Morphology Analysis in Middle-Downstream Area of Progo River Due to the Debris Flow

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Abstract. One of the problems that occur in Progo River is the formation of sediment in the downstream section. The sediment material in the upstream become the source of sediment supply for the downstream area. Excess sediment supply from upstream causes morphological changes in a relatively short time. The morphological changes in riverbed will be affected hydraulics conditions. Hydraulics have an important role in the process of aggradation and degradation in the riverbed. Furthermore, the process of erosion and sedimentation will affect the stability of the construction in the water. In the Progo River, there are building of infrastructure such as revetment, bridge, irigation intake, groundsill and weir. Based on the results numerical model of hydraulic analysis system, approximately 87,000,000 m^3 of sediment settles on the Progo River in 2015. Aggradation and degradation have been occured very intensively in middle-downstream area of the Progo River. Sediment movement simulation also showed that the sediment supply of lava can prevent excessive bed degradation. But if there is no longer for the supply of sediment, bed degradation process will occur. This indicates that the management of the sediment supply in the upstream area must be managed properly.

INTRODUCTION

Mount Merapi is one of the most active volcanoes in the world, located in Central Java and Yogyakarta, Indonesia. Based on the records from 1500 to 2000, there are at least 32 of 61 eruptions of Mount Merapi caused lava flood (Lavigne et al., 2000). 2010 eruptions of Mount Merapi, October 26th, known as the largest eruption since 1872 (Indonesian National Board for Disaster Management, 2011).

Mount Merapi eruption causes of primary and secondary hazards. The primary danger is an immediate danger posed when the volcano erupted, like a stream of lava, heat clouds, ash, toxic gasses, and pyroclastic flows. The secondary hazard that caused by volcanic eruptions is cold lava flood. Cold lava is concentrated sediment flow consisting of stone, gravel, sand and volcanic ash mixed with water.

Volcanic eruptions that occurred in 2010, resulting in a debris flow with a material volume of 150 million m^3 spread in the rivers that have upstream at Mount Merapi (Giyarsih et al., 2014). The eruption resulted in debris flow with numerous volume of sediment which scattered in rivers that have upstream at Mount Merapi. One of the rivers that affected is the Progo River. With the main river length about 138 kilometers, the Progo River has an upstream at Mount Sindoro and has a catchment area approximately 243,833.086 hectares. Some tributary from Progo River has an upstream at Mount Merapi such as Bedog River, Krasak River, Apu River, Babeng River, Batang River, Putih River, Pabelan River and Blongkeng River.

The morphological changes in the Progo River due to the debris flow is very fast, especially in the middle-downstream area. In this section, there are building of infrastructure such as revetment, bridge, irigation intake, groundsill and weir which sustain the course of the economy in Yogyakarta particularly and in Central Java generally. The stability of these infrastructures will be influenced by erosion and sedimentation. Because of that, the volcanic disaster management at the river such as Progo River become the important things that must be considered.

TRANSPORT SEDIMENT MECHANISM

The sediment transport is a function of the velocity of the river flow and sediment particle size. Sediment particle sizes as small as clay and dust can be transported the flow of water in dissolved form (dissolved load). Fine sand moved by way of floating (suspended load), while the larger particles such as coarse sand tend to move by jumping (saltation load). Larger particles, for example, gravel will move by creeping or rolling on the river bottom (bed load). Figure 1 illustrates the movement of sediment.

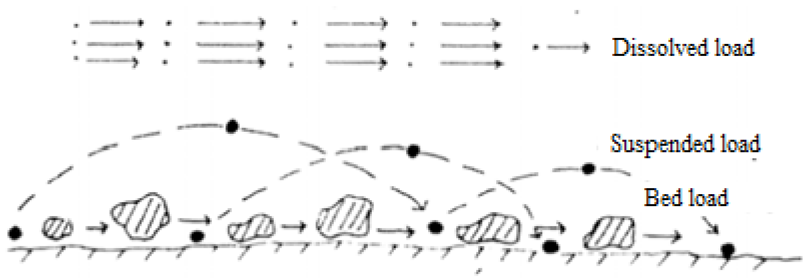


FIGURE 1. The movement of sediment illustration (Asdak, 1995).

Erosion and Sedimentation of Volcanic Rivers

Research on the effect of bedload transport related to the effect of bed deformation has been investigated by Kamphuis (1990), Thompson and Amos (2004). The results show that bedload transport can cause changes in the shear stress, increase or decrease, of the bed surface. The increase of shear stress can cause degradation and the decrease of shear stress can cause aggradation. The bedload transport consumes a portion of the energy of flow and causes an increase or a decrease of the flow velocity (Carbonneau and Bergeron, 2000).

In this research, The Engelund-Hansen function is used to predict the sediment transport. The general transport equation is represented by:

$$g_s = 0.05\gamma_s V^2 \sqrt{\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma}-1\right)}}\left[\frac{\tau_o}{(\gamma_s-\gamma)d_{50}}\right]^{3/2} \qquad \text{i)}$$

where, g_s is the unit sediment transport, γ is the unit weight of water, γ_s is the unit weight of solid particles, V is the average channel velocity, τ_o is the bed level shear stress, d_{50} *is* the particle size of which 50% is smaller.

As water flow in a channel, the shear stresses developed on the bed and banks. If the shear stress on the bed or bank is more than the critical shear stress, erosion will occur, and deposition will occur elsewhere (Harsanto, 2012).

METHODOLOGY

The research location is in the Progo watershed area. Section of the river that used as the object of research is a section of Progo River along ±57 km from downstream to the middle section that located at Hydrological Station of Duwet. The objective of this research is to study the morphology process due to the hydraulic changes in Progo River that caused by debris flow from Mount Merapi. The mathematical models can be used to estimate the aggradation and degradation process in riverbed. The results are depicted in a longitudinal section map as a reference for disaster-prone areas.

In this study, software HEC-RAS v.4.1.0 is used to perform one-dimensional hydraulic calculations for morphology analysis in longitudinal section. The hydraulics parameters which analyzed in this research are water surface elevation, flow velocity, and shear stress. Scope and delimitation of study in this research are cross section simplification in numerical modeling as a rectangle because of the width of the channel of Progo River ten times larger than the height of water flow which classified as the wide channel and bed gradation homogenization along modeling section.

Modeling Calibration

One-dimensional modeling in this research use secondary data such as hydrograph data, topography, and coordinates of infrastructure in the Progo River. Hydrograph data, from October 2010 until October 2015, is used as boundary condition in the upstream of modeling section. In the downstream modeling section, average slope is used to calculate normal depth as boundary condition in the HEC-RAS. Sediment gradation analysis which obtained by the sediment samples taken at the Progo River section around Kebon Agung II Bridge is used to define the riverbed gradation in modeling. Figure 2 shows the data that used as input in the modeling process.

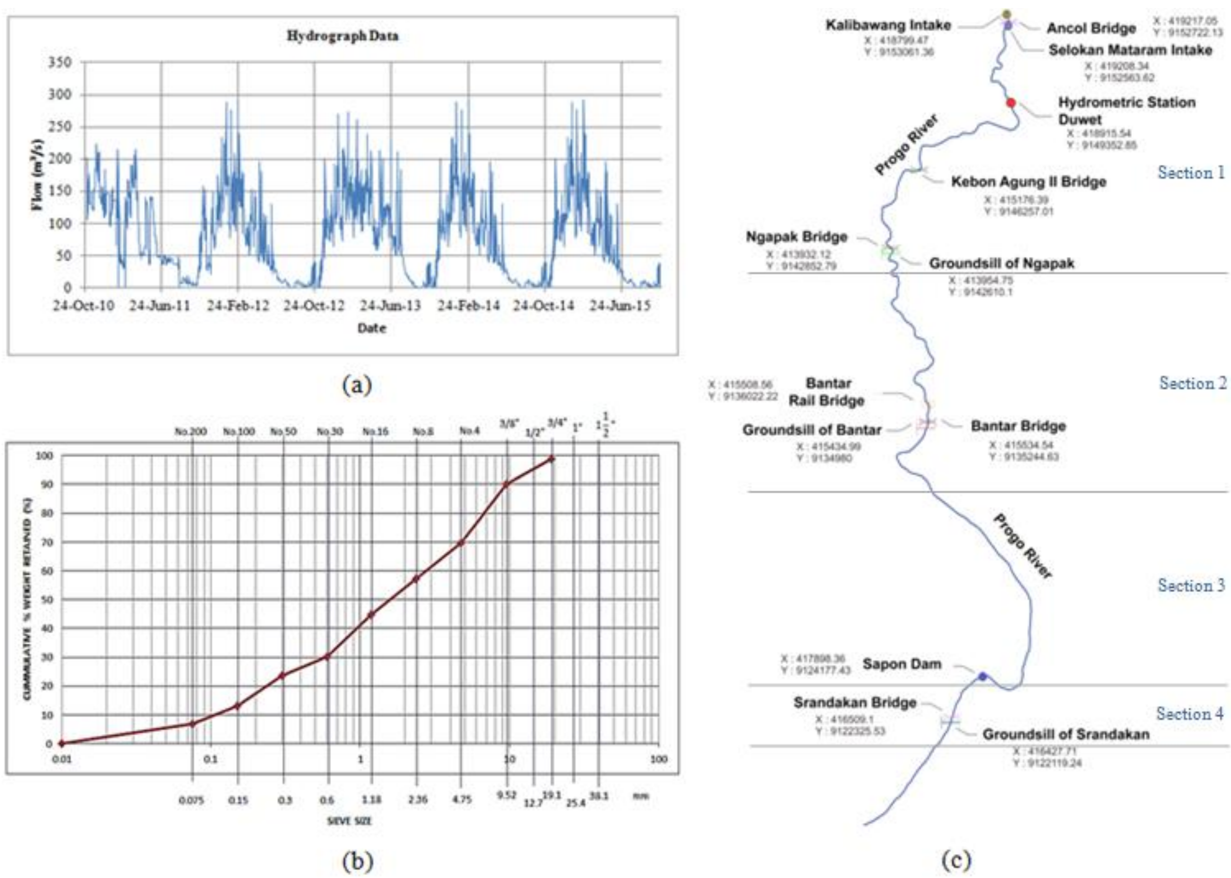


FIGURE 2. Boundary data in modeling using HEC-RAS, (a) hydrograph data, (b) sediment gradation in the riverbed modeling, (c) layout model and coordinate of infrastructure in the Progo River.

Modeling calibration is obtained in several steps. First, in the coefficient manning calibration process, measurement depth and velocity of water is conducted in several section at Progo River such as Kebon Agung II Bridge, Bantar Bridge and Srandakan Bridge. This data is used as check point for hydraulic condition in modeling simulation. Based on calibration modeling results, the coefficient manning of Progo River is defined between 0.045 and 0.050. In the second steps, trial and error method is used to calibrate the sediment input in the modeling process. Some of the data that used are conducted by direct measurement on the field such as height and width of sedimentation in several sections. The volume of sediment measurement in different time period is based on imaging data from *software google earth*. The volume of sediment input in the model is obtained by matching the data between the manual calculation based on imaging measurement with the data based on simulating which using HEC-RAS in longitudinal section. Figure 3 shows the sediment load series as an input at Progo River based on result sediment volume calibration.

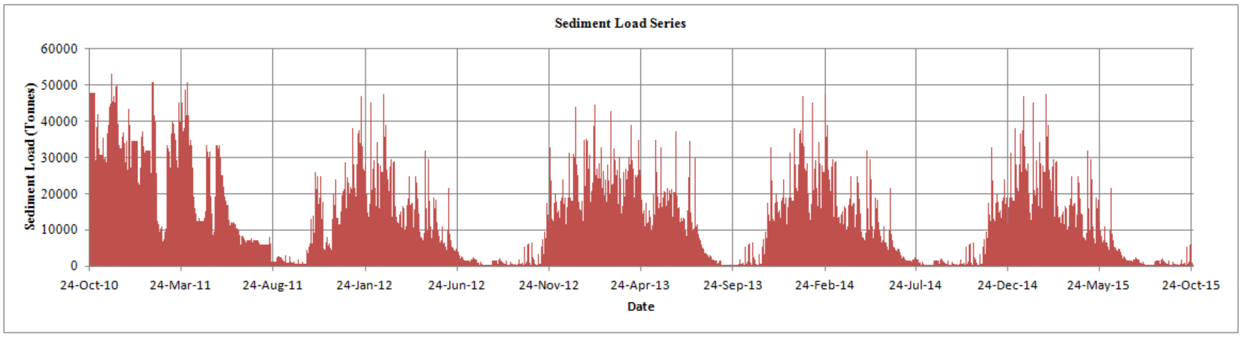
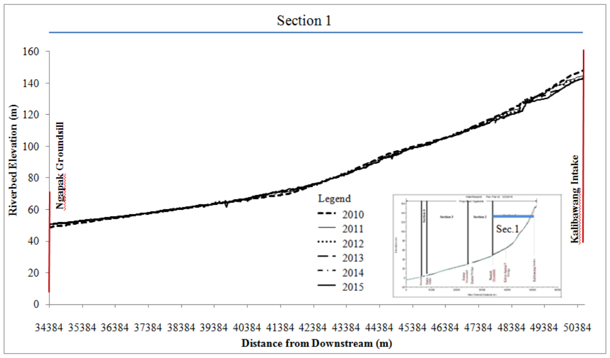


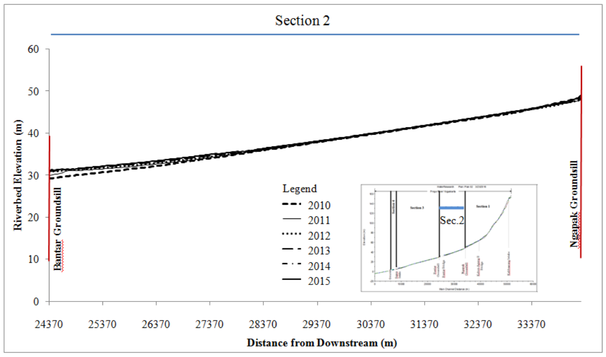
FIGURE 3. Sediment load series as an input in numerical modeling simulation

RESULTS AND DISCUSSION

The morphology changes analysis in this research is obtained based on longitudinal section of the river. Section analysis is divided into four parts which can bee seen in Fig. 2(c). Section 1 starts from Duwet hydrological station until Ngapak groundsill with average slope 0.007. Section 2 starts from Ngapak Groundsill until Bantar Groundsill with slope 0.0018. Bantar Groundsill until Sapon Intake is Section 3 with slope 0.0015. In the downstream area, Section 4 starts from Sapon Intake until Srandakan Groundsill with average slope 0.0013. Figure 4 shows the comparison riverbed elevation in longitudinal section for each section from 2010 to 2015.



(a)



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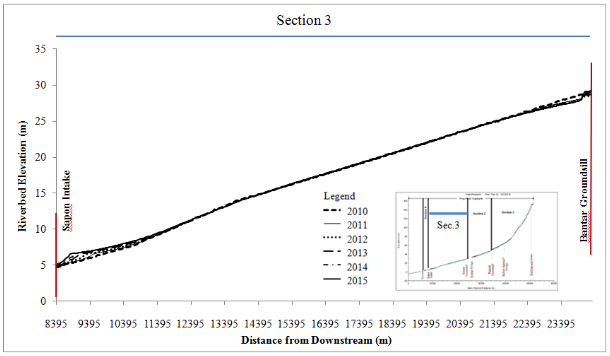

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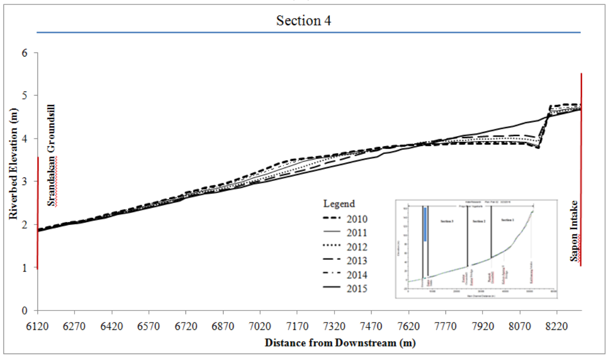

(d)

FIGURE 4. Riverbed elevation of Progo River in longitudinal section, (a) Section 1, (b) Section 2, (c) Section 3, (d) Section 4

Based on the modeling simulation results, In Section 1, riverbed elevation has changed in the downstream of Kalibawang Intake approximately 100 cm/year of degradation and in the upstream of Ngapak Groundsill approximately 63.6 cm/year of aggradation. In Section 2, degradation occur 4.8 cm/year in the downstream of Ngapak Groundsill and aggradation occur 38.2 cm/year in the upstream of Bantar Groundsill. In Section 3, degradation in the downstream of Bantar Groundsill and aggradation in the upstream of Sapon intake are 15.8 cm/year and 24.8 cm/year, respectively. In Section 4, 13 cm/year of degradation occur around 125 m after Sapon Intake to the downstream area and 7.2 cm/year of aggradation occur in the upstream of Srandakan Groundsill.

The results of the discharge analysis of sediment transport using HEC-RAS based on the Engelund-Hansen function is 47,6441.1 m^3/day which settles in middle-downstream area of the Progo River. Figure 5 shows the estimated volume of sediment that enters the Progo River after 2010 Mount Merapi eruption.

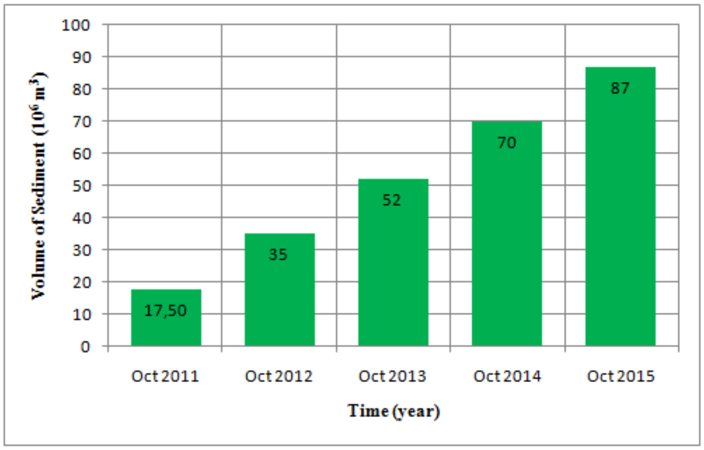

FIGURE 5. Volume of sediment at the Progo River

CONCLUSION

The one-dimensional simulation due to debris flow in longitudinal section has been performed to understand the morphological changes in the Progo River. The obtained results are as follows.

1. The morphological changes in the Progo River that caused by 2010 Mount Merapi eruption is very fast, especially in the middle area. Approximately 87,000,000 m^3 of sediment, 57.9% from 150 million m^3 of sediment which spread on the river around Mount Merapi, settles on the Progo River in 2015.
2. The debris flow in the middle area of the river with the steep slope, 0,007, can cause significant change for hydraulic parameters. Aggradation and degradation have been occured very intensively in this section. Instability on the pillars of the bridge, such as Ancol Bridge, can occur because of erosion. On the other side, the downstream with ramp slope, 0,0018, only aggradation has occurred, especially before groundsill. In this section, the water gate for intake can be covered by the sedimentation.
3. Sediment movement simulation showed that the sediment supply of lava can prevent excessive bed degradation. But if there is no longer for the supply of sediment, bed degradation process will occur. This indicates that the management of the sediment supply in the upstream area must be managed properly.

ACKNOWLEDGEMENT

The authors would like to acknowledge Universitas Muhammadiyah Yogyakarta for the funding support of the research project. I am also grateful to my supervisor Jaza'ul Ikhsan and Puji Harsanto who encourage me to pursue this research. The Research Group batch 2016, Titi Nurjanah, Indri Rahmandhani Fitriana, Mochammad Dwi Aprilianto, were collected as a collaborative research group discussion. All this support is greatly appreciated.

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