Table 4 Social economic impacts

Year	Evacuated	Damaged houses	School	Bridges
2010/1	5082	319	5	9
2012/3	74	21	-	-

In addition giving the negative impact, debris flow also provides benefits to the potential of material for sand mining. Based on the survey, in almost all the locations, there are sand mining activities, with small to medium scale. The intensity of sand mining has tendency greater if compared with before the eruption of 2010. **Fig. 5** shows a sand mining activity at Kebun Agung Bridge in Progo River.

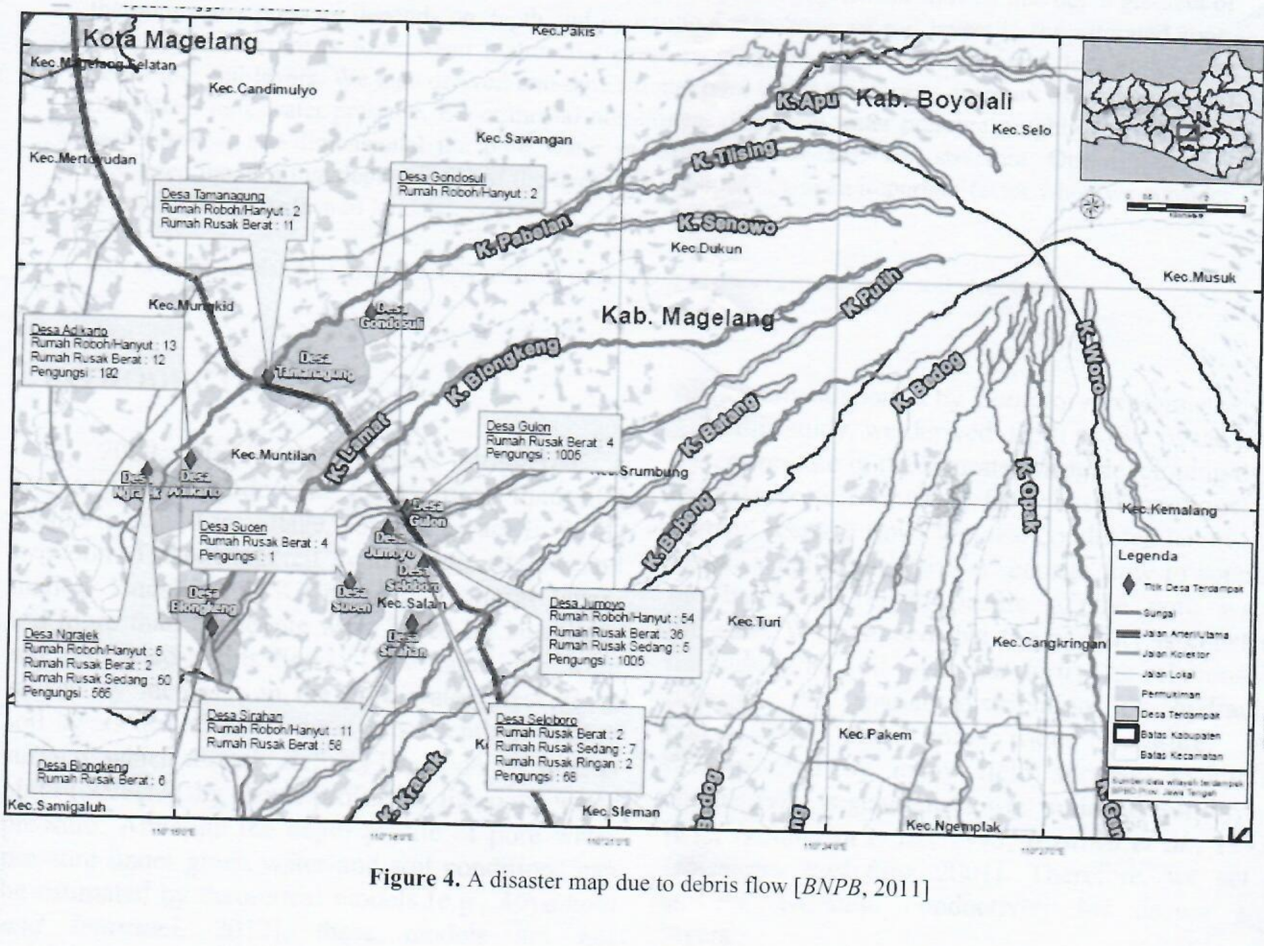

Figure 4. A disaster map due to debris flow [*BNPB*, 2011]

Figure 5. A sand mining activity in Progo River

7. CONCLUSION

Based on the result, it can be concluded from this study is: there has been a change in morphology due to debris flow after the eruption of Merapi in 2010. The mean diameter of riverbed material in Progo River is smaller than in its tributaries. Debris flow has caused losses in social aspects, such as causing residents to be evacuated and damage on infrastructure. Sand mining activities are more intensive after the eruption of Merapi in 2010.

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REFERENCES

Kironoto, B.A. (1997): Hydraulic of Sediment Transport: Post Graduate Program, Gadjah Mada University, Indonesia.

Rosgen, D. (1996): Applied River Morphology, Widland Hydrology, Pagosa Springs, Colorado, United State of Amerika.

Sulaiman, M. (2008): Study on porosity of sediment mixtures and a Bed-porosity Variation model. Kyoto, Department of Civil and Resources Engineering, Kyoto University, Japan

Website:

http://www.bbws-so.net/download/map/37/xDAS%20PROGOxklimatologi.jpg, accessed June 28th, 2013

http://geospasial.bnpb.go.id/2011/01/17/peta-wilayah-terdampak-banjir-lahar-dingin-g-merapi/, accessed June 22nd, 2013