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The Rainfall Effect Analysis of Landslide Occurrence on Mount Slopes of Wilis

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***Abstract*— Water is a significant factor in the occurrence of landslides when rainwater absorbs into the impermeable layer of soil and causes the soil to experience weathering; thus, that the soil is not strong enough to withstand the water load. Therefore, rainfall, as well as a land slope that affects the acceleration of runoff, becomes an important indicator that affects the potential for landslides. In this research, the effect of rainfall intensity on landslide was analyzed based on monthly data collected from 81 rain gauge stations. This idea was an effort to support research related to landslides mapping on the steep area. Thus, the analysis of potential landslides that vary according to rainfall changes monthly was obtained. La Nina phenomenon in 2016 causes the intensity of rainfall in the dry season to be quite high. However, the intensity values continued to show a significant change between dry and rainy seasons. The area of low landslide hazard changed significantly for low rainfall intensity (July 2016) and high intensity in April 2017. The total area of landslide hazard in April 2017 was 1.09 and 0.82 times more massive than in August 2016 for high and moderate potential hazards, respectively. Based on the characteristic of rainfall that change frequently and water as the primary trigger of the landslide, in determining the potential for landslides, rainfall factors need to be considered more detailed.**

***Keywords*— landslides hazard; La Nina; Mount Wilis; rainfall effect.**

I. INTRODUCTION

Hydro-meteorological disaster is one of the phenomena that occurred at any time, could cause harm to any aspect. One of the disasters is a landslide that is often resulting in loss of property even of life and damage other facilities that could have an impact on economic and social conditions [1]. Water is a significant factor in the occurrence of landslides when rainwater absorbs into an impermeable layer of soil and causes the soil to experience weathering; thus, it was not strong enough to withstand water loads. This factor increased soil load that causing ground movement on the sliding plane because in this field occurs weathering and soil layers, which is not able to withstand the load of water that penetrates the layer [2].

Principally, landslides occurred when the force retaining found the slopes that cannot contain the weight or force size was lower than the driving force of the load water seep or penetrate the soil. Soil density and strength affect the retention force. While affecting the propulsive force was the angle of slope of the land, type of soil and rock, as well as water [2]. Rainfall becomes an important indicator that supports the potential for landslides in very steep locations. The slope of the land affects the acceleration of runoff [3]. La Niña has strong relation with rainfall phenomena [4]–[7]. N La Niña phenomenon reported during a dry session of 2016 affected Indonesia’s area. Its cooler surface waters lead to less rising air, therefore fewer clouds than average in the central Pacific. Conversely, there was more rising air, clouds, and rainfall over Indonesia during that event [8].

High intensity of rainfall in a short time could be causing a low landslide. Then high-intensity rainfall in a long time could lead to higher potential landslides than before [9]. Several studies of rainfall had ever done, such as studied, to determine the duration and intensity of rainfall patterns [10], [11]. The objective of this research was to know the effect of rainfall intensity induced by La Nina to a local landslide phenomenon on Mount Slopes of Wilis. This work was an effort to support research related to landslides mapping on the steep area. Thus, the analysis of potential landslides that vary according to rainfall changes every month was obtained.

II. MATERIALS AND METHOD

A. Study Area and Data

The research related to the effect of rainfall on landslides was performed on Mountslopes of Wilis (07 ° 46 '27 "S to 07 ° 57' 6" S and 111 ° 38 '45 "E to 111 ° 40' 40" E). This area has a maximum altitude of 2,563 meters above sea level, which is administratively in a part of six regencies, including Madiun, Ponorogo, Nganjuk, Kediri, Trenggalek and Tulungagung as presented in Figure 1.

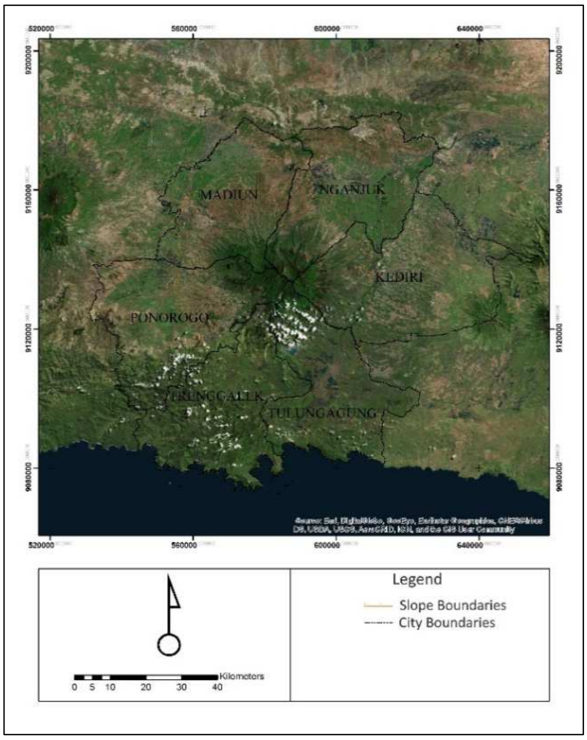

Fig. 1 Location of Mount Wilis

The data used in this study was the monthly rainfall data for one year, ranging from May 2016 to April 2017, which was collected by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) Karangploso, East Java. Data consisted of 81 rainfall monitoring stations spread throughout the area of study. Average monthly data for all stations and each station were presented in Figure 2 and Table 1-6. Considering the landslide event on April 2017, this research was focused on the data taken one month prior the events. As a comparison, the lowest rainfall intensity in July was analyzed.

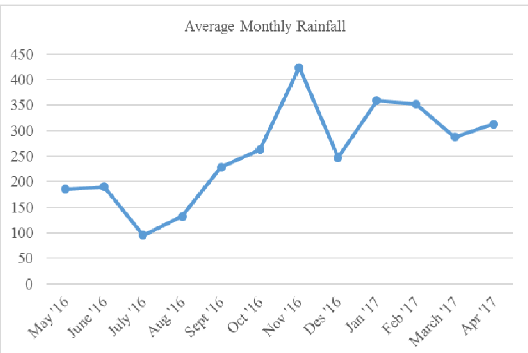

Fig. 2 Monthly rainfall from rain gauge

TABLE I
JULY 2016 AND MARCH 2017 MONTHLY RAINFALL DATA OF NGANJUK

No.	Station name	Rainfall (mm)	
		July 2016	**March 2017**
1	Sumber Pecan	42	518
2	Tempuran	47	350
3	Kedung Maron	40	275
4	Tretes	100	238
5	Patihan	76	470
6	Soko kedung	99	261
7	Pulses	69	306
8	Pace	78	269
9	Tunglur	42	257
10	Badong	52	280
11	Klodan	60	369
12	Palu Ombo	80	197
13	Sawahan	69.9	273.3
14	Genjeng	30	403

TABLE II
JULY 2016 AND MARCH 2017 MONTHLY RAINFALL DATA OF MADIUN

No.	Station name	Rainfall (mm)	
		July 2016	**March 2017**
1	Sidomulyo I/Dawuan	62	174
2	Mlilir / DAM Gombal	77	400
3	Sugihwaras/Saradan	32	186
4	Dolopo	31	304
5	PG Pagotan	49	225
6	Curry	0	202
7	DAM Sareng	35	226
8	Wungu I/Dungus	54	176
9	Wungu II/Cau	98	222
10	Cermo	35	211
11	Kandangan	32	319
12	Gemarang	6	228
13	Kebonagung/Wates	3	85
14	Patihan I/PG. Rejo Agung	53	362
15	Klegen	70	450
16	Kertoharjo II/Madison PU	66	442
17	Banjarrejo/PG. Kanigoro	194	336
18	Kenongorejo/Pilang Kenceng	68	378

TABLE III
JULY 2016 AND MARCH 2017 MONTHLY RAINFALL DATA OF KEDIRI

No.	Station name	Rainfall (mm)	
		July 2016	**March 2017**
1	Damarwulan	62	493
2	Wonomarto	25	47
3	Sidorejo	82	282
4	Baye	91	338
5	Kras	48	455
6	Kunjang	61	365
7	Cerme	72	359
8	Tales	94	554
9	Tiron	23	368
10	Letter	62	493
11	Jugo	284	486
12	Kedak	27	406

TABLE IV
JULY 2016 AND MARCH 2017 MONTHLY RAINFALL DATA OF PONOROGO

No.	Station name	Rainfall (mm)	
		July 2016	March 2017
1	Wilangan	138	265
2	Kauman/Sumoroto	0	175
3	Badegan	48	108
4	Prayungan/Sawo	57	239
5	Wagir lor/Ngebel	70	89
6	Pudak Wetan	138	265
7	Sooko	115	235
8	Ngrayun	35	347
9	Talun	89	265
10	Kesugihan	151	244
11	Pulung	79	265
12	Bangunsari/Ponorogo	32	283
13	Cottage/Babadan	94	225

B. Data Processing

1) Pre-Processing. Rainfall data for the research area was collected from 81 stations, which are distributed in the six regencies' areas that surround Mount Wilis. The data provided in the form of excel data contains the coordinates of the station as well as monthly rainfall intensities. Data was rearranged in order to be incorporated into the software to process its spatial interpolation value from all stations.

2) Spatial Interpolation. Spatial interpolation was processed using Inverse Distance Weighted [12]–[14]. This method assumes the simple weight at the point in the vicinity, and the value obtained close to a value near the point than those further away from the point and will change the value based on the distance from the point [15].

TABLE V
JULY 2016 AND MARCH 2017 MONTHLY RAINFALL DATA OF TRENGGALEK

No.	Station name	Rainfall (mm)	
		July 2016	March 2017
1	Gemaharjo Watulimo	526	224
2	Tawing/Munjungan	661	288
3	Duren/Tugu	138	229
4	Pule	115	235
5	Dompyong/Dams	161	518
6	Surodakan/Bagong	81	308
7	Gemblebingulan Wetan	25	186
8	Prambon	94	218
9	Wonocoyo/Pelvis	295	231

TABLE VI
JULY 2016 AND MARCH 2017 MONTHLY RAINFALL DATA OF TULUNGAGUNG

No.	Station name	Rainfall (mm)	
		July 2016	March 2017
1	Sumberingin Kidul/Ngunut	50	250
2	Nglurup/Source Pandan	273	358
3	Nyawangan/Ngantup	165	339
4	Kalidawir	45	143
5	Ngantru	59	125.1
6	Duo	67.6	119
7	Mixed Land	78.5	139
8	Besuki	85.5	57.6
9	Paingan	167	261
10	Rejotangan	50	232
11	Mojopanggung	127	333
12	Bolorejo	132	242
13	Spring	221	494
14	Paging Wojo	174	358
15	Source Manggis	108	344

TABLE VII
DISTRIBUTION OF MONTHLY RAINFALL VALUE CLASSES

Class	Information
0-100 mm	Low
100-300 mm	Medium
300-500 mm	High
> 500 mm	Very high

3) Reclassification. Rainfall data then classified into three classes. Low *range*, medium range and high intensity for as 0-300 mm, 300-500 mm and above 500, respectively [16]

TABLE VIII
WEIGHT RAINFALL INTENSITY CLASS

Factor	Class	Score
Rainfall (mm / month)	<300 mm	1
	300-500 mm	2
	> 500 mm	3

III. RESULT AND DISCUSSION

A. Rainfall Intensity Differences

Rainfall data, as presented in Figure 2 showed the differences of rainfall intensity during the dry season (May - October 2016) and the wet season (November 2016 - April 2017) at all the observed sites. However, the high intensity occurred in the dry season (in reasonable condition, it should be no rain) was considered as an influence of La Nina phenomenon. A comparison between predicted rainfall data produced by BMKG with a rainfall due to the La Nina phenomenon showed significant differences [17].

In the rainy season, rainfall data taken in March 2017, one month before the occurrence of a significant landslide in the area of Ponorogo in April 2017. As for the dry season, data was taken in July 2016 by considering the lowest rainfall intensity among all observed times. The range of values of rainfall and the number of stations recording data were shown in Table 9 and Table 10.

TABLE IX
RAINFALL EVENTS IN JULY 2016

No.	Monthly precipitation (mm)	Number of Stations
1	0-100	61
2	100-300	18
3	300-500	0
4	> 500	2

TABLE X
RAINFALL EVENTS IN MARCH 2017

No.	Monthly rainfall (mm)	Total stations
1	0-100	4
2	100-300	44
3	300-500	30
4	> 500	3

Almost all monitoring stations in July 2016 were at a low level with a range of values 0-300 mm. In contrast to March 2017 in which nearly 50% of the total number of stations was at the medium level, and there were three stations with high rainfall.

B. *Rainfall Distribution Map*

Rainfall distribution map that created using spatial interpolation from 81 distributed rain gauge stations in July 2016 and March 2017 could be seen in Figure 3 (a) and (b), respectively. The intensity of rain in the dry and rainy seasons can affect a significant change in the level of vulnerability to landslides. This is because rainfall with a large amount of water can lead to soil saturation; thus, it can increase susceptibility to landslides. The water factor is the major contributor to landslides.

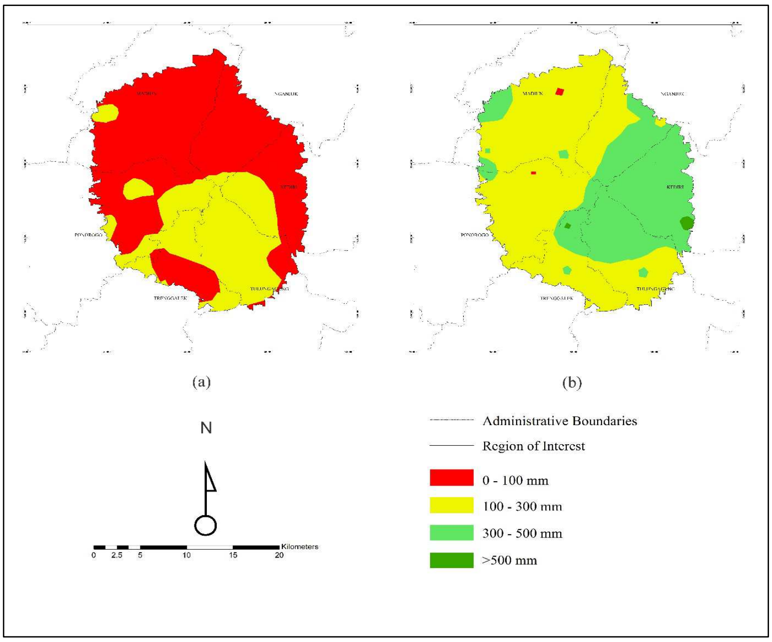

Fig. 3 Rainfall Distribution Map (a) July 2016 (b) March 2017

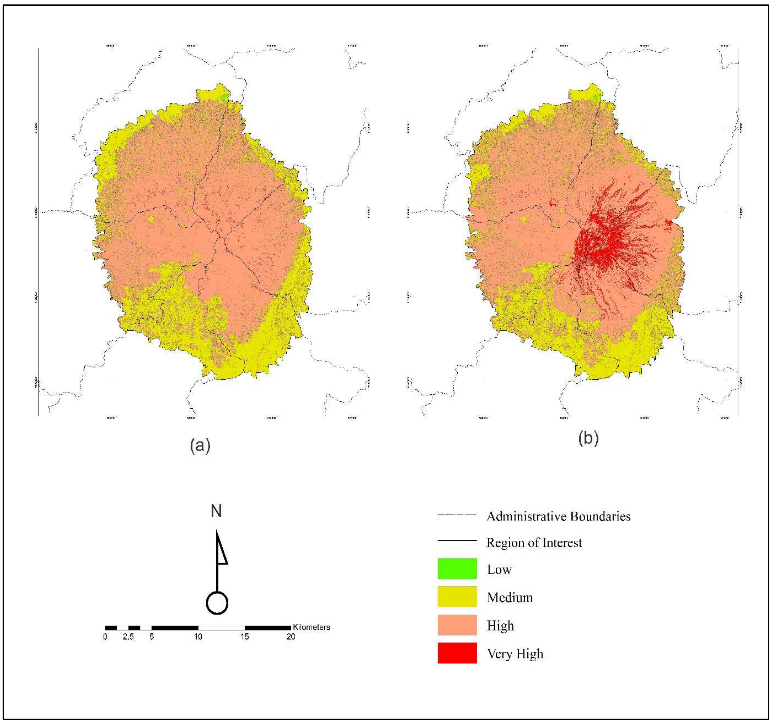

Fig. 4 Landslide Hazard Map (a) August 2016 (b) April 2017

C. The Effect of Rainfall to Landslide

Figure 4 showed the effect of different rainfall intensity that affects the landslide event. In April 2017, a rainfall data of march 2017 saturated the potential landslide area. The area of low landslide hazard was different significantly for low (in July 2016) and high (March 2017) rainfall intensity. Even though the landslide hazard of 2016 was lower than of 2017, the hazard index was at a high level. This condition was affected by abnormal rainfall during the dry session that induced by the La Nina phenomenon. The total area of landslide hazard in April 2017 increased from 1807 to 1975 km^2 and decreased from 931 to 764 km^2 for high and moderate potential hazards, respectively.

D. Reported Landslide Events.

During 2016-2017, Regional Disaster Management Agency (BPBD) in the area of Mount Slopes of Wilis collected landslide events in their area. Fig 5 shows the distribution of landslide during 2016 and 2017. The data was based on the landslide event in one sub-district, which means one occurrence in one sub-district will be represented as a total area of its sub-district.

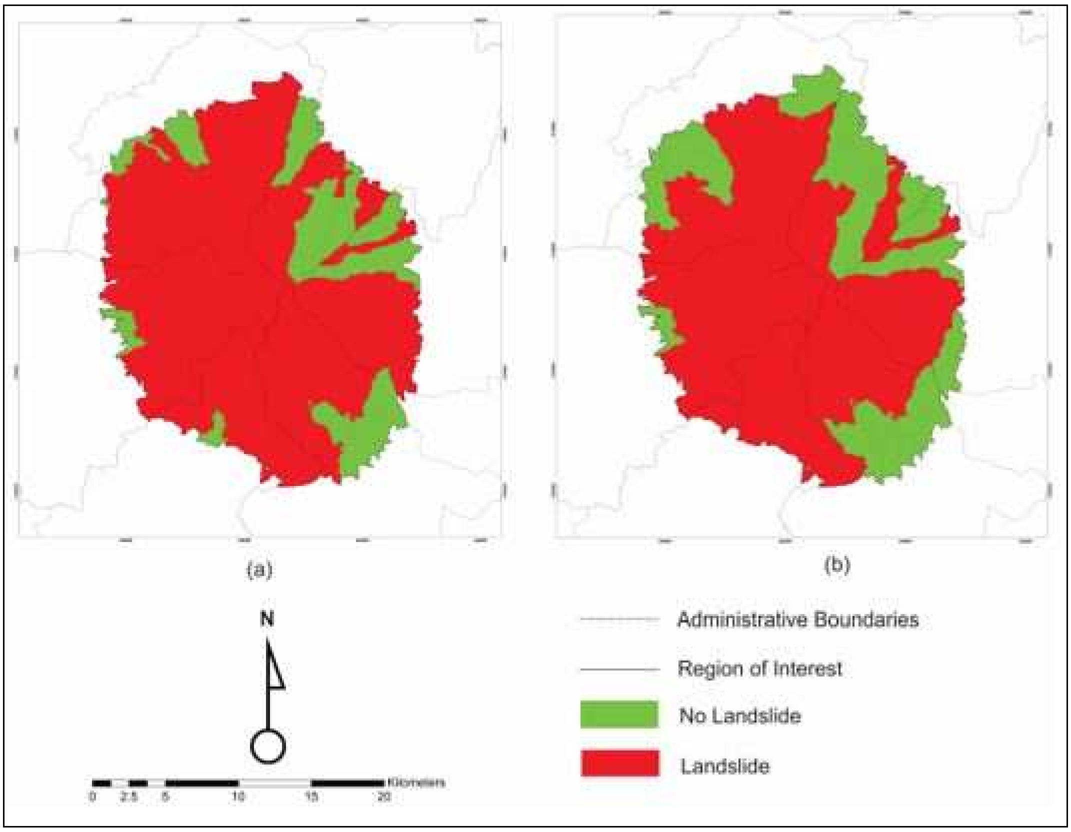

Fig. 5 Landslide events in (a) 2016 (b) 2017

Fig 4 and 5 gave a consistent pattern between predicted and actual landslide events. Even though in dry sessions, many events occurred during 2016 as an effect of La Nina.

IV. Conclusions

Remote sensing technique can be used to perform a physical analysis of landslides on the Mountslopes of Wilis. The data used to determine the potential of landslides include slope data, soil and rock types, rainfall, and land cover. From these four parameters, slope and soil/rock data changed in an extended period, land cover in medium period time, and rainfall in a short period. The area of low landslide hazard changes significantly for low rainfall intensity (July 2016) and high intensity in March 2017. The total area of landslide hazard in April 2017 was 1.09 and 0.82 times more massive than in August 2016 for high and moderate potential hazards, respectively.

Even though the landslide hazard of 2016 was lower than of 2017, the hazard index was at a high level. This condition was affected by abnormal rainfall during the dry session that induced by the La Nina phenomenon. The phenomenon causes rainfall in dry session and triggers the landslide hazard. Based on the characteristic of rainfall that change frequently and water as the primary trigger of a landslide, in determining the potential for landslides, rainfall factors need to be considered more detail

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