Rainfall Thresholds for Sediment Related Disasters in Ambon City, Indonesia

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Ambon city of Indonesia is extremely vulnerable to climatic hazards and the frequency of sediment related disasters appears to increase. In 2012 and 2013, more than one hundred of sediment related disasters occurred especially in the settlement area. Empirical thresholds were used in this study. Empirical threshold has been considered as collecting rainfall data for sediment related disaster events from 2007 to 2013. The purpose of this study was to determine rainfall thresholds for possible sediment related disaster occurrence in Ambon city. The results show that the sediment related disasters occurred in short periods (2 hours) with a high average intensity and longer periods (48 hours) with a lower average intensity in Ambon city. We determined new rainfall thresholds for possible sediment related disaster occurrence with the regression value of $I = 83.88D^{-0.80}$ (I is the average rainfall intensity in mm/hr and D is duration in hr). It is expected that the new rainfall thresholds could be used for development of a warning system in Ambon city.

Keywords: Sediment related disaster, rainfall threshold, warning system, Ambon city

1. INTRODUCTION

Ambon city of Indonesia is extremely vulnerable to climatic hazards and the frequency of sediment related disasters appears to increase. In 2012 and 2013, more than one hundred of sediment related disasters occurred especially in the settlement area. The damage was particularly severe in the city and at several sites along the transportation network. The sediment related disasters resulted in hundreds of destroyed houses, including 43 deaths, numerous injured people and hundreds people evacuated. Estimated economic losses caused by these sediment related disasters are worth of about 35 million US dollars [*BPBD*, 2012; 2013].

A threshold is defined as the minimum or maximum level of some quantity needed for a process to take place or a state to change [*White et al.*, 1996]. A minimum threshold defines the lowest level below, which a process does not occur. A maximum threshold represents the level, above which a process always occurs, i.e., there is a 100% chance of occurrence whenever the threshold is exceeded [*Crozier,* 1996]. For rainfall-induced slope failures a threshold may represent the minimum intensity or duration of rain, the minimum level of pore-water pressure, the slope angle, the reduction of shear strength or the displacement required for a landslide to take place. Threshold can also be defined for parameters controlling the occurrence of landslides, such as the antecedent hydrological conditions or the (minimum or maximum) soil depth required for failures to take place [*Reichenbach et al.*, 1998].

The objective of this study is to determine rainfall thresholds for possible sediment related disaster occurrence in Ambon city. The results of the study can be used for development of a warning system in the study area.

2. STUDY AREA

Ambon is a city on the island of Ambon, Maluku Province, Indonesia. Located at 3° – 4° South latitude and 128° – 129° East longitude. Regarding land use of Ambon city, 66.51 % of the land use is natural forest, 15.60 % is paddy field, 10.26 % is mix garden, and 7.63 % is settlement (**Fig. 1**). The area of Ambon city is about 337 km^2 with 73 % topographic conditions of slopes over 20°. The geology is composed of volcanic rocks

(69.02 %), coral (14.86 %), ultramafic rocks (6.46 %), alluvium (4.60 %), *sandstone*, shale, siltstone, with intercalations of *conglomerate* and limestone (4.42 %), and granite (0.64 %). The elevation ranges from 0 – 50 m (19.74 %), 50 – 100 m (14.61 %), 100 – 200 m (26.76 %), 200 – 300 m (18.95 %), 300 – 400 m (10.01 %), and >400 m (9.93 %). The average annual rainfall is about 3,481 mm/year (1989 to 2013) with high intensity rainfall occurring from May to August (**Fig. 2, 3**).

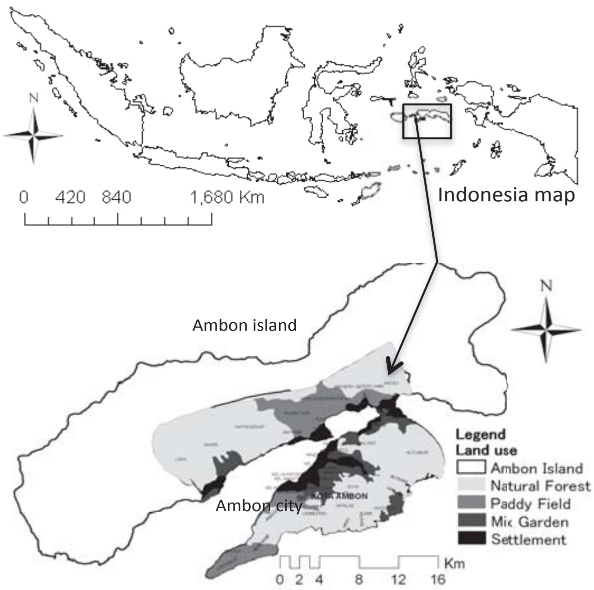

Fig. 1 Study area in Ambon city, Indonesia.

In the last 5 years, the population is experiencing a high growth that reaches 7.49 % annually. The population is around 387,000 people. The area in Ambon city is relatively small and the high increase of population has been causing scarcity of habitable land, this situation force many citizens to build their houses in steep slopes with a high risk of sediment related disasters especially with strong intensity of rainfall (**Fig. 4, 5**).

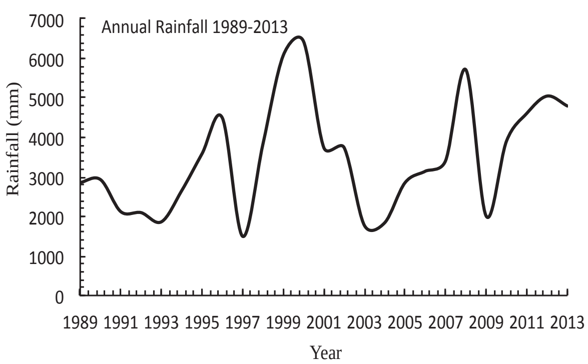

Fig. 2 Annual rainfall from 1989 to 2013 in Ambon city, Indonesia.

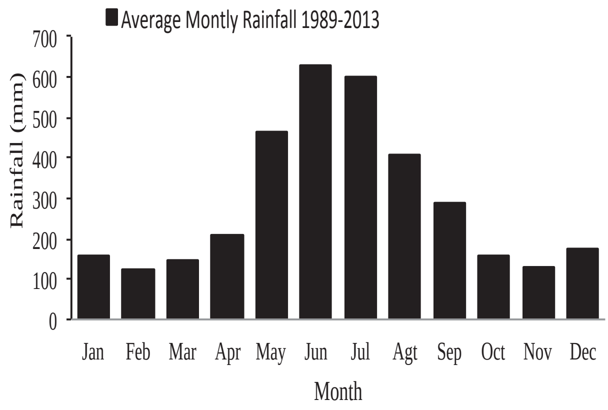

Fig. 3 Average monthly rainfall from 1989 to 2013 in Ambon city, Indonesia.

Fig. 4 Houses in steep slopes of Ambon city with a high risk of sediment related disasters.

Fig. 5 Sediment related disaster in Ambon city, occurred on July 15, 2012.

3. METHODOLOGY

In general, two types of rainfall thresholds can be established; empirical thresholds and physical thresholds [*Aleotti*, 2004]. The empirical thresholds refer to relational values based on statistical analysis of the relationship between rainfall and landslide (sediment related disaster) occurrences [*Campbell*, 1975; *Caine*, 1980; *Larsen and Simon*, 1993; *Crozier*, 1999; *Guzzetti et al.*, 2004; *Dahal and Hasegawa*, 2008; *Hasnawir and Kubota*, 2009], whereas physical thresholds are usually described with the help of hydrologic and stability models that take into account the parameters such as relationships between rainfall and pore-water pressure, suction, infiltration, slope morphology, and bedrock structures [*Montgomery and Dietrich*, 1994; *Crosta*, 1998; *Terlien*, 1998; *Crosta and Frattini*, 2001; *Jakob and Weatherly*, 2003]. Antecedent rainfall [*Crozier*, 1999; *Rahardjo et al.*, 2001] also plays an important role in the determination of rainfall thresholds.

This study has used empirical thresholds. To determine rainfall thresholds for possible sediment related disaster occurrence in Ambon city, we first prepared a database of rainfall events that resulted in sediment related disasters from 2007 to 2013. Records of rainfall data and history of sediment related disasters were collected from the Meteorological, Climatological and Geophysics Agency and from the National Disaster Management Agency. The regression for rainfall thresholds is obtained from the relationship between the average rainfall intensity (I, mm/hr) and duration (D, hr).

4. RESULTS AND DISCUSSION

The rainfall in Ambon city is very different from the rainfall conditions elsewhere in Indonesia, where generally the stronger rainfalls occur from December to March. In this study we used hourly rainfall data to establish critical rainfall for the occurrence of sediment related disaster. The critical rainfall indicates the amount of rainfall from the time (‘‘zero point’’) in which a sharp increase in rainfall intensity and the triggering of the sediment related disaster is observed. Forty-five rainfall events resulted on more than two hundred sediment related disasters in Ambon city in the period from 2007 to 2013. Average amount of rainfall during all events with sediment related disaster occurrence was 171 mm with minimum rainfall of 101 mm (**Fig. 6** and **Table 1**). There is not any report or information about sediment related disaster before 2007. However, it can be presumed that before 2007 many sediment disasters occurred.

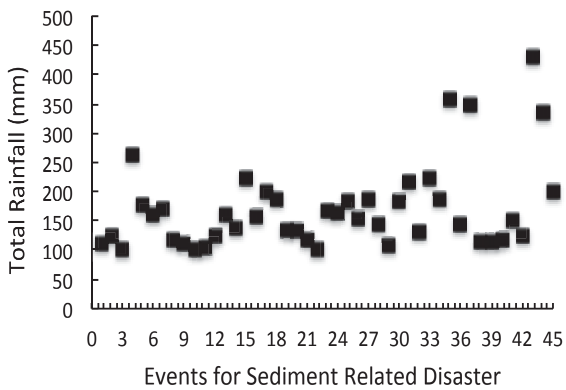

Fig. 6 Rainfall events for sediment related disaster in Ambon city, 2007 to 2013.

Table 1 Cases of sediment related disasters, duration and average rainfall intensity in Ambon city from 2007 to 2013

No	Date	Duration (D, hr)	Average Rainfall Intensity (I, mm/hr)	Total Rainfall (mm)
1	June 09, 2007	4	28	110
2	June 12, 2007	4	31	124
3	June 14, 2007	4	26	102
4	June 28, 2007	48	5	263
5	June 29, 2007	12	15	176
6	September 09, 2007	4	40	160
7	June 02, 2008	5	34	170
8	August 09, 2008	4	29	117
9	August 14, 2008	4	28	112
10	August 15, 2008	2	51	101
11	August 16, 2008	3	35	106
12	September 05, 2008	10	13	125
13	September 09, 2008	8	20	161
14	September 10, 2008	3	46	139
15	June 12, 2010	48	5	224
16	June 16, 2010	26	6	157
17	July 20, 2010	26	8	202
18	August 04, 2010	7	27	187
19	April 30, 2011	3	45	134
20	May 13, 2011	3	45	136
21	May 20, 2011	2	59	117
22	May 22, 2011	4	25	101
23	May 24, 2011	28	6	169
24	May 26, 2011	28	6	163
25	May 27, 2011	26	7	183
26	June 04, 2011	26	6	153
27	July 30, 2011	28	7	188
28	August 01, 2011	4	37	146
29	May 24, 2012	3	36	109
30	May 26, 2012	6	31	185
31	June 07, 2012	36	6	218
32	June 08, 2012	3	43	130
33	June 18, 2012	30	7	222
34	June 28, 2012	6	31	188
35	July 15, 2012	26	14	360
36	July 31, 2012	3	49	146
37	August 01, 2012	48	7	348
38	August 25, 2012	3	38	115
39	September 16, 2012	3	39	116
40	October 06, 2012	3	39	118
41	July 12, 2013	4	38	152
42	July 17, 2013	3	41	123
43	July 25, 2013	48	9	432
44	July 30, 2013	48	7	334
45	July 31, 2013	4	50	200

The regression value of rainfall thresholds for sediment related disaster (line [100]) was $I = 83.88D^{-0.80}$, where I is the average rainfall intensity in mm/hr and D is the duration of rainfall in hours (**Fig. 7**). This regression is considered as a reliable rainfall threshold for the study area, above which, sediment related disaster events may occur. In Ambon city the sediment related disasters occurred in short periods (2 hours) with high average intensity at least 51 mm/hr, and longer periods (48 hours) with a lower average intensity at least 5 mm/hr.

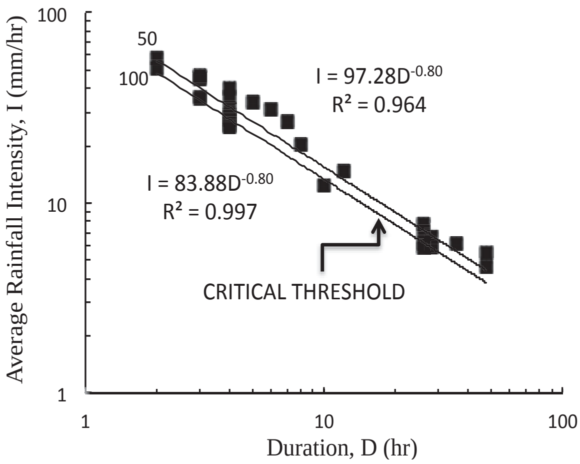

Fig. 7 Rainfall thresholds for sediment related disaster in Ambon city, 2007 to 2013. Line [100] encompasses 100% of the available data and represents the triggering threshold; the other limit [50] represents different percentage of points in the graph.

An interesting use of empirically based thresholds is in warning systems for sediment related disasters. *Caine* (1980) first established worldwide rainfall threshold values for landslides. Similar threshold values have been proposed for "global" [*Crosta and Frattini*, 2001]; for California [e.g., *Cannon and Ellen*, 1985; *Wieczorek*, 1987; *Wieczorek et al.*, 2000], the Southern European Alps [*Cancelli and Nova*, 1985; *Ceriani et al.*, 1992], pre-Alpine regions of northern Italy [*Guzzetti et al.*, 2004], the Piedmont region of Italy [*Aleotti*, 2004], Korea [*Kim et al.*, 1991], southern China [*Li and Wang*, 1992], Japan [*Cotecchia*, 1978; *Yatabe et al.*, 1986; *Yano*, 1990; *Hiura et al.*, 2005]; Puerto Rico [*Larsen and Simon*, 1993]; central and southern Europe thresholds [*Guzzetti et al.*, 2007]; Himalaya, Nepal [*Dahal and Hasegawa*, 2008]; Mt. Bawakaraeng, Indonesia [*Hasnawir* and *Kubota*, 2009]. Recently *Saito et al.* (2010) reviewed representative rainfall thresholds for shallow landslides in all Japan.

Compared to the global threshold [*Crosta and Frattini*, 2001; *Caine*, 1980] or California thresholds [*Wieczorek*, 1987], Mt. Bawakaraeng thresholds [*Hasnawir and Kubota*, 2009], Japan thresholds [*Saito et al.*, 2010], central and southern Europe thresholds [*Guzzetti et al.*, 2007], the Ambon city thresholds needs high intensity rainfall for sediment related disasters to occur, but when the rainfall duration exceeds 48 hours, the rainfall intensity is less than that in the global thresholds [*Caine*, 1980]. However, compared to the Himalaya thresholds [*Dahal* and *Hasegawa*, 2008], before the rainfall duration exceeds 5 hours, the Ambon city needs high intensity rainfall for sediment related disasters to occur (**Fig. 8**).

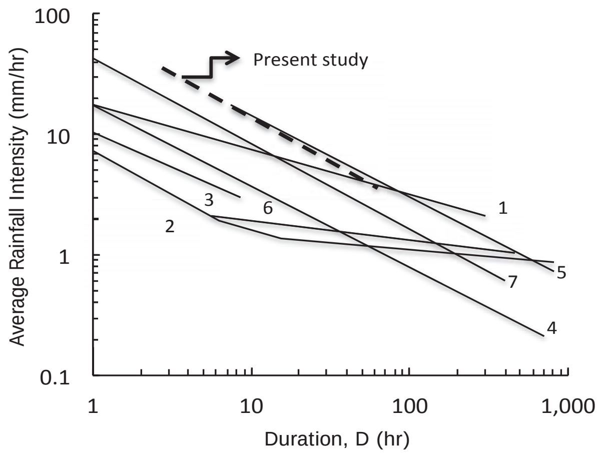

Fig. 8 Rainfall thresholds curve for sediment related disasters in the Ambon city and comparison of the rainfall thresholds from various studies with the present studies. Dotted line: Ambon city thresholds. 1, *Caine*, 1980 (global); 2, *Crosta and Frattini*, 2001 (global); 3, *Wieczorek*, 1987 (California); 4, *Guzzetti et al.*, 2007 (central and southern Europe); 5, *Dahal and Hasegawa*, 2008 (Himalaya, Nepal); 6. *Saito et al.*, 2010 (Japan); 7, *Hasnawir and Kubota*, 2009 (Mt. Bawakaraeng, Indonesia).

Fig. 9 describes an operating procedure for evacuation based on rainfall thresholds. The procedure is activated after the quantitative precipitation rainfall forecast. Based on forecast, a preliminary assessment is made of the probability that the warning and critical thresholds will be exceeded. In a situation of ‘‘ordinary attention’’, in which it is assumed that the critical limits will not be exceeded, the forecasting procedure is repeated. Vice versa, if the forecast predict rainfall exceeds the warning and triggering thresholds, i.e. indicating a potentially critical situation, the alert phase is activated and, in landslide-prone areas, a risk assessment procedure is initiated in real time. This implies the acquisition of rainfall data recorded by the involved rain gauges; data on antecedent rainfall for periods of 10 days prior to the event; ‘‘historic’’ information on the rain gauges (rainfall return times, mean annual rainfall, etc.). At this stage, the rainfall data has to be analyzed in order to identify the beginning of critical rainfall on the time-cumulative rainfall curve, i.e. the rainfall that may potentially trigger soil slips. Once the point of origin of the rain paths (‘‘zero point’’) has been identified, the precipitation trend can be traced on specific graphs in relation to the warning threshold that has been adopted. The alarm phase is activated once the warning thresholds are exceeded, and the emergency procedure is implemented [*Aleotti*, 2004].

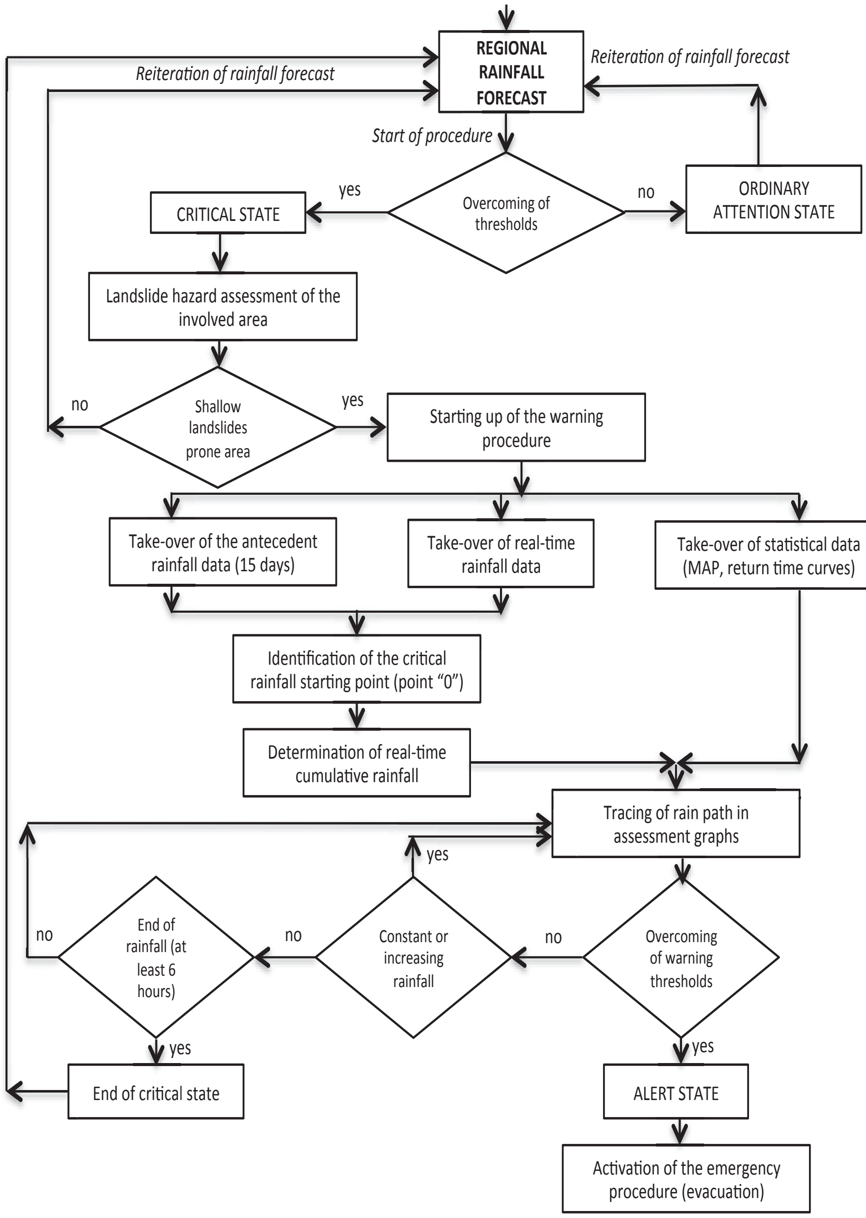

Fig. 9 Operating procedure based on thresholds [*Aleotti*, 2004]

5. CONCLUSIONS

In Ambon city the sediment related disasters occurred in short periods (2 hours) with a high average intensity and longer periods (48 hours) with a lower average intensity. We determined new rainfall thresholds for possible sediment related disaster occurrence with the regression value of $I = 83.88D^{-0.80}$. We expect that the new rainfall thresholds can be used for development of a warning system in Ambon city.

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