RAINFALL CHARACTERISTIC ON THE SLOPES OF MOUNT MERAPI REGION

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ABSTRACT

Debris flow phenomenon on the slopes of Mount Merapi area has potentially became catastrophic natural due to its great destructive force and velocity. One of many triggers is the rainfall with a certain intensity and duration. The temporal and spatial characteristic of rainfall varies and influenced by various factors, such as topography and climate. Dharma (2012) suggested defining the characteristics of the intensity of rainfall using rainfall data with a shorter duration according to statistical tests to establish the best empirical IDF formula. This study was using 30 minutes rainfall data to determine the representative duration and distribution pattern of rainfall. The empirical formula of Sherman, Kimijima, Haspers and Mononobe method is applied to determine the relationship of rainfall intensity and duration. Debris flow occurrence and rainfall data were analyzed using method A of MLIT guidelines to establish standard rainfall for the warning and evacuation criteria of debris flow prediction. Sherman formula has shown the best fit to the IDF characteristics of the rainfall on Mount Merapi. Rainfall distribution pattern has shown the high intensity rainfall in the first hour and then decreased in the next hour which means the distribution for the duration of 6 half-hours are, 12%, 28%, 25%, 16%, 12%, and 7%, respectively. Based on the critical line, 5 mm of standard rainfall was gained for warning (R1) and 28 mm for evacuation (R2).

Keywords: rainfall intensity, debris flow

1 INTRODUCTION

Mount Merapi eruption in 2010 has damaged and caused huge losses for Yogyakarta and Central Java Province. Debris flow has caused fatalities and major damage to public and private infrastructures. Moreover, the volume of ejected material is estimated nearly 140 million that is led to debris flow disaster. Debris flow on the slopes of Mount Merapi is triggered by the occurrence of rainfall with a certain duration and intensity. In order to determine the characteristics of short duration rainfall (<3 hours), the analysis of extreme rainfall distribution as the form of rain magnitude, intensity, duration and frequency was carried out. That rainfall characteristic information at Mount Merapi can be used for analyzing the debris flow. This research aims to determine the rainfall intensity-duration formula analytically and empirically which is in accordance with the short duration rainfall characteristics, and rainfall distribution, and determine the Critical Line (CL), Warning Line (WL), and Evacuation Line (EL) in order to develop warning system regarding to debris flow in Woro River. Rainfall characteristics is expected to be able to support the development of early warning systems in Mount Merapi corresponding to debris flow by applying rainfall intensity (mm/h) and working rainfall (mm).

2 DEBRIS FLOW PREDICTION BASED ON RAINFALL CHARACTERISTICS

2.1 Debris Flow Prediction using Critical Line

Rainfall intensity is the depth of rain falling into the ground surface per unit time, usually in mm/h and mm/day (Triatmodjo, 2008). According to Sosrodarsono and Takeda (1985) rain can be classified based on its intensity.

Debris flow is a flow of a mixture of water with a high concentration of sediments slide down through the high slopes. Debris flow is not directly related to the eruption, but it can occur in volcanic and non-volcanic regions (Kusumobroto, 2006). Such conditions, which may lead the debris flow, are steep slope of the valley, sediment material availability around the mountain as the ejected material, and rainfall in considerable amounts.

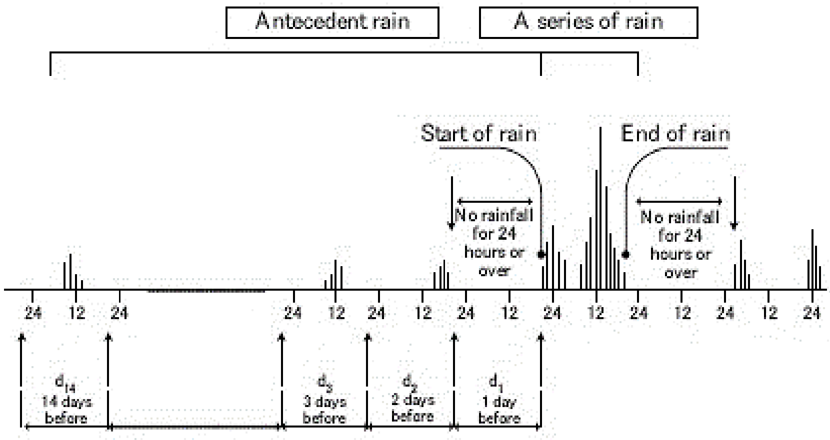


Figure 1. Concept of a series of rain and the antecedent rain

One sequence of rain within more than 24 hours of non-rainfall duration before and after is called by "a series of rain". Total amount of rainfall during that period is called by "continuous rainfall (RC)" This relationship is shown in Figure 1.

The working rainfall (R_W) is a cumulative rainfall which affected by antecedent rainfall. In general, debris flows occur under the influence of under not only rainfall triggering debris flow, but also antecedent rainfall. The degree of influence of an antecedent rainfall is deemed declining as duration time of causing rainfall increase. CL curve separates rainfall data of debris flow occurs termed as causing rainfall and rainfall data which not directly caused the debris flow termed as non-causing rainfall (see Figure 2).

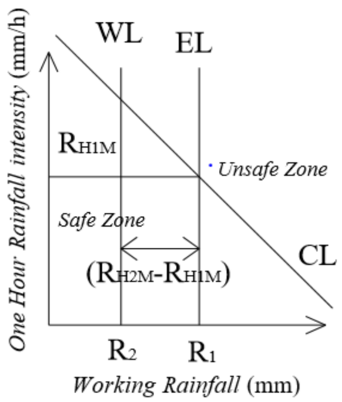


Figure 2 Critical Line based on MLIT (2004).

2.2 Spatial and Temporal Characteristic of Rainfall

Spatial characteristics of rainfall in Mount Merapi area can be analyzed by considering several matters, i.e. correlation between elevation of rainfall station and frequency of rainfall intensity, and distribution or rainfall intensity, total day rainfall, and annual rainfall which can be calculated by comparing elevation and location of rainfall station towards wind direction. In order to get the correlation between elevation of rainfall station and annual rainfall, the following formula (see Equation 1) is used:

$$R = a + bH \quad (1)$$

where R is annual rainfall depth (mm), a and b are constant values for curve slope, while H is elevation (m).

Temporal characteristics of rainfall in Mount Merapi area can be analyzed using rainfall intensity and frequency of rainfall occurrence, which is shown at Equation (2):

$$I_T = R_T / T \quad (2)$$

where I_T is mean rainfall intensity at T-time (mm/hour), R_T is rainfall depth during T-time (mm), and T is duration of rainfall (hour).

The accuracy of IDF analysis can be observed using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). Formula of RMSE and MAE is shown at Equation (3) and (4):

$$RMSE = \sqrt{\frac{\sum_{j=1}^{m}\sum_{k=1}^{n}(I_{jk} - I^*_{jk})}{mn}} \quad (3)$$

$$MAE = \frac{\sum_{j=1}^{m}\sum_{k=1}^{n}(I_{jk} - I^*_{jk})}{mn} \quad (4)$$

where *m* is number of variation of rainfall duration, *n* is number of variation of return period, I_{jk} is analytical rainfall intensity for *j* duration and *k* return period, and I^{*}_{jk} is rainfall intensity based on empirical formula.

3 CREATING CRITICAL LINE, WARNING LINE, AND EVACUATION LINE FOR DEBRIS FLOW

Ngandong, Argomulyo, Ngepos, Girikerto, and Sorasan rainfall stations are used for analyzing the characteristics of rainfall, while Deles and Batur rainfall stations and PTMA Karangbutan are used for CL, WL and EL analysis. The locations of each rainfall station are listed in Table 1. The selection of the five rainfall stations are based on data availability and distribution of 30 minutes rainfall, which representing variability of elevation. Deles station is chosen since it is located in the most upstream area. Figure 3 shows location of research. Research flow chart is depicted in Figure 4.

Table 1. Location of rainfall stations

Station	Coordinate		Elevation	Administrative Location
ARR/AWLR	Longitude	Latitude	(m) +MSL	
Ngandong	110° 24' 27.6"	07° 35' 43.8"	840	Ngandong, Turi Sub-district, Sleman Regency
Argomulyo	110° 21' 49.93"	07° 33' 21"	720	Argomulyo, Dukun Sub-district, Magelang Regency
Ngepos	110° 35' 8.57"	07° 58' 6.46"	607	Ngepos, Srumbung Sub-district, Magelang Regency
Girikerto	110° 23' 21.2"	07° 37' 36.5"	550	Girikerto, Turi Sub-district, Sleman Regency
Sorasan	110° 28' 0.8"	07° 41' 24.3"	300	Sorasan, Ngemplak Sub-district, Sleman Regency
Deles	110° 28' 15"	07° 34' 46.2"	1098	Deles, Kemalang Sub-district, Klaten Regency
Batur	110° 27' 8.5"	07°36' 56.80"	745	Batur, Cangkringan Sub-district, Sleman Regency
Karangbutan	110° 28' 9.4"	07°35' 48.7"	904	Sidorejo, Kemalang Sub-district, Klaten Regency

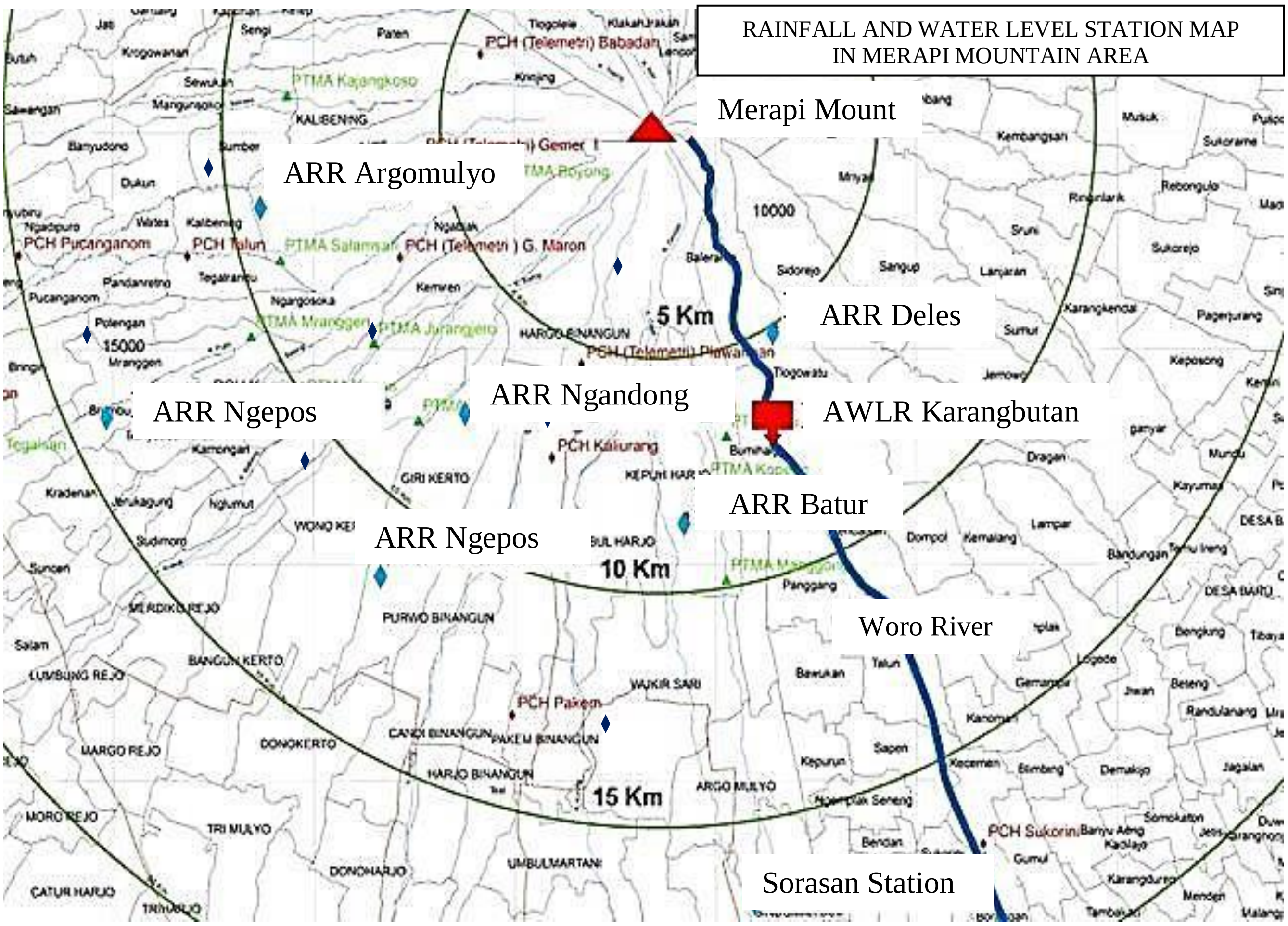


Figure 3. Location of research area

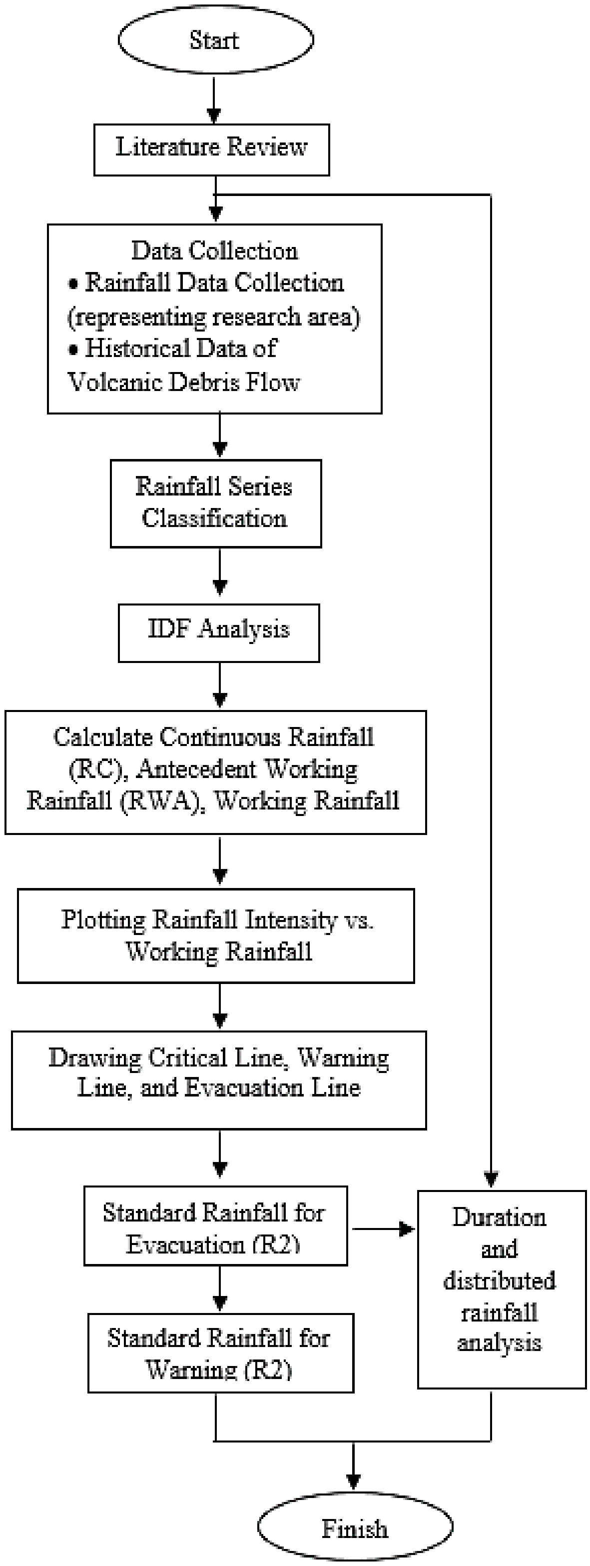


Figure 4. Research flow chart.

4 RESULTS AND DISCUSSIONS

The results of frequency analysis of rainfall intensity for a return period of 2, 5, 10, and 25 years at Ngepos Station can be seen at Table 2.

Table 2. Rainfall intensity at Ngepos Station

Duration (hours)	Rainfall Intensity (mm/hour)				Distribution
	T=2 years	*T*=5 years	*T*=10 years	*T*=25 years	
0.5	91	145	207	329	Log Pearson III
1.0	76	126	175	264	Log Pearson III
1.5	60	95	128	187	Log Pearson III
2.0	54	78	91	105	Normal
2.5	38	45	49	55	Log Normal
3.0	33	39	42	45	Log Pearson III

Constanta value for Sherman and Kimijima formula at Ngepos Station shown in Table 3. Rainfall intensity within short duration period at Ngepos Station based on Sherman formula was shown in Table 4. Comparison of IDF analysis using Sherman, Kimijima, Haspers, and Mononobe method are depicted from Figure 5 thru Figure 8.

Table 3. The constant empirical formula at Ngepos Station

Formula	*T* (years)	Constanta		
		a	*b*	*N*
Sherman	2	68.96	-	0.56
	5	106.34	-	0.75
	10	141.64	-	0.92
	25	202.94	-	1.16
Kimijima	2	104.80	0.46	0.56
	5	111.07	-0.01	0.75
	10	115.71	-0.21	0.92
	25	124.98	-0.38	1.16

Table 4. Rainfall intensity based on Sherman formula at Ngepos Station

Duration (hours)	Rainfall Intensity (mm/hour)			
	T=2 years	*T*=5 years	*T*=10 years	*T*=25 years
0.5	102	179	268	454
1.0	69	106	142	203
1.5	55	79	98	127
2.0	47	63	75	91
2.5	41	54	61	70
3.0	37	47	52	57

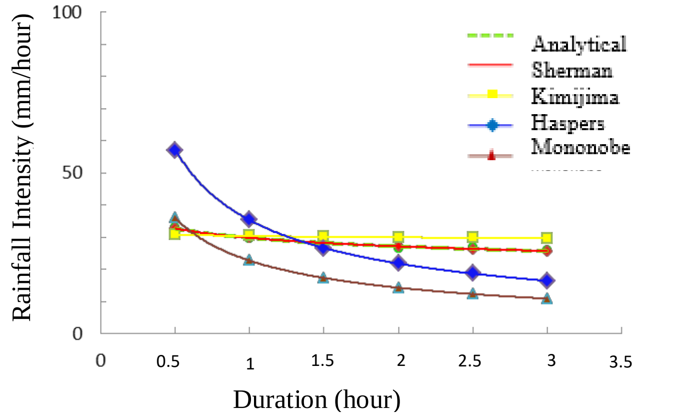


Figure 5. IDF Curve at Ngepos Station with 2 years of return period.

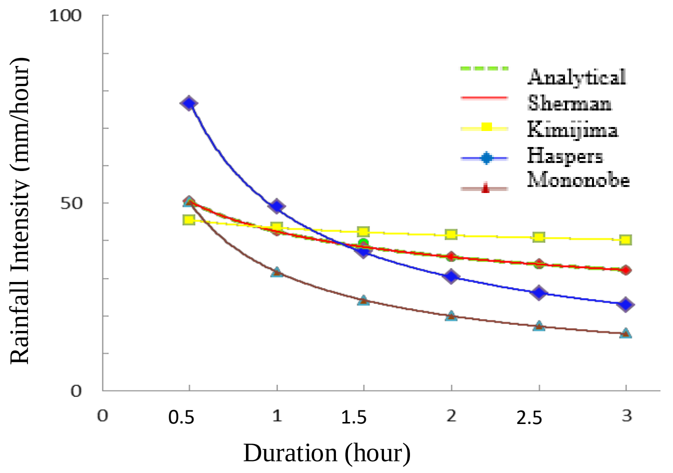


Figure 6. IDF Curve at Ngepos Station with 5 years of return period.

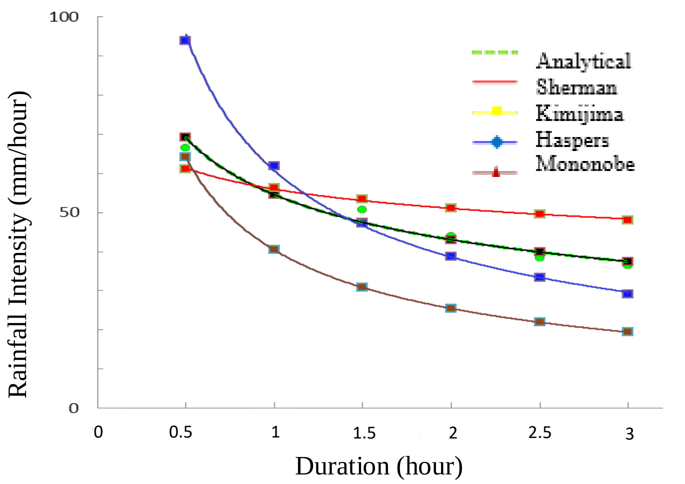


Figure 7. IDF Curve at Ngepos Station with 10 years of return period.

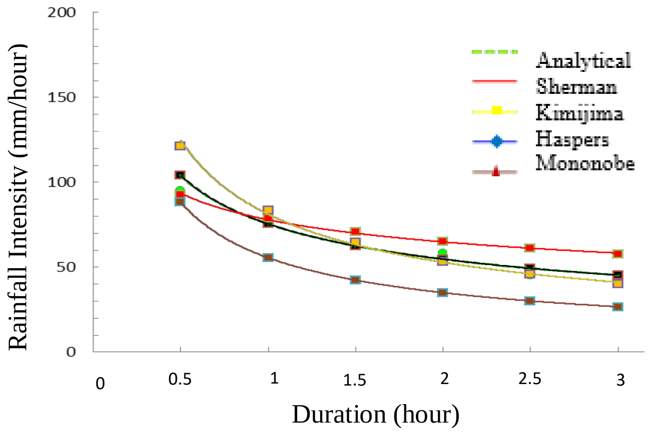


Figure 8. IDF Curve at Ngepos Station with 25 years of return period.

The methods for determining the performance criteria or model calibration against field observations can be approached using Root Mean Square Error (RMSE) Method (Drogue, et al., 2002). Table 5 and Table 6 show that Sherman formula has the least error among other formulas.

Table 5. RMSE test results of the rainfall intensity formula

Station	Sherman	Kimijima	Haspers	Mononobe
Ngandong	4.10	7.04	9.20	26.32
Argomulyo	11.94	16.87	14.16	26.93
Ngepos	36.63	331.87	57.15	33.26
Girikerto	10.42	10.97	13.29	23.91
Sorasan	1.76	4.51	7.29	11.67

Table 6. MAE test results of the rainfall intensity formula

Station	Sherman	Kimijima	Haspers	Mononobe
Ngandong	3.49	6.03	8.20	14.66
Argomulyo	7.99	12.87	8.38	17.06
Ngepos	24.57	91.58	38.62	24.61
Girikerto	7.75	7.90	9.02	14.36
Sorasan	1.39	4.14	6.71	7.00

Average of rainfall distribution for whole stations has a similar pattern. The first hour of rainfall is the highest, then declined for the next hours (see Figure 6).

The comparison between rainfall intensity and working rainfall at Deles and Batur station are shown in Figure 10 (a) and 10 (b), respectively. Critical line divides the area into two zones, namely safe zone and unsafe zone. Critical line for Woro River case is depicted at Figure ~~8~~ 11. It is created from two points of causing rainfall at the most left side and extends to cross X and Y axis. Safe zone consists of non-causing rainfall. Critical line crossing Y axis has value of 17mm/h. Since RH1M at Station Deles is 18 mm/h (>17 mm/h), the evacuation line from intersection of RH1M and critical line apparently could not be drawn.

RH1M value from rainfall data at Batur Station is 44 mm/hour, while RH2M value is 67 mm. RH1M that is 44 mm/hour horizontally crossed critical line, then created vertical line crossing x axis, so called evacuation line. The evacuation line crossing x axis value is called R2. R2 value is 28 mm. Next step is to create warning line. RH2M minus RH1M is equal to 23 mm (RH2M -RH1M). The warning line is created from parallelize evacuation line to the left 23 mm (RH2M -RH1M). The warning line crossing x axis value is called R1. R1 value is 5 mm.

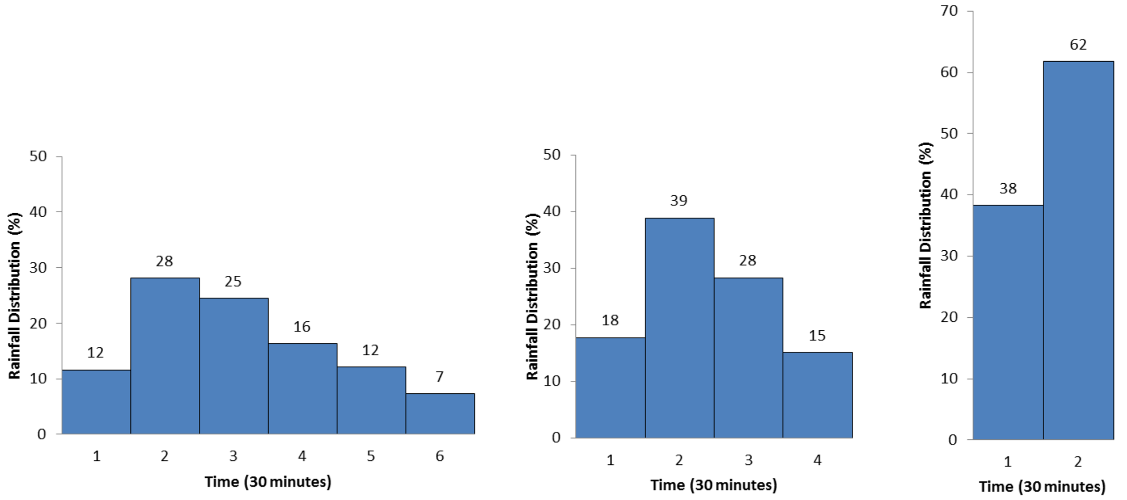
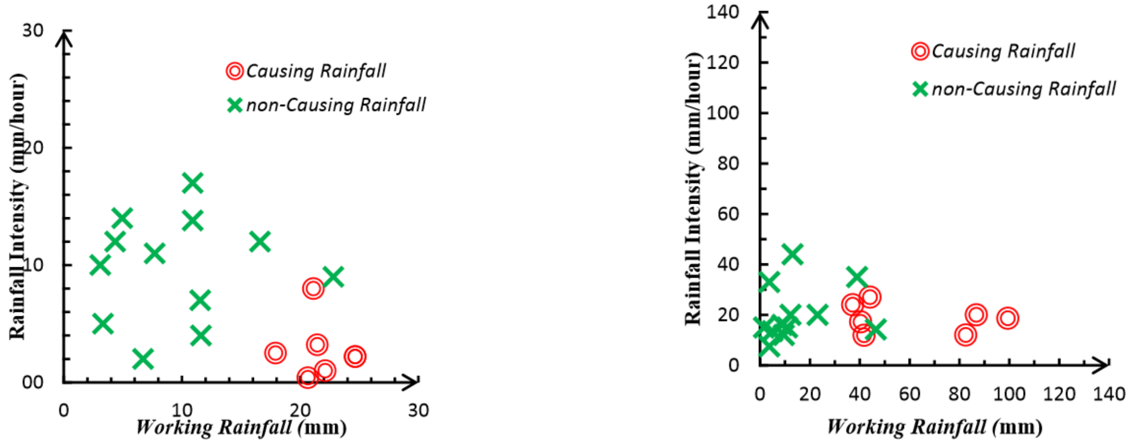
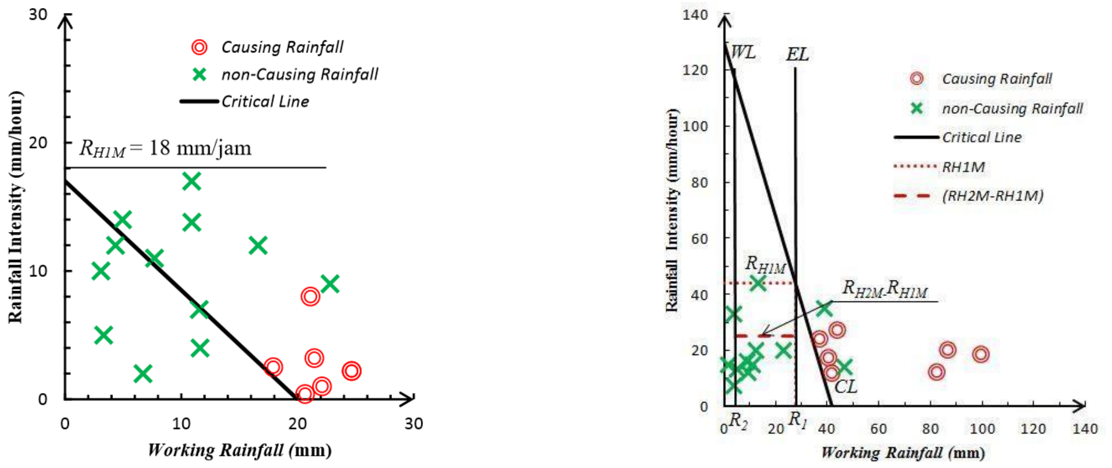


Figure 9. Average of rainfall distribution



(a) (b)

Figure 10. (a) Rainfall intensity vs. working rainfall Deles Station , (b) Rainfall intensity vs. working rainfall Batur Station



(a) (b)

Figure 11 (a) Plotting critical line at Deles Station, (b) Plotting critical line, warning line, and evacuation line at Batur Station

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Overall, from the research, some conclusions can be drawn as follows:

a) The best empirical formula for estimating rainfall intensity around Mount Merapi is Sherman formula.
b) Based on critical line at Batur Station, standard rainfall for evacuation is 28 mm and standard rainfall for warning is 5 mm.
c) Causing rainfall having small values may cause difficulty in creating the critical line

5.2 Recommendations

Some recommendations which can be given are:

a) Highest elevation of rainfall recorder station should get more attention due to data reliability.
b) Deduction coefficient for antecedent rainfall needs deepen research due to the variation of deposit material.
c) An early warning system for debris flow disaster based on standard working rainfall is the best practice for supporting the existing systems.

REFERENCES

Drogue, et al., 2002. *Calibration of a Parsimonious Rainfall-Runoff Model: a Sensitivity Analysis from Local to Regional Scale.* Switzerland, Lugano.

Kusumobroto, H., 2006. *Fenomena Aliran Debris dan Faktor Pembentuknya [Debris Flow Phenomenon and Forming Factor]*. Semarang.

MLIT (Ministry of Land, Infrastructure and Transport), 2004. *Guidelines for Development of Warning and Evacuation System against Sediment Disaster in Developing Countries, Japan*, Tokyo: Infrastructure Development Institute.

Sosrodarsono, S. & Takeda, K., 1985. *Hidrologi Untuk Pengairan [Hydrology for Irrigation]*. Jakarta: PT. Pradnya Paramita.

Triatmodjo, B., 2008. *Hidrologi Terapan [Applied Hydrology]*. Yogyakarta: Beta Offset.

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