

Research Article

Peak flood volume and its suspended sediment at various rainfall in Kedungbulus catchment in Gombong, Central Java, Indonesia

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Abstract

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Flood is a natural disaster that frequently happens and causes many material and immaterial losses. During flooding, the suspended sediment is carried along by the streamflow. The amount of sediment transported varies and depends on natural and anthropogenic factors. Limited studies have been conducted regarding the relationship between peak flood volume and its sediment content. Therefore, a study with the purpose to understand the relationship of rainfall characteristics, peak flood volume, and suspended sediment was undertaken in Kedungbulus Catchment in Gombong, Central Java, Indonesia. The size of Kedungbulus catchment is 37.8 km². To collect the required data, an automatic stream water level recorder was installed in the outlet of the catchment. In addition, an automatic and two conventional rain gauges were set up inside the catchment. Hydrograph and statistical analysis were conducted on 2016-2017 data. The results showed that during the study period, the highest peak flood volume occurred on October 8, 2016. The flood duration was 490 minutes, with the time to peak was 135 minutes. At the highest peak flood volume, the stream water was 5,091,221 m³, and the suspended sediment was around 2,394 tons. Rainfall depth significantly affects the peak flood volume and its suspended sediment. The rainfall intensity and Antecedent Soil Moisture Content (ASMC) weakly correlate with peak flood volume and its suspended sediment content.

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Introduction

Flood is more frequently happen in recent decades, and their impacts are more severe due to the high pressure of population growth (Liu et al., 2004) and urban development (Dammalage and Jayasinghe, 2019). Due to the high dense population, consequently, the demand on lands for settlement, agricultural, and industrial areas increase and over carrying capacity of the watersheds. The increase in flood disasters is not only at the local scale, but it also happens globally (Zhou et al., 2018). As in other parts of the world, Indonesia has often experienced floods.

In Central Java Province, 150 floodings occurred in 2020 (<https://jateng.bps.go.id/indicator/>).

Factors affecting flood can be natural biophysical properties of watersheds such as slope steepness, geomorphologies (Olang and Früst, 2011; Ayalew et al., 2014; Vanier et al., 2014; Asfaha et al., 2015; Geris et al., 2015) and rainfall properties as an input of watersheds system (Paschalis et al., 2014). Besides natural characteristics, anthropogenic factors, which are land use and land cover changes, have essential impacts on flooding (Kundu and Olang, 2011; Appolonio et al., 2016; Szwagrzyk, 2018). In addition, flooding can be caused by non-proper

drainage systems and expansion of impervious areas due to high housing density in urban regions (Zope et al., 2017; Myronidis and Ioannou, 2019; Rubinato et al., 2019; Psomiades et al., 2020).

Flooding does not only occur in urban areas, but it can happen in rural areas and even in watersheds covered by large forests. Heavy rain in forested watersheds will cause saturation on the forest floor (Basuki et al., 2017). In this situation, rain water cannot enter into deeper soil layers, and all of the rain water becomes direct runoff. It flows to lower areas or directly goes to streams.

The energy of rain drops and surface runoff leads to soil erosion for areas with steep slopes and improper land covers. The eroded soil will be carried out along with the stream water as suspended sediment. Within a watershed, the amount of suspended sediment is affected by rainfall characters consisting of rainfall depth and duration (Fang et al., 2013). At a single rainfall event, sediment load significantly correlated with rainfall depth, peak discharge, the amount of water yield, and maximum rainfall intensity in 30 minutes (Nu-Fang et al., 2011). Our literature review shows that studies on the relationships between rainfall, peak flood volume and sediment yield are rarely found. Yet, understanding relationships among the variables

mentioned above will provide an overview of watersheds conditions. It can be used for planning and implementing watershed management activities, hence avoiding the exploitation of natural resources and preventing further watershed degradation. This is also stated by Duvert et al. (2012), who observed limited study concerning relations between suspended sediment yield and peak discharge. Based on the background above, therefore a study was conducted in order to understand relationships between rainfall properties, peak flood volume, and suspended sediment of the study area.

Materials and Methods

Description of the study area

Kedungbulus catchment located in Gombong, Kebumen District, Central Java, is selected as the studied catchment. The stream channel and the position of the study area are provided in Figure 1. The size of the catchment is 37.8 km² and around 47% of the catchment covers by pine plantations. The catchment is also covered by mix garden (30%), paddy field (9%), and shrub (7%). The settlement occupies only 2% of the catchment, bareland 1%, and water body 1% (Basuki et al., 2018).

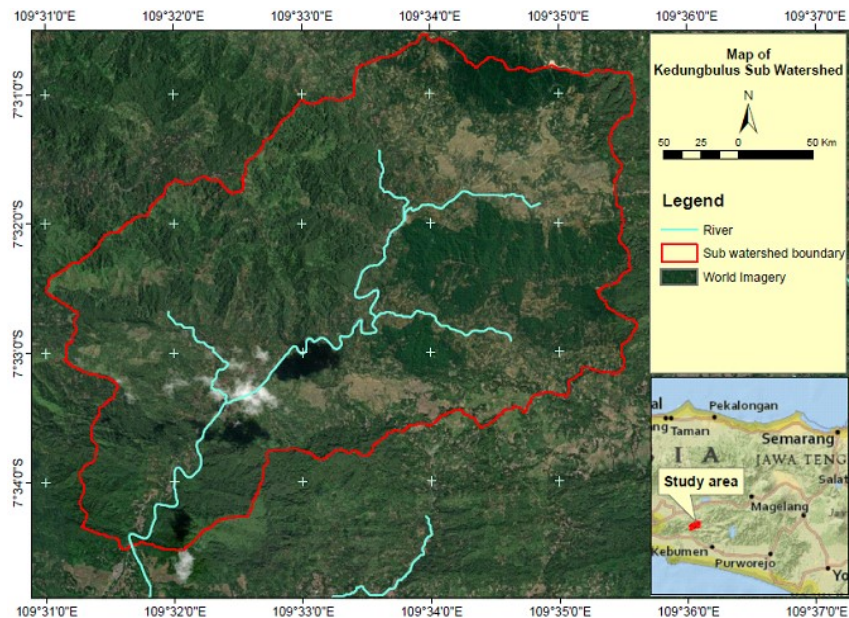


Figure 1. Situation map of Kedungbulus catchment.

The characteristics of Kedungbulus catchment is described in Pramono et al. (2016; 2017). The form of Kedungbulus catchment is circular with its circularity (p) is 29.7 km, and the ratio circularity (R_o) is 0.54. The elevation varies from 37 to 526 m from sea level with a slope from 10 to 30%. In addition, the longest river is 10.1 km, with a river slope of around 1.4% (Pramono et al., 2016; 2017).

Data collection

A stream water level recorder was installed in the outlet of the Kedungbulus catchment. The device was set up for a 5-minute recording of the stream water level. The data were downloaded once in two months. An automatic rain gauge was installed in the upper catchment. In addition, two conventional rain gauges

were installed at the upper and lower parts of the catchment. Rainfall intensity and rainfall depth were calculated from the recorded data of the automatic rain gauge. The conventional rain gauges only record daily rainfall data. The conventional tools are used as data comparison and to back up in case the automatic tool shows an error

Data analysis

Flooding at every rainfall event was selected from the collected data from 2016 to 2017. To obtain a good shape of a single peak discharge, the selected data were graphed. The stream water level data were converted into stream water discharge, then converted into suspended sediment discharge. The conversion used stream discharge and sediment discharge rating curves. Afterwards, the stream discharge data were converted into volumes. Rainfall intensity was obtained from an automatic rain gauge. The recorded rainfall event was converted into mm/hour. Rainfall depth was calculated for every rainfall event. Antecedent Soil Moisture Content (ASMC) was

calculated from the amount of rainfall within 5 days prior to flooding (Dune and Leopold, 1978).

Results and Discussion

Hydrograph analyses were explored from 2016 to 2017 data. However, only a few data were used for further analysis because of many irregular shapes of the hydrographs with two flood peaks. An irregular hydrograph does not depict a flood event as a conical shape with one flood peak or peak volume. The term peak flood in this paper does not necessarily refer to over bank flood (Robinson et al., 2003). The selected hydrographs are presented in Figure 2. The highest peak flood volume happened on October 8, 2016. At this time, heavy rainfall with a depth of 93 mm and intensity of 179 mm/hour produces a total volume of 5,091,221 m³. The flood occurs for 8 hours and 10 minutes. Various times to peak shown in Figure 2 indicated that the fastest time to peak (30 minutes) occurred on October 31, 2016, at a rainfall depth of 30 mm and rainfall intensity of 120 mm/hour.

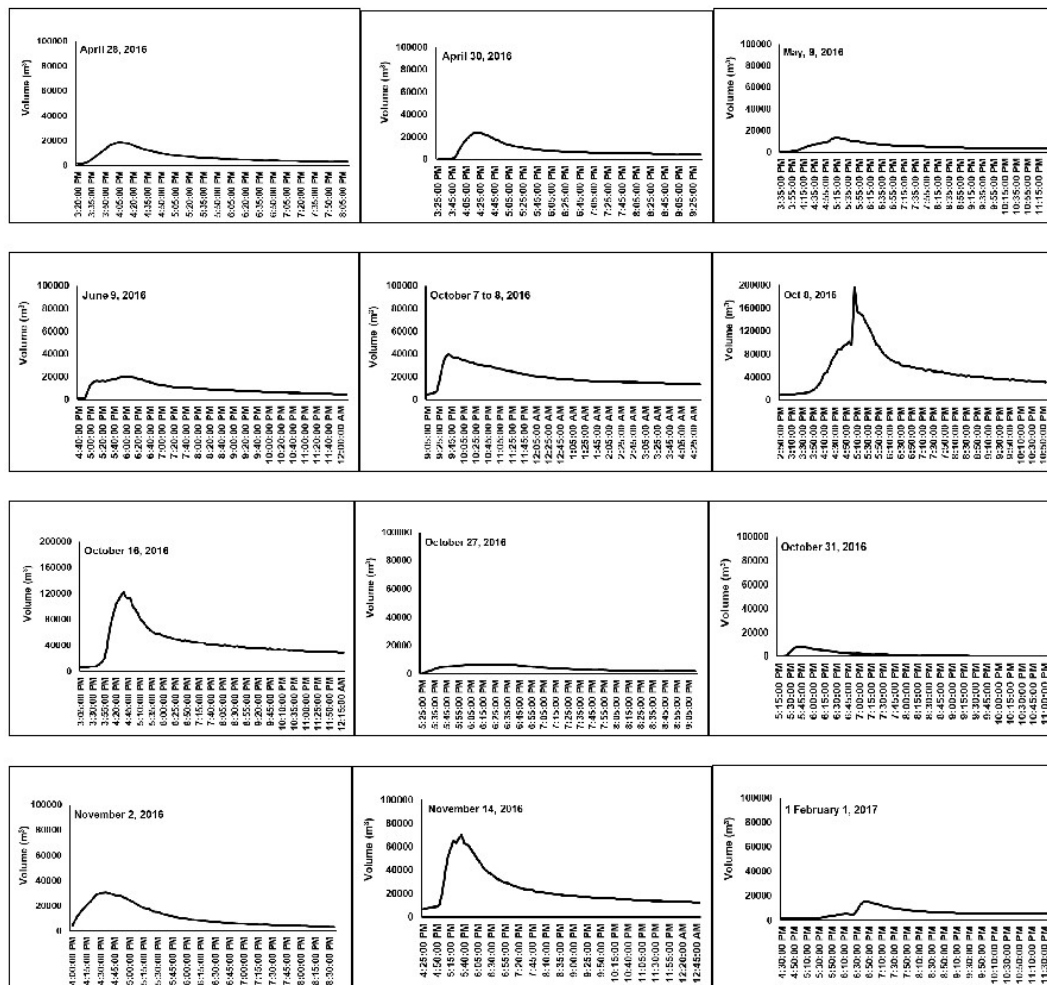


Figure 2. Hydrograph of the peak volumes in Kedungbulus catchment with its size 37.8 km².

The longest time to peak happens twice, on October 8, 2016, and February 1, 2017. Although the time to reach the peak flood volume is similar in those dates, the rainfall depth, rainfall intensity, and ASMC are different. As a comparison, Olang and Früst (2011) have observed that large floods cause a shorter time to peak. In addition, they have found that lower rainfall exhibits a more diverse time to peak than the bigger rainfall. Regression analysis between the duration of time to peak with rainfall depth and rainfall intensity shows no correlation among these variables. Whereas ASMC significantly has relationship with time to peak and produces $t = 2.75$, significance (p) = 0.02, $R^2 = 0.43$. The relationship slightly increases ($R^2 = 0.44$) when the three variables are regressed with the time to peak.

Inversely with the time to peak, the peak flood volume has a significant relationship with rainfall depth at 95% of the confidence interval. The relationship between rainfall depth and total peak flood volume produces a t -value of 2.45 and significance (p) = 0.04. Although the increase in

rainfall intensity and ASMC causes the increase in total peak flood volume, however; the relationships are non-significant. In line with our research, Nu-Fang et al. (2011) have found that rainfall depth is the major contributor to runoff; it also means stream volume. Multiple regression analysis of the three independent variables with the peak flood volume increases the R^2 (0.62). The scatter plots between these three variables are presented in Figure 3.

The total peak flood volumes and sediment yields during the study period are presented in Table 1. The highest sediment yield is 2519 tons, observed on October 16, 2016, and followed by sediment yield on October 8, 2016. Although the rainfall depth, rainfall intensity, and ASMC on October 8 are higher than those on October 16, the sediment yield is slightly lower, which is 2394 tons (Table 1). This could be caused by the difference in the duration of the flood. Based on Figure 2, the flood duration on October 8, 2016, is 490 minutes, while on October 16, 2016, the stream needed 570 minutes to reach a stable condition.

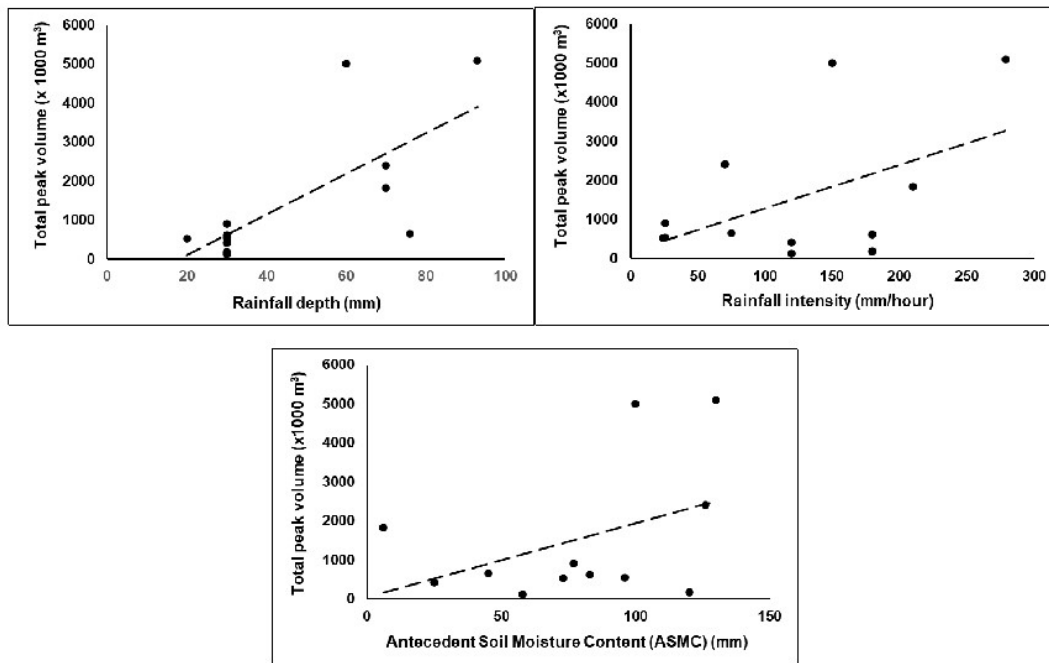


Figure 3 The scatter plots between these three variables.

The uncertain result in sediment yield at the basis of a rainfall event is also found in the previous research. Duvert et al. (2012) have examined that sediment yields base on a single rainfall event were uncertain; however, the sediment yield estimated annually produced reasonably accurate. According to Fang et al. (2012), sediment generation is greatly affected by rainfall regime consisting of rainfall amount, duration and frequency. Regarding the movement of sediment, De Girolamo et al. (2015) have observed that around 94% of the suspended sediment is carried by

streamflow during the high flow season, and only 0.1% is transported in the low flow period.

Regression analysis using a single variable of rainfall properties with suspended sediment is provided in Table 2. The highest relationship among the rainfall properties with the suspended sediment is rainfall depth. At a laboratory scale, Defersha and Melesse (2012) have examined that rainfall intensity does not impact sediment concentration. Further observation shows that the effect of rainfall intensity on sediment concentration and sediment yield varies

according to its soil type and antecedent soil moisture (Defersha and Melesse, 2012). This result slightly differs from the study conducted by Nadal-Romero et al. (2008), who have found that maximum rainfall intensity affects sediment concentration and its flow. Meanwhile, Dominic et al. (2015) more focused on examining the impact of rainfall characteristics in dry and wet seasons on sediment generation. The study has revealed that suspended sediment is more affected by rainfall intensity in the dry season and by rainfall depth and its duration in the rainy season.

Multiple regression analysis by incorporating rainfall depth, rainfall intensity, and ASMC as the independent variables with suspended sediment as dependent variable is presented in Table 3. The three variables contribute 62% ($R^2 = 0.62$) to the amount of suspended sediment during the flood events. This means that the three variables together have effects on the suspended sediment in the Kedungbulus catchment.

Table 1. Total peak flood volume and sediment at every rainfall event in Kedungbulus catchment with catchment size 37.8 km².

Rainfall/event (mm)	Total peak flood volume (m ³)	Suspended sediment (ton)
30	412,962	320
30	611,778	453
20	526,832	436
30	897,966	650
70	1,827,222	1128
93	5,091,221	2394
60	5,004,903	2519
30	172,034	157
30	117,113	115
76	652,771	444
70	2,402,966	1402
30	537,902	433

Note: Based on data from 2016 to 2017

Table 2. Regression analysis between rainfall depth, rainfall intensity, and ASMC with suspended sediment at 95% confidence interval in Kedungbulus catchment.

Dependent variable	Independent variables	n	R ²	t	Sig. (p)
Suspended sediment (ton)	Rainfall depth (mm)	12	0.52	3.29	0.008
	Rainfall intensity (mm/hour)	12	0.21	1.65	0.130
	ASMC (mm)	12	0.16	1.37	0.199

Note: Data analyzed from 2016 to 2017.

Table 3. Multiple regression analysis by incorporating rainfall depth, rainfall intensity, and ASMC with suspended sediment at 95% confidence interval in Kedungbulus catchment.

Dependent variable	Independent variables	t	Sig. (p)
Suspended sediment (ton)	Constant	-1.51	0.17
	Rainfall depth (mm)	2.45	0.04
	Rainfall intensity (mm/hour)	0.50	0.63
	ASMC (mm)	1.38	0.20

Notes: The size of Kedungbulus Catchment is 37.8 km². R^2 of the multiple regression = 0.62. Data analyzed from 2016 to 2017.

Conclusions

During the study period, the peak flood volume and its suspended sediment vary greatly, the peak flood ranges from 117,113 m³ to 5,091,221 m³, and the suspended sediment varies from 115 tons to 2,519 tons. The peak flood volume and its suspended sediment have a significant relationship with rainfall depth, whereas rainfall intensity and ASMC have a lower relationship with peak flood volume and sediment yield. Time to the peak has a significant relationship with ASMC; however, it has a weak relationship with rainfall depth and intensity. Although rainfall intensity or ASMC as a single factor does not significantly affect peak flood volume

and suspended sediment, integrating these variables with rainfall depth significantly affects peak flood volume and suspended sediment. These three variables contribute 62% to peak flood volume and suspended sediment. The rest of 38% is influenced by other variables such as slope steepness, land cover and physical soil properties.

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