Sediment Characteristics of Bed Load Transport in Downstream of Progo River, Indonesia

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Abstract. Progo River is one of the rivers that has a sediment supply from volcanic and non-volcanic areas. Sediment transport, especially the bed load transport, it is very influential on the phenomenon of river degradation and aggradation. Therefore, a study to determine the characteristics of bed load transport is needed and important. The research was carried out in the downstream part of Progo River. Sampling locations were taking in four locations, namely Ancol Bridge, Kebon Agung II Bridge, Kebon Agung I Bridge and Bantar Bridge. The bed load transport measurement tool was used Helley Smith (WMO, 1980) equipment. Every river cross section is taken three times. The results showed that the sediment type of bed load transports is silty sand, with specific gravity values of 2.67 to 2.70. The average diameter values (D50) of the bed load transports vary greatly from 0.129 mm to 0.454 mm. The values of bed load transports vary greatly and are influenced by the values of the discharges. The correlation between bed load transport and discharge is linear, with R values are 0.85 to 0.99.

Keywords: Bed load, Helley Smith, Progo River, Volcanic Area.

1. Introduction

A knowledge of sediment transport will make it possible to estimate suspended sediment carried by the stream or sediment moving on the riverbed. An understanding of the phenomenon of sediment transport, especially bedload transport, is needed to be able to predict more valid sedimentation and erosion processes in a river. Some experts have issued a formula for bedload transport based on laboratory experiments with predetermined conditions. As it is generally known, the calculation result of the sediment transport using one formula comparing another formula, will give different results, and sometimes the difference is quite large. Therefore, a research on the characteristics of bedload transport still needs to be done, especially on rivers in Indonesia which have their own characteristics.

The problem related sediment that occurs in the Progo River is the formation of sediment deposits in the lower reaches of the river which causes changes on river morphology in a relatively short time. These sediment deposits are caused by excessive sediment supply from the 2010 Merapi eruption (Harsanto, et al., 2015). Changes in river morphology will change the flow conditions such as water level, flow velocity, and shear stress. Flow hydraulic plays an important role in the process of aggradation/ sedimentation and degradation/erosion of riverbed (Manonama 2003). The process of erosion and sedimentation greatly affects the balance of the riverbed configuration. The riverbed
configuration factors are strongly influenced by speed, flow time and flow depth (Suwartha, 2001). In addition, people tend to use as much sediment as possible to support regional development. However, sediment mining can also have a negative impact on ecosystems and reduce river regulatory safety (Ikhsan, et al., 2010).

The eruption of Mount Merapi in 2010 caused the Progo River to experience changes in river morphology, changes in physical sediments and riverbed material porosity values. To know how much sediment transport occurs on the River Progo will help prevent undesirable things from happening. Based on this reason, it is important to analyze the sediment transport in Progo River.

2. Eruption of Mount Merapi

It is well known that Mount Merapi is one of the most active volcanoes in the world. It is 2,968 m high and is located in the island of Java at 7°32'26.99" S 110°26'41.34" E on the border between the Central Java and the Yogyakarta Special Provinces. It has erupted 41 times in the last 200 years including 15 major eruptions. It generally erupts every 3 years with a major eruption every 9 years. The history of its eruptions is shown in Figure 1.

Figure 1. The Historical Activities of Mount Merapi (Ikhsan, 2010)

Volcanic activity occurred on the western slope during 1830–1870 and on the north western slope at the end of the 1800s. During 1903 and 1904, the volcanic activities moved to the eastern slope, then to the south eastern slope during 1905 and 1906, and then to the north western slope during 1909–1913.

In the period from 1940–1994, volcanic activities were confined mainly to the southwestern slope, except for a short period on the northern slope during 1954–1956. During 1999–2001, volcanic activities moved from the southwestern slope to the western slope. The eruption in June 2006 occurred on the south eastern slope. And the latest eruption took place on the north western and the south eastern slopes in October 2010.

Its eruptions have produced large amounts of volcanic material as ash falls, lava, and pyroclastic flows. Produced sediment is deposited on the slopes of Mount Merapi (as shown in Figure 2) and is partly transported by water flow to the downstream areas through the tributaries that originate in the volcano. Some tributaries of Progo River are originated in the north western slope of Mount Merapi. The morphology and transport sediment in Progo River are induced by the sediment from Mount Merapi.

2.1 The Progo River

The Progo River is a river that flows in the Central Java and the Yogyakarta Special Provinces. The river is originated on the slopes of Mount Sumbing, which cross to the southeast and its estuary is the Indian Ocean, at Trišik Beach, Bantul Regency. The main river length is ± 138 km and the watershed area is 2830 km2 (Mananoma et al., 2003). On the Progo River, there are many tributaries that originated on the Mount Merapi, namely the Krasak River, Batang River, Putih River, Blongkeng River and Pabelan River.
3. Study areas and Methods

3.1 Study areas

The research locations of bedload transport in the Progo River were at Ancol Bridge in the Bligo village (Ngluwar Sub Distrik, Magelang Regency), Kebon Agung II Bridge in Sendang Minggir village (Sleman-Kulon Progo Regency), Kebon Agung I Bridge (Kulon Progo-Sleman Regency) and Bantar Bridge (Bantul-Kulon Progo Regency). The distance between Ancol Bridge-Kebon Agung II Bridge, Kebon Agung II Bridge-Kebon Agung I Bridge, and Kebon Agung I Bridge- Bantar Bridge are 7.65 km, 4.64 km, and 8.74 km, respectively. The study area is shown in Figure 3.
3.2 Hydrometry survey

3.2.1. Equipment. The data needed in this study are sediment transport, flow velocity, river depth, slope of bank river, and cross section of the river. The sediment transport data is taken every 2 hours. The equipment needed in the research in the field includes floats, stopwatches, odometer, depth measurement and Helley Smith equipment. The equipment used in the laboratory is a tool used to determine the specific gravity of the material from sediment transport and gradation of the material. Figure 4 shows the Helley Smith equipment.

![Figure 4. Helley Smith Equipment](image)

**Methods**

Flow velocity measurement was conducted by using floats. The floats are used as a flow rate measurement tool if flow velocity is required with a relatively small degree of accuracy, because what is measured is surface velocity. To get a velocity that represents a cross section of the river, then the results of surface velocity measurements need correction with a constant value of 0.85 - 0.90. Measurements of water level were carried out manually by carrying out the elevation of the water surface indicated on the normal water gauge. Measurements of cross-sectional area require water level; and measurement of water level were done using a stick with a measuring sign. Measurement of flow width is also used to find out the width of the riverbed which will be used to get river cross section area. Measurement of flow width was carried out using a width measuring instrument and measuring channel width was taken using odometer.

The method for measuring bedload and equipment are still in the developing stage, so there is no single method or equipment suitable for all field conditions. For this study, sediment transport data collection was carried out in the rainy season between March and April. Data collection techniques were from the upper part of bridges using the Helley Smith tool (WMO, 1980) with the help of pulleys. Then, the results of measurements of bedload are taken to the laboratory to be analyzed for specific gravity and gradation. Furthermore, an analysis of the characteristics of sediment transport at the points used as testing/survey is carried out.

This bedload transport study is a direct research in the field, taking samples using Helley Smith equipment. This research took in four locations, namely Ancol Bridge, Kebon Agung II Bridge, Kebon Agung I Bridge and Bantar Bridge. To get the bedload value that is close to its original condition, the Helley Smith equipment must be modified.

**Efficiency Calculation of Helley Smith Equipment**

\[
e = \frac{K_a}{K_r} \tag{1}
\]

where,


\( e \) = Efficiency of the bedload measuring equipment (%)  
\( Ka \) = Quantity of sediment captured by the bedload equipment  
\( Kr \) = Quantity of sediment transported if the bedload equipment is not placed on  
\( e = \frac{0.261}{0.35} \times 100 \% \)  
\( e = 74.57\% > 70\%, \) take a middle value (the value of efficiency of the equipment between 40\% - 100\%)

**Sediment Transport Analysis After Modification**

The amount of sediment transport captured by Helley Smith equipment can be calculated using the equipment below:

\[
qb = \frac{100W}{e b t}
\]  

where,

- \( Qb \) = Bedload transport per unit width after being modified based on the equipment efficiency  
- \( W \) = The weight of the sample caught by the equipment during a period  
- \( e \) = Efficiency of the equipment (%)  
- \( b \) = Width of the equipment  
- \( t \) = Time of measurement

**Bedload Transport of Full Cross Section**

\[
Y2 = \frac{X2Y1}{X2}
\]  

where,

- \( X1 \) = Mouth area of the Helley Smith equipment (m²)  
- \( X2 \) = Bedload transport by the Helley Smith equipment (kg/hour)  
- \( X3 \) = Area of flow cross section (m²)  
- \( Y2 \) = Bedload transport carried by river flow (kg/hour)

**Bedload Transport of 1/8 h Cross Section**

Related sediment transport in a river, there are three layers of sediment transport, namely bedload, suspended load and surface load. Then, it can be assumed by reviewing the cross section which is at 1/8 of the depth of the river. In analyzing the calculation of this paper taken 1/8 from the depth of the river, for example, to a depth of 6 meters, the calculation of the sediment is 0.75 meters. This value is compared to the empirical method calculation.

\[
Y2 = \frac{X2Y1}{X1}
\]  

where,

- \( X1 \) = Mouth area of the Helley Smith equipment (m²)  
- \( Y1 \) = Bedload transport by the Helley Smith equipment (kg/hour)  
- \( X2 \) = River cross section area (m²)  
- \( Y2 \) = Bedload transport carried by river flow (kg/hour)
4. Results and Discussion

4.1 Hydrometry Data

The measurement results of river hydrometry at the selected locations are shown in the Table 1 as follows:

| Location      | Date         | Velocity (m/s) | Cross Section Area (m²) | Discharge (m³/s) |
|---------------|--------------|----------------|--------------------------|------------------|
| Ancol         | 13 March 2017| 1.02           | 110.87                   | 113.58           |
| Ancol         | 14 March 2017| 1.09           | 110.90                   | 120.61           |
| Ancol         | 15 March 2017| 1.13           | 128.58                   | 144.87           |
| Kebon Agung 2 | 26 March 2017| 1.10           | 119.70                   | 131.67           |
| Kebon Agung 2 | 26 April 2017| 1.16           | 120.20                   | 139.43           |
| Kebon Agung 2' | 27 April 2017| 1.20           | 123.10                   | 147.72           |
| Kebon Agung 1 | 22 March 2017| 1.161          | 104.23                   | 121.01           |
| Kebon Agung 1 | 23 March 2017| 1.286          | 113.10                   | 145.44           |
| Kebon Agung 1 | 26 March 2017| 1.574          | 150.62                   | 213.28           |
| Bantar       | 16 March 2017| 0.832          | 190.83                   | 158.72           |
| Bantar       | 17 March 2017| 0.612          | 162.76                   | 99.64            |
| Bantar       | 19 March 2017| 0.644          | 170.87                   | 110.11           |

Table 1 shows that the velocity at each survey location is vary between 0.612 m/s to 1.574 m/s. The lowest velocity was measured at the Bantar Bridge on March 17, 2017, and the largest velocity at the Kebon Agung 1 Bridge was measured on March 26, 2017. The lowest velocity occurred in Bantar Bridge because this location is downstream of the Progo River, and as well as at this location, there is a groundsill in the lower part of the bridge, causing the slope of the river to be mild which causes the velocity at this location to be the lowest compared to other locations. The largest velocity value occurred at Kebon Agung 1 Bridge, because this location has the largest slope as well as the location is a sediment transport area. In addition, the biggest velocity occurred on March 26, 2017, because on that date there was rain in the upper reaches of the Progo River. Based on Table 1 also shows that the measured discharge varies from 99.64 m³/s to 213.28 m³/s. The lowest discharge was measured on March 17, 2017 at the Bantar Bridge and the largest discharge was measured on March 26, 2017 at the Kebun Agung 1 Bridge.
4.2 Sediment Transport

The results of the sediment transport values at each point are shown in Table 2 as below.

**Table 2. Results of Sediment Transport Measurements at the Survey Locations**

| Location       | Date            | $1/8 H$ (m$^3$/s) | Full Cross Section (ton/day) |
|----------------|-----------------|-------------------|-----------------------------|
| Ancol          | 13 March 2017   | 0.19              | 1.54                        |
| Ancol          | 14 March 2017   | 0.21              | 1.69                        |
| Ancol          | 15 March 2017   | 0.35              | 2.85                        |
| Kebon Agung 2  | 26 March 2017   | 0.53              | 4.25                        |
| Kebon Agung 2  | 26 April 2017   | 0.51              | 4.10                        |
| Kebon Agung 2  | 27 April 2017   | 0.65              | 5.26                        |
| Kebon Agung 1  | 22 March 2017   | 2.88              | 22.54                       |
| Kebon Agung 1  | 23 March 2017   | 8.27              | 66.50                       |
| Kebon Agung 1  | 26 March 2017   | 19.22             | 153.76                      |
| Bantar         | 16 March 2017   | 3.37              | 27.68                       |
| Bantar         | 17 March 2017   | 2.16              | 17.31                       |
| Bantar         | 19 March 2017   | 3.04              | 23.82                       |

Based on Table 2, it is shown that the results of measurements of sediment transport are vary between 1.54 ton/day up to 153.76 ton/day. The smallest sediment transport was measured at the Ancol Bridge and the largest one was measured at the Kebun Agung 1 Bridge. From the measurement data, it shows that there is a tendency for sediment transport to occur from the upstream (Ancol Bridge) to the downstream (Kebun Agung 1 Bridge), getting bigger, even though the value of the water discharge is relatively balanced. This shows that between the Ancol Bridge to Kebun Agung 1 Bridge is a sediment transport area, and a large erosion occurs on this area. In the river part between the Agung Kebun 1 Bridge and Bantar Bridge, based on the measurement results, there is a tendency for the deposition process to occur. The variation of sediment transport that occurs is very large among the location being reviewed, especially in Ancol Bridge and the Kebun Agung 2 Bridge, which they are small because the distance between the bridge and riverbed at Ancol Bridge and Kebun Agung 2 Bridge is very large, causing difficulties in lowering and raising the Helley Smith equipment. This condition causes the possibility of the sediment caught in the Helley Smith equipment lost during the lifting process of the equipment. In addition, with a distance is too large, to put the mouth of Helley Smith’s equipment in the direction of the flow that occurs is more difficult comparing a short distance.
When the mouth of Helley Smith equipment does not parade perfectly, the sediment caught by the equipment is not optimal.

4.3. Characteristics of Sediment Transport Material

To identify the transported material, in this paper author used two parameters, namely a specific gravity and average diameter (d50) of sediment transport material. The results are shown in Table 3.

**Table 3. Results of Measurement of Specific Gravity and Gradation of Sediment Transport Material**

| Location         | Specific Gravity (ton/m³) | D50 (mm) | Note     |
|------------------|---------------------------|----------|----------|
| Ancol            | 2.68                      | 0.129    | Silty Sand |
| Kebon.Agung 2    | 2.70                      | 0.408    | Silty Sand |
| Kebon Agung 1    | 2.67                      | 0.454    | Silty Sand |
| Bantar           | 2.69                      | 0.169    | Silty Sand |

Table 3 shows that the transported material is relatively uniform, and its type is silty sand, with the values of density varying between 2.67 to 2.70. The gradation of sediment transport material is also varying, with the D50 averaging between 0.129 mm to 0.454 mm. From this data, sediment transport materials at Ancol Bridge and Bantar Bridge are softer than in the Kebun Agung 2 Bridge and the Kebun Agung 1 Bridge. This is due to the greater velocity and steeper slope of the riverbed in Kebon Agung Bridge compared to the same parameters at Ancol Bridge and the Bantar Bridge.

4.4. Correlation Between Discharge and Sediment Transport

By using data of sediment transport discharge calculation, their correlation can be found, whether positive, negative or uncorrelated.

\[
 r = \frac{\sum (X-X) (Y-Y)}{\sqrt{\sum (X-X)^2 \cdot \sum (Y-Y)^2}} \quad (5)
\]

\[
 r = \frac{\sum xy - \frac{\sum x \cdot \sum y}{n}}{\sqrt{\left(\frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n}\right) \cdot \left(\frac{\sum y^2 - \frac{(\sum y)^2}{n}}{n}\right)}} \quad (6)
\]

The value of r is always between -1 and +1 (-1 < r <+1)

where,

\( r = +1 \), it means there is a perfect positive correlation between X and Y.
\( r = -1 \), it means there is a perfect negative correlation between X and Y.
\( r = 0 \), it means there is no correlation between X and Y.
Table 4. Correlation Value between Water Discharge and Bedload Transport in the Survey Locations

| No | Location          | Discharge m³/s (X) | Bedload (ton/day) (Y) | r value |
|----|-------------------|--------------------|-----------------------|---------|
| 1  | Ancol Bridge      | 113.58             | 1.54                  | 0.99    |
| 2  | Ancol Bridge      | 120.61             | 1.69                  |         |
| 3  | Ancol Bridge      | 144.87             | 2.85                  |         |
| 4  | Kebon Agung 2 Bridge | 131.67         | 4.25                  | 0.85    |
| 5  | Kebon Agung 2 Bridge | 139.43         | 4.10                  |         |
| 6  | Kebon Agung 2 Bridge | 147.72         | 5.26                  |         |
| 7  | Kebon Agung 1 Bridge | 121.01         | 22.54                 | 0.88    |
| 8  | Kebon Agung 1 Bridge | 145.44         | 66.50                 |         |
| 9  | Kebon Agung 1 Bridge | 213.28         | 153.76                |         |
| 10 | Bantar Bridge     | 158.72             | 27.68                 | 0.99    |
| 11 | Bantar Bridge     | 99.64              | 17.31                 |         |
| 12 | Bantar Bridge     | 110.11             | 23.82                 |         |

Table 4 shows that there is a close relationship between water discharge and bedload transport. The correlation between the two parameters is indicated by the value of r which varies between 0.85 to 0.99. The smallest r value obtained in Kebon Agung 2 Bridge is 0.85. This is due to the very high condition of the Kebun Agung 2 Bridge, so that to measure bedload transport faces more problems compared to other locations. The largest r value occurs in the Bantar Bridge and Ancol Bridge, with r value of 0.99. Based on Table 4, it can be concluded that the greater water discharge, it means the greater bedload transport that occurs.

5. Conclusions and Recommendations
The conclusions from the research on the characteristics of bedload transport in the Progo River using the Helley Smith equipment are as follows:

1. Measured water discharges are varying from 99.64 m³/s to 213.28 m³/s.
2. The variation of bedload transport is very large among the survey locations, which varies between 1.54 ton/day to 153.76 ton/day.
3. Specific gravity of sediment transport materials varies between 2.67 to 2.70 and the type is silty sand type. The mean diameter (D50) is between 0.129 mm to 0.454 mm.
4. The relationship between bedload transport and water discharge is directly proportional, with the value of varying between 0.85 to 0.99.

Based on experience during measuring basic sediment transport with Helley Smith tools, several recommendations can be proposed by the author for future researchers if they will conduct research with Helley Smith tools as follows:
1. If the distance between a river water surface and a bridge is too high, an alternative location is needed, because it will cause serious difficulties, especially when lowering and raising the equipment, which can give impact in measurement of sediment transport.

2. The Helley Smith equipment is better when equipped with a camera to guide/assist in directing the mouth of the equipment so that it can be in the same direction with the water flow, finally the sediment can be captured by the equipment optimally.

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References
[1] Iqbal Z, and Mirakhor A 2012 Financial inclusion: Islamic finance perspective Journal of Islamic Business and Management 2(1) 35-64.
[2] Harsanto P, Ikhsan J, Pujianto A, Hartono E, Fitriadin A A, Kuncoro A H B 2015 Sediment Disaster Characteristics on the Volcanic River. Proceedings of the 5th National Seminar on Civil Engineering Seminar in 2015, ISSN: 2459-9727 pp. H 200-H 206. (in Indonesia)
[3] Mananoma T, Legono D, and Rahardjo A P, 2003 Natural Phenomena of Erosion and Sedimentation of Lower Progo River Journal and Development of Water (Jurnal dan Pengembangan Keairan) 10 (1) pp. 1-70 (in Indonesia)
[4] Suwartha. N 2001 Hydraulics Study of Sediment Transport Pattern in the Lower Progo River (Thesis) Yogyakarta:Universitas Gadjah Mada Indonesia (in Indonesia)
[5] Ikhsan J, Fujita M, and Takebayashi H 2010 Sediment Disaster and Resource Management in the Mount Merapi Area, Indonesia International Journal of Erosion Control Engineering 3(1) pp. 43-52
[6] Ikhsan J 2010 Study on Integrated Sediment Management in an Active Volcanic Basin (Dissertation) Kyoto University Japan (unpublished)
[7] Lavigne F, and Thouret J C 2002 Sediment transportation and deposition by rain triggered lahars at Merapi volcano, Central Java, Indonesia Journal of Volcanology and Geothermal Research Vol. 49 pp. 45-69.