Flash flood in Arau watershed, West Sumatera: a mitigation study

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Abstract. Flash flood often occurs in West Sumatera. In spite of heavy rain, flash floods are also caused by the landslide in the riverside that blocks the river as a natural dam. The natural dam can be broken at any time, depending on storage capacity. Flash flood occurs when the dam is broken. The aim of the research is to mitigate flash floods based on parameters influencing flood and landslide. The research was conducted in Arau watershed, West Sumatera. Parameters that have a direct proportion of floods are maximum daily rainfall, watershed shape, river gradient, drainage density, slope, and land cover. Parameters influencing landslides are antecedent soil moisture, slope, geologic type especially fault line, soil depth, and land cover. GIS is used to analyze the factors influencing flood and landslide spatially. The results show that more than 50% of the Arau watershed are slightly high and high vulnerability due to its natural condition. Furthermore, the locations of fault, especially in the riverside, should be noticed because this location could become a natural dam causing flash flood. In order to reduce flash flood impact, the natural dam should be opened as soon as possible.

1 Introduction

Flash floods are one of the most destructive natural disasters. It took place not only in highly exploited areas but also in pristine areas such as in Bohorok (North Sumatera) and Wasior (West Papua) [1]. Flash floods are different by nature from riverine and other floods and are particularly devastating due to their suddenness and volume of water and debris [2]. The flash floods are abrupt and difficult to predict [3]. Flash floods result from high rainfall intensity [4]. Flash floods have characteristics such as: increasing river flow above its flow capacity, occurs very quickly, less than six hours and carries debris [5]. Flash floods took place in short duration [6] with a huge volume containing debris [2]. Furthermore, flash floods are not only caused by high rainfall intensity but also due to hydrology, topography, land use, timing and other factors [7]. Landslides are caused not only by rainfall but also by vegetation cover [8].

The main factor of the flash flood is extreme rainfall intensity. Together with a landslide in the riverside it blocks the river causing a natural dam. The river water pressure breaks the natural dam cause flash flood which is characterized by high water velocity with mud, log, and boulders [1]. The characteristics of the flash flood are abrupt, more quickly, huge damage, usually take place in a small catchment, often in time together with flood in small river and landslides [9].

The National Disaster Management Agency (BNPB) recorded more than 500 floods and landslides occurring along with floods since 2000 [10]. The most frequently affected provinces are Central Java, West Java, East

Java, and West Sumatra. In other countries such as in Tahiti in February 2014, a big flood occurred in this valley. 860 mm of rain fell for 8 days and the water level reached 150 cm high while it is 40 cm in normal regime. Thirty minutes after a rainfall peak, the river water level was at its maximum covering an area of 15 km² [6].

Although flash floods are very devastating, mitigation for flash floods has not been fully understood [11]. In spite of heavy rain, flash floods are also caused by trees and others debris and decreasing drainage capacity [6]. Many factors affect flash flood such as antecedent soil moisture content and watershed characteristics [12]. In order to make risk map of the flood in the watershed, parameters such as area, slope, time of concentration, and runoff volume should be investigated. The area of the watershed is the highest effect on the peak floods [13]. Soil types, altitude, slope, land cover, and rainfall can be used to determine flooding area [3]. The research focused on identifying the possibilities of flash floods caused by natural dams in Arau watershed, West Sumatra.

Geographical Information System (GIS) is used for predicting flash floods location. Some factors influencing flash floods will be collected and analyzed using GIS. [3] concluded that systematic analysis of morphometric parameters within drainage networks using a GIS can provide significant value in understanding sub-basins drainage characteristics with respect to flash flooding. [14] suggested that the estimation of flash flood risk can be analyzed by combining morphometric and watershed characteristics.

Padang City has a unique location, the city is flat but the upper part of the watershed is hilly with steep slopes

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with high rainfall intensity. One of the watershed flow in Padang is Arau watershed. This conditions caused Padang city prone to flood and flash flood.

Padang city has been struck by flood for many times, for example, May, 5 -6, 2004; December 24, 2007; September 12, 2012; and March 22, 2016 (Sumbarsatu.com, "Padang Express" Thursday 13 September 2012 in [15]). In order to reduce risk, a mitigation flash flood in Arau watershed should be done.

2 The material and method

2.1 Time and location

This research was conducted in the Year 2015 in Arau watershed, West Sumatera Province. The selection of this location is due to West Sumatra Province is one of the provinces with the most flash flood occurrence. Arau watershed includes Padang Pariaman, Solok districts and Padang and Solok City.

2.2 Materials

The data used are daily rainfall for the last 10 years, 1:250,000 administrative map, 1:250,000 land cover map published by the Ministry of Environment and Forestry, 1: 250.000 RePPProT map published by BIG, 1: 250,000 geological map published by the R & D Center for Geology and DEM image downloaded from Earth Explorer USGS. The analysis tool used is ArcGIS

2.3 Method

Determination of vulnerable locations to flash flood obtained by integrating flood vulnerability map and landslide vulnerability map. The method of determining flood and landslide vulnerabilities are obtained from [16]. Parameters used for this study is showed in Table 1.

Table 1. Parameters used to determine the susceptibilities of flood and landslide.

Parameters/ weight	Classification	Category	Score
Floods			
Average maximum daily rainfall in the wet month (mm/day) 35%	< 20 21 – 40 41 – 75 75 – 150 > 150	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Watershed shape 5%	Oval Slightly oval Moderate Slightly round Round	Low Slightly low Moderate Slightly high High	1 2 3 4 5
River gradients 10%	< 0,5 0,5 – 1,0 1,1 – 1,5 1,6 – 2,0 > 2,0	Low Slightly low Moderate Slightly high High	1 2 3 4 5

Parameters/ weight	Classification	Category	Score
Drainage density 5%	Sparse Slightly sparse Moderate Slightly dense Dense	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Average of watershed's slope 35%	< 8 8 – 15 15 – 25 25 – 45 > 45	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Land cover 10%	Natural forest/ protection Production forest/ plantation Dryland, shrubs Rice field, terraced dry land Dryland, settlement	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Landslides			
Antecedence moisture condition (5 days) in mm 31.25%	< 50 50 – 99 100 – 199 200 – 300 > 300	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Slope 18.75%	< 25 25 – 44 45 – 64 65 – 85 > 85	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Geological form 12.50%	Alluvial plains Calcareous hills Granite hills Sedimentary rock hills Basalt hills-clay shale	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Existence of fault line 6.25%	No Yes	Low High	1 5
Soil depth (regolith depth) 6.25%	< 1 1 – 2 2 – 3 3 – 5 > 5	Low Slightly low Moderate Slightly high High	1 2 3 4 5
Land cover 25%	Natural forest Shrub/bush/ grass Production forest/ plantations Dryland/ homestead garden Rice field/ settlements	Low Slightly low Moderate Slightly high High	1 2 3 4 5

Sources: [16]

The vulnerability classes of floods and landslides are calculated by multiplying the weight of each parameter to the score (Table 1). The total value then divided into 5 (five) classes ranging from low vulnerable to highly vulnerable. The determination of the weight for each parameter is subject to

change and will be the priority for the next study. The range for each classification is presented in Table 2 [16].

Table 2. Vulnerability classes.

Vulnerability	Value
Not vulnerable	< 1.7
Slightly vulnerable	1.7 – 2.5
Moderate	2.5 – 3.4
Slightly high	3.4 – 4.3
High	> 4.3

Since flash flood occurs due to floods after the landslide, flash flood events determined by overlaying both flood and landslide using Table 3.

Table 3. Flash flood classes.

	Not vulnerable	Slightly vulnerable	Moderate	Slightly high	High
Not vulnerable	1	1	1	2	3
Slightly vulnerable	1	2	2	3	4
Moderate	1	2	3	3	4
Slightly high	2	3	3	4	5
High	3	4	4	5	5

3 Result and discussion

3.1 Flood and landslide parameters analysis

The rainfall parameter is used to define flood and landslide vulnerabilities where flood vulnerability used maximum daily rainfall and landslide used the Antecedence Soil Moisture content (ASM) in five consecutive days.

From the nearby rainfall stations, the recorded 10 years daily rainfall data are calculated for its maximum daily and ASM and using SPLINE in ArcGIS the maximum and ASM maps are created. The result shows that the maximum daily rainfall in Arau watershed only has one value, while the ASM has two. The value of the rainfall parameters is presented in Table 4.

Since the rainfall parameter contributes more than 30% of the total weight in both disasters, it is important to make sure that the rainfall data is accurate and up to date.

Table 4. Maximum daily rainfall in Arau watershed.

Category	Flood		Landslide	
	Max rainfall (mm)	Ha/%	ASM (mm)	Ha/%
Moderate	41 - 75	--	100 - 199	10,088.1/ 33.7
Slightly high	75 – 150	29,906/ 100	200 – 300	19,817.8/ 66.3

As mentioned before, the flood event depends on the watershed characteristics [3]. In this study, the watershed shape, river gradient and drainage density of Arau watershed are developed from DEM, and the result is shown in Tabel 5.

Table 5. Characteristic of Arau watershed.

Parameters	Classification	Category
Watershed shape	Slightly round	Slightly vulnerable
River gradient	1.1 – 1.5	Moderate
Drainage density	Slightly sparse	Slightly low

Similar to rainfall parameter, slope parameter is used by both flood and landslide, but with a different range of classes. The threshold of slope in the event of the landslide is 25%, meaning that the landslide will not occur if the slope <25% regardless of other parameters. The slope classes for flood and landslide parameters are presented in Table 6.

Table 6. Slope classes in Arau watershed.

Category	Flood		Landslide	
	Slope class	Ha/%	Slope class	Ha/%
Low	< 8	8,009.3 /26.8	< 25	14,802.3 /49.5
Slightly low	8 – 15	2,670.6 /8.9	25 – 44	9,094.2 /30.4
Moderate	15 – 25	4,035.5 /13.5	45 – 64	4,261.0 /14.2
Slightly high	25 – 45	9,097.4 /30.4	65 – 85	1,142.8 /3.8
High	> 45	6,092.7 /20.4	> 85	605.4 /2.0

Slope is another important parameter in determining areas prone to flood or landslide [13]. Therefore it is important that the data provided is reliable. In this study the slope map was generated from DEM, so that grouping the slope class according to different categories is possible. From Table 6, it is shown that Arau

watershed is prone to flood, but nearly 50% of the area is safe from landslide due to the flat slope (less than 25%).

The geological parameters such as rock type and fault line are important factors to influence the level of landslide vulnerability, especially fault line. According to the geological map from the Centre for Geology, Arau watershed is dominated by granite rock hills (51.5%) and sedimentary rock hills (40.8%). The later is more prone to landslide than that of the granite hills. Faultline is rather difficult to incorporate into the analysis since there is no clear definition to measure the extent of each fault line. In this study, the fault lines were buffered up to 100 meters with an assumption that the fault line area is within 100 meters.

Similar to slope parameter, land cover in Arau watershed is used to analyze occurrences of flood and landslide. In general, the denser plant covers the soil that reduces the volume of runoff, and at the end, it will prevent the flood. On the other hand, the heavier plant will burden the soil in the sloped area and triggers the landslide. The condition of land cover in Arau watershed is presented in Table 7.

Table 7. The condition of land cover in Arau watershed.

Category	Flood		Landslide	
	Slope class	Ha/%	Slope class	Ha/%
Low	Primary and secondary forest	17,605.5 /58.9	Primary forest	14,932.5 /49.9
Slightly low	Plantations	--	Shrub	2,457.4 /8.2
Moderate	Shrub, dryland with shrub	3,251.2 /10.9	Secondary forest, plantations	2,565.3 /8.6
Slightly high	Dryland, rice field	3,899.7 /13.0	Open area, dryland, dryland with shrub	3,099.7 /10.4
High	Settlement, open area, mining	5,149.6 /17.2	Settlement, rice field	6,851.1 /22.9

Table 7. indicates that Arau is not prone to both flood and landslide since more than 50% of Arau watershed is covered with primary forest [8] that categories as low/not vulnerable to both flood and landslide. On the other hand, the settlement is land cover type that causes land prone to flood and landslide. The settlement, especially in the upper watershed will increase the flooding possibility when people made their ground surface impermeable.

3.2 flood and landslide vulnerability

Using the criteria in Table 1. and 2. the vulnerability of Arau watershed to flood and landslide could be formulated. Table 8 showed the distribution of flood and landslide based on the districts.

Table 8. Distribution of areas vulnerable to flood and landslide.

District/ city	Vulnerability to flood (ha)			Vulnerability to landslide (ha)		
	Slightly low	Moderate	Slightly high	Not vulnerable	Slightly high	High
Padang city	12.441,5	6.434,4	5.804,6	13.675,0	7.184,1	3.821,3
Solok city	339,2	5,9	-	138,0	207,1	-
Solok district	1.205,1	55,6	-	316,0	904,1	40,5
Padang Pariaman district	3.619,7	-	-	673,6	2.946,1	-
Total	17,605.4	6,495.9	5,804.6	14,802.6	11,241.5	3,861.9

Most of Arau watershed comprised of Padang city (82.5%), followed by Padang Pariaman (12.1%), Solok (4.2%) and Solok city (1.2%). Table 8. showed that the vulnerability of Padang city is slightly high to flood and slightly high up to high to landslide. Other locations, on the other hand are not as vulnerable as Padang city. Solok district, for example, although it has more than 40 ha areas prone to landslide, but with moderate category to flood, the change of a big disaster is smaller than Padang city.

Table 7. also shows that nearly 50% of Arau watershed is not prone to landslide. [16] found that the landslide will not take place in areas with a slope less than 25%. Therefore areas with the slope less than 25% will not be prone to landslide regardless of the land cover or other parameters.

For more detailed information about slope in Arau watershed, Padang Pariaman has the steepest slopes compared to Solok and Padang. Its slopes are dominated by 25-45% (54.7%) and 45-65% (23.7%), then Padang Pariaman is more prone to landslide compared to the other two districts. In contrast, Padang city has the largest flat areas (0-8%) compared to Solok and Padang Pariaman, therefore it is more likely to get flood than the landslide.

3.3 flash flood vulnerability

Flash flood vulnerability is derived from overlaying flood vulnerability to landslide vulnerability. This corresponds to the occurrence of landslide [1], where the breakage of the natural dam caused by the previous landslide is done by the flood.

By overlaying flood and landslide vulnerabilities using Table 3, a flash flood map could be derived. Fig. 1 shows the extent of flash flood vulnerability in Arau watershed, while Table 9 showed the numbers.

Fifty percent of the total Arau watershed are moderate to highly susceptible to flash flood. Most of Solok, both city and district and Padang Pariaman are slightly high susceptible to flash flood, but since those areas are only 1.2, 12.1 and 4.2 percents of the Arau watershed respectively, it gave the impression that that city and district only contributed a small portion to the whole watershed.

Fig. 1. Flash flood vulnerability of Arau watershed

Table 9. The extent of the flash flood in Arau watershed.

District/ city	Vulnerability to flash flood (ha/%)				Total area (ha)
	Not suscep tible	Moderat e	Slightly high	High	
Padang City	13,675/ 55.4	5.7/0	9,447.5/ 38.3	1,552.3/ 6.3	24,680.5
Solok City	138/ 40.0	0.2/0.1	206.9/60.0	--	345.2
Solok District	673.6/ 18.6	1.7/0	2,944.4/ 81.3	--	3,619.7
Padang Paria man District	316.0/ 25.1	0.6/0	922.7/73.2	21.4/1.7	1,260.6
TOTAL					29,906.0

The high vulnerability to flash flood in Padang city are at Lubuk Kilangan, Pauh and Koto Tangah sub-districts, in Padang Pariaman district mostly is at Batang Anai, while in Solok district are at Kubung and Gunung Talang. Those areas should be taken care of and observed especially during rainy seasons to prevent them from flash flood disasters.

The high susceptibility of Arau watershed to the flash flood is due to the natural condition, which has a steep slope (more than 25%) that goes straight to the flat areas on the beach.

Once the susceptibility of the flash flood in the Arau watershed is mapped, it important that each city/district understand which area is prone to flash flood. Since flash flood is affected by the landslide [1] the location prone to landslide should be noticed, because this area has the possibility to be blocked. Once the river is blocked by landslide materials, it will become a natural dam and ready to turn into the flash flood. To make the location of areas prone to flash flood more accurate, added information such as the existence of fault line will help.

For locations vulnerable to flash flood, community participation become important [17], and local wisdom about the flash flood in West Sumatera is present. This local wisdom of the community about flash flood will become one of the mitigation programs.

4 Conclusions

Flash flood location could be mapped by overlaying flood and landslide maps. Using this method Arau watershed in West Sumatera is found to be vulnerable to flash flood, where more than 50% of the area is slightly high and high.

The natural condition in Arau watershed caused high susceptibility to flash flood. Padang, Padang Pariaman and Solok areas which were in Arau watershed is prone to flash flood, thus those areas should be noticed. The natural blockage could happen along the rivers especially in Padang City where landslide vulnerability is high. Since the local wisdom about the flash flood is present, the community could be participated to make sure that the natural dams will be taken care.

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