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ORIGINAL ARTICLE

Landslides Hazard Mapping Using Remote Sensing Data in Ponorogo Regency, East Java

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***Abstract*:** East Java, Indonesia is the region with the third most abundant disaster event in Indonesia, with an incidence event of 287 in 2016 which increased to 20% from the incidence in 2015 (287 occurrences). Almost 98% of the disaster in this region was a hydro-meteorological disaster such as a landslide near mountain-slope. To mitigate the losses due to the landslide disaster, it is necessary to map the hazard zone through hazard assessment which includes topographic and geological mapping, soil vulnerability, and rainfall monitoring. This study is the early part of the development of landslide risk reduction methodologies in East Java. Hazard studies were conducted using medium resolution satellite data / Sentinel 2A (for land cover analysis), high-resolution Radar data / TerraSAR data (for slope mapping) and geological data (for soil and stone types) as well as precipitation data over area of study. By updating a weighting factor for each parameter based on landslide event over the area of study, the more accurate map could be created using available data. Thus, this landslide-hazard map becomes a part of spatial planning recommendation that should be implemented by the local government.

Keywords: Risk Assessment, landslide, East Java

1. INTRODUCTION

Landslide is the movement of slope-forming material in the form of rocks, rendering material, soil, or mixed material, moving down or out of the slope (PVMBG 2005). The main trigger factor of landslide is water. Water that seeps into the soil will increase the weight of the soil. If the water penetrates to the impermeable soil that acts as a slip plane, then the soil becomes slippery, and the weathering soil above it will move along the slope and out the slope. According to the process of occurrence, a landslide is grouped into falls, topples, slides spreads and flows (Hungr, Leroueil, and Picarelli 2014). Center for Volcanology and Geological Hazard Mitigation (PVMBG 2005)

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grouped landslide into six types, i.e. translation, rotation, movement of blocks, stone debris, soil floating, and the flow of materials. The most frequent landslides types occur in Indonesia were translational and rotational landslides. The report of the Regional Disaster Management Agency (BPBD) of East Java states that in 2016, there have been 386 disasters from the total of national disaster events (2384 incidents). About 98% of accidents in East Java were dominated by hydro-meteorological disasters such as landslides, floods, and whirlwinds. East Java, especially some districts located on the slopes of Mountain Wilis are landslide-prone areas (PVMBG 2017). The recent occurrence of landslide disaster on the slopes of Mount Wilis covering the areas of Ngawi, Kediri, Trenggalek, Ponorogo, and Magetan in 2017 requires a thorough mitigation effort (Widodo, Syaifuddin, and Rochman 2017). Unfortunately, in this area, there was no a high accuracy of landslide hazard map for supporting mitigation efforts. Thus, the main objective of this study was to create the map by calculating the causes of landslides from existing remote sensing and other related data. It was obtained by processing a medium resolution of optical satellite data (for land cover classification), a high resolution of radar data in the form of a digital elevation model (for slope), geological data to obtain the type rock and soil and rainfall data during the last year.

2. METHODOLOGY

2.1 STUDY AREA

This research was conducted in mountain-slope of Wilis, East Java. Administratively, this area located in 7 districts: Ngawi, Kediri, Trenggalek, Ponorogo, Magetan, Trenggalek and Madiun. Following data availability, time consideration, and recent landslide occurrence, our preliminary research was started from the area of Ponorogo district (eastern part only) as presented in Figure 1. This place has area of 637,829 km^2 with altitude variation from 100 to 2,496 meter (above sea level).

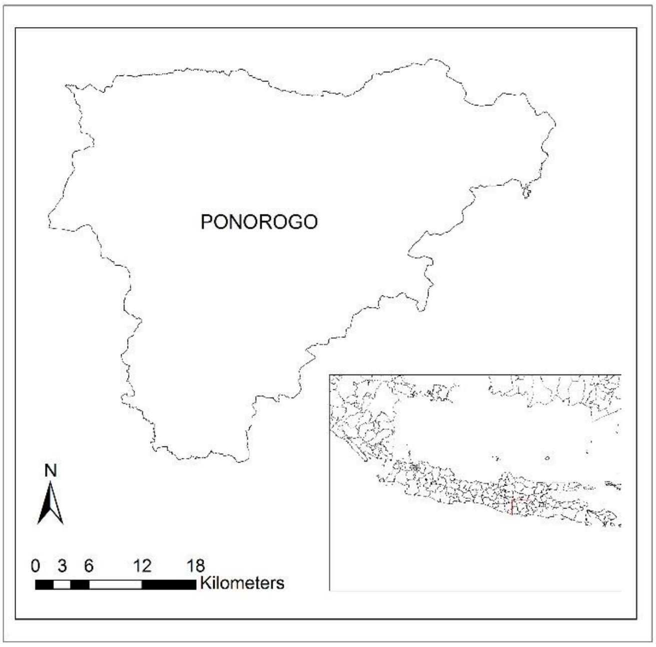

Figure 1 Study Area

2.2 DATA AND SOFTWARE

Mapping of landslide hazard was conducted by using data related to landslide control factor, i.e. slope, land cover, rainfall, and lithology. For this purpose, four data types were required, as follow:

a) **Optical satellite data**
   Sentinel 2A (S2A_tile_20170628_49MEM_0) was recorded on 28 Jun 2017 with cloud cover over scene of 2.57% was used to generate land cover map over study area. This data has 10-meter spatial resolution at band Red, Green, and Blue.
b) **High Spatial Accuracy of DEM data**
   TerraSAR (3 scenes covering study area) with a grid size of 9 meters as used as the source of DEM (Digital Elevation Model). This data can produce contours with intervals of 4.5 meters and high accuracy of land slope data.
c) **Geological map**
   A geological map (MADIUN: Number 1508-

2) produced by the Geological Agency of Indonesia was used as a basis of lithological information.

d) Precipitation data

Annual rainfall data was obtained from BMKG (Indonesian Agency for Meteorology, Climatology, and Geophysics).

e) Recent landslide events report

This information is required to validate and revise the result of landslide hazard map.

For conducting this research, ArcGIS Desktop from ESRI (ESRI 2017) was used as a primary software.

2.3 Research Method

This research utilized various data source to estimate the main factor related to landslide hazard. The first data is optical satellite imagery (in this case is Sentinel 2A belongs to European Satellite Agency) with a spatial resolution of 10 m (highest in medium spatial resolution class) (ESA 2015). The land cover map was made from this data throughout supervised classification process. The second data is TerraSAR (radar data) with 9 m grid cell size of DEM (digital elevation model) data. Slope map was produced from this DEM from DEM to slope conversion process. The third data is geological map produced by Geological Agency of Indonesia. This map was used as a basis of lithology and soil types information. The last data is annual precipitation data (rainfall data) obtained from BMKG. The flowchart was presented in Figure 2.

Following the SNI No 13-7124-2005 and revised version No 201/KEP/BSN/9/2016 (Indonesian National Standard) for landslide mapping from satellite data (BSN 2005; BSN 2016) and BRR Aceh Nias (National Agency for Rehabilitation and Reconstruction) four landslide main factor above then weighting it based on its contribution for landslide

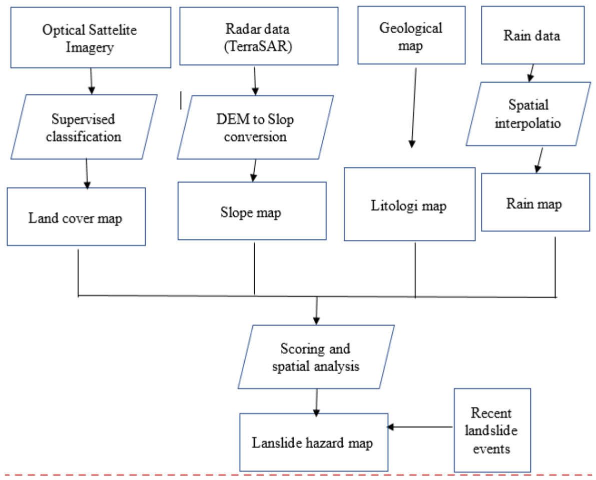

Figure 2 Flowchart

(Bayuaji, Nugraha, and Sukmono 2016; Paripurno, E.T., Theml, Sven., Darsoatmodjo, Nurwadjedi, Tohari, Santoso, Pawitan, Rehmann, Kuntjoro GP, Syamsudin, J., Suryadi, I., Vatvani, D., Marchand, M., Jansen, D., Waryono, D., Solichin, Adiningsih, S.E., Radjab, F.A, Amhar, F., Darmawan 2008). Slope and Lithology were 30%, other parameters (landcover and precipitation) were 20%. Each parameter than classified and indexed based on its vulnerability as presented in Table 1.

Slope was classified into four classes: Low (0%-8%), Moderate (8%-25%), High (25%-40%) and Very high (40%-100%) with the index of 1, 2, 3 and 4, respectively. Precipitation was classified into three classes: < 2000 mm/yr, 2000-3000 mm/yr, >3000 mm/yr with the index of 1, 2 and 3. In this area, the precipitation is about 1500 mm/yr. For land cover, it was classified into: Cloud, Waters, Rice fields, Forest, Settlement and Plantation area with the index of 0, 0, 1, 1, 1 and 2, respectively. The last parameter is lithology; it was classified based the geological layer in the geological map. All parameters then converted into a vector format and spatially process by union function in ArcGIS by considering the weight factor for each parameter with the LSI (Landslide index) value ranged from 0-3.5. The final stage of this process is performing classification based landslide index and regrouping all polygon into four classes: Low, Moderate, High and Very High as presented in

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Table 2.

The LSI is related to landslide hazard map that validated using recent landslide event on April 1, 2017.

Table 1 Landslide factor and its indices

Factor		Class	
Slope	30%	0%-8%	1
		8%-25%	2
		25%-40%	3
		40%-100%	4
Precipitation (mm/yr)	20%	< 2000	1
		2000-3000	2
		>3000	3
Landcover	20%	Cloud	0
		Waters	0
		Rice fields	1
		Forest	1
		Settlement	1
		Plantation area	2
Lithology (soil and rock types)	30%	Batu Terobosan	1
		Batuan Gunung Api Wilis	1
		Formasi Jaten	1
		Formasi Kabuh	1
		Formasi Mandalika	1
		Formasi Wonosari	1
		Formasi Wuni	1
		Alluviums	2
		Endapan Alluvium	2
		Morfonit Dangean	3
		Morfonit Ngebel	3
		Morfonit Sedudo	3
		Morfonit Tangjungsari	3
		Morfoset Jeding Patukbanteng	3
		Morfosit Argacala	3

Table 2 LSI and vulnerability

LSI		Vulnerability
0	0.875	Low
0.875	1.75	Moderate
1.75	2.625	High
2.625	3.5	Very High

3. RESULT AND DISCUSSION

A land cover map generated from Sentinel 2A satellite data was presented in Figure 3. The entire image might not be indicated in a limited space because of the large area of study and the detail of information. Thus, Figure 3 was the sample of a small area of study only. In general, all image pixels were classified into Cloud (white color, no ground information if cloud exists), Waters, Rice fields, Forest, Settlement, and Plantation area. In Figure 3, the area was dominated by a mixture of rice field and scattered settlement.

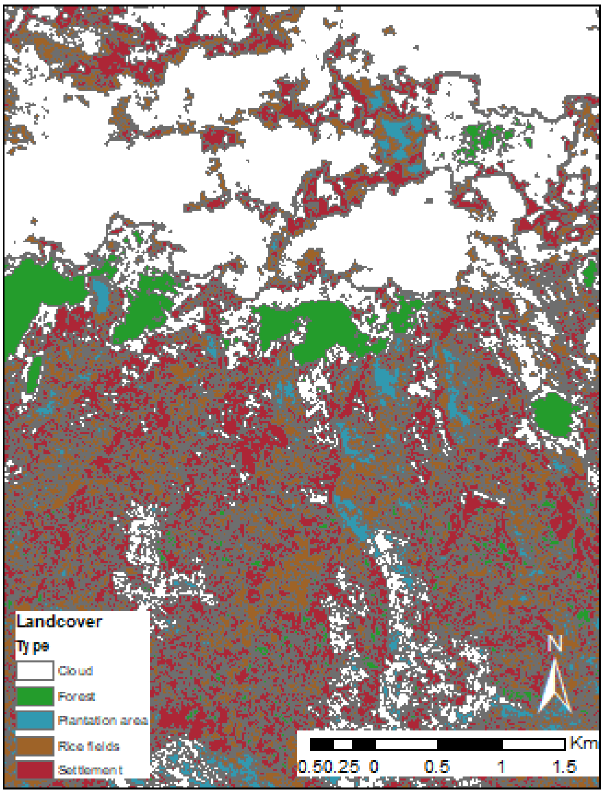

Figure 3 Landcover

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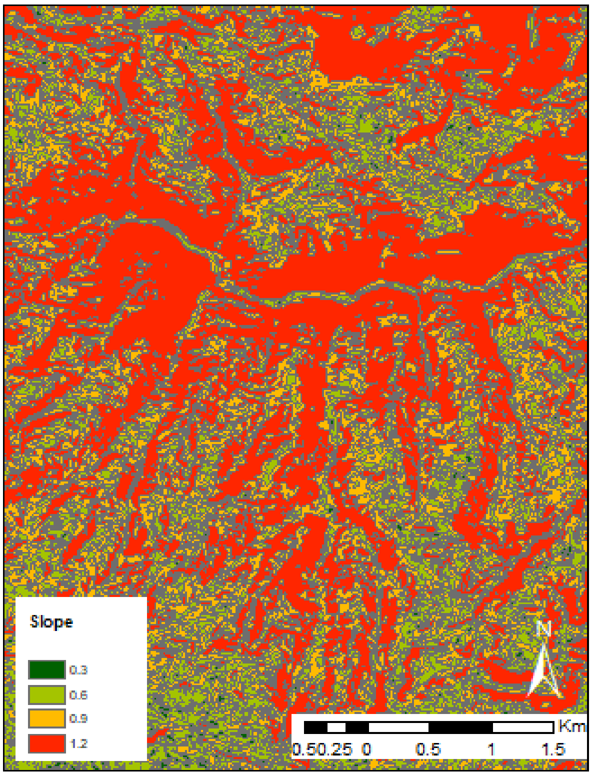

Figure 4 Slope Map

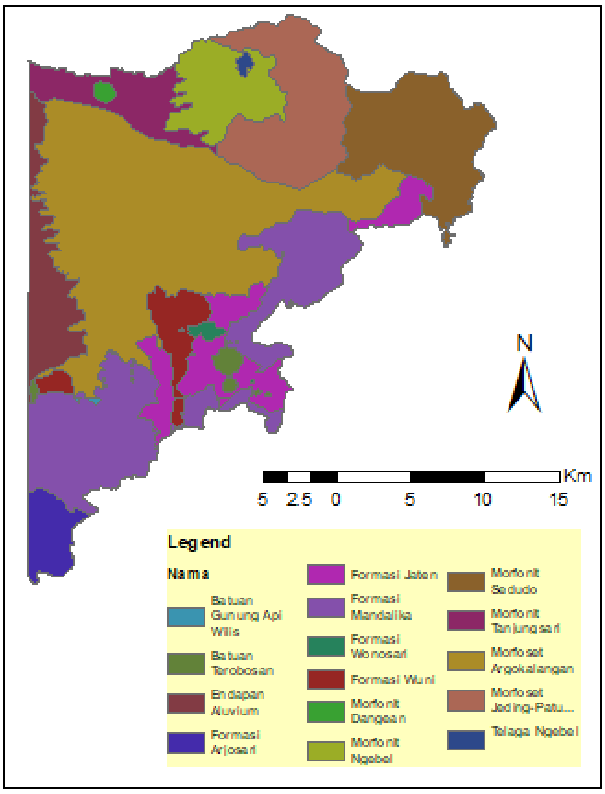

Figure 5 Lithological Map

Figure 4 is a slope map. This map was generated from a high accuracy DEM (terrain elevation data) and classified based on the slope of the terrain. Red color means the steepest hill with the slope value ranged from 40% to 100 %. This class also dominant in north-eastern part of study area. Figure 5 is a lithological map contained different types of soil and stone. Morfoset (morphocet) and morfonit (morphonit) were dominant in this area. Three landslide factors above (Figure 3-5) as well as precipitation data (not drawn here, no local rain gauge station in this area. The average one from the nearest station was used), were spatially analyzed using ArcGIS by considering the weight factor for each parameter.

The LSI map was presented in Figure 6 and classified based on the LSI index (related to its vulnerability as given in Table 2). Figure 6 showed the landslide hazard in East Ponorogo. Moderate and High vulnerability were dominant. Dark color means the polygon of the various class was too small and scattered. Very high vulnerable class (red color) could not be seen because the area was too small and surrounded by a sizeable area of another polygon. Thus, the map was zoomed-in to maximize the visibility of red area pixels exemplified in Figure 7. *Please see Appendix 1 for more detail map.*

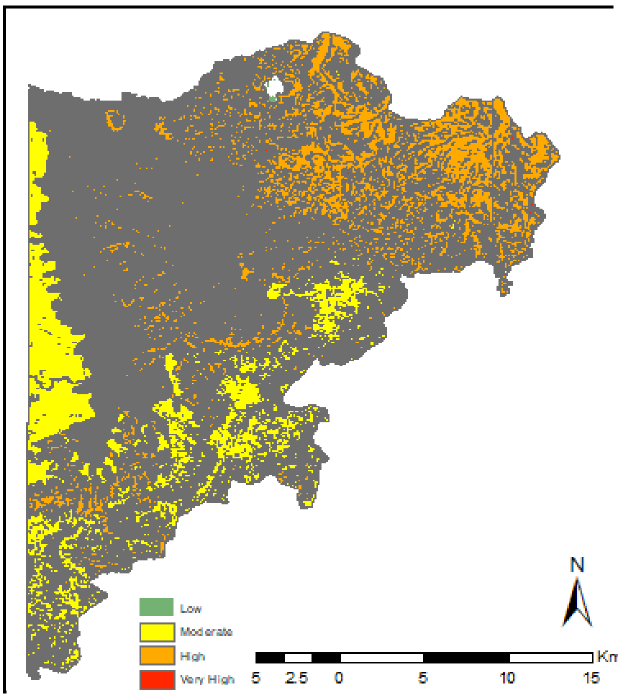

Figure 6 Landslide Index

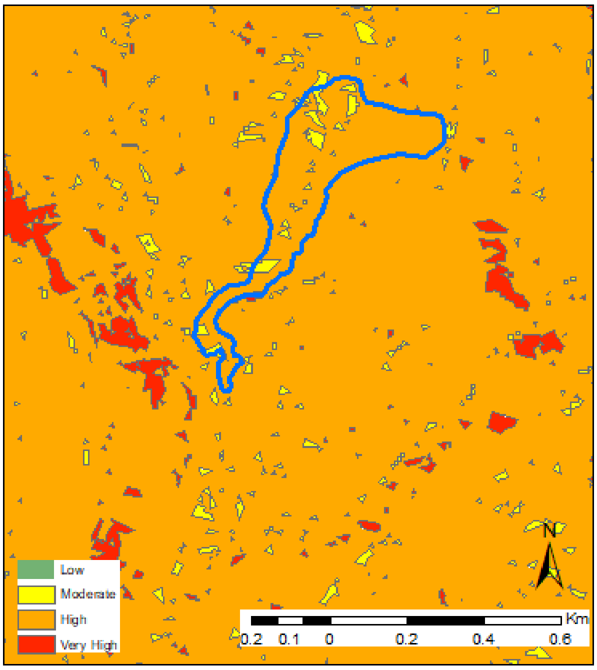

Figure 7 Zoomed area and Validation

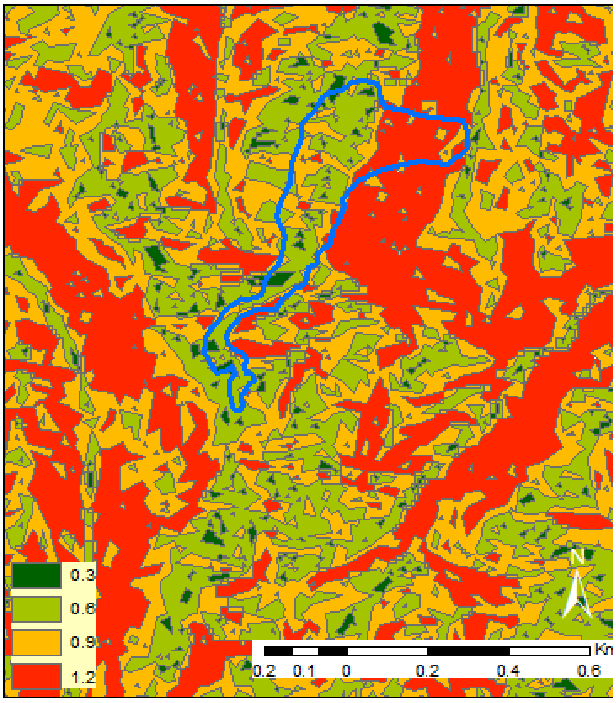

Figure 8 Slope and Recent Landslide

Furthermore, a landslide hazard map in Figure 6 was validated with recent landslide event occurred on April 1, 2017 (Figure 7). A polygon data of landslide area made from a field survey and UAV-based mapping was overlaid as a blue polygon. It can be seen that the landslide area was on the orange and yellow area of LSI map (it should be happened in the red area). It was indicated that the disaster occurred in moderated and highly vulnerable area (not very high one). An analysis was performed to investigate the discrepancy by overlying the landslide hazard map (or LSI map) with a slope map as presented in Figure 8. The north-east area of landslide was on the steepest slope that reported as the starting point of April 1's landslide. It was indicated the weight of each landslide parameter as in Table 1 should be adjusted by increasing the factor of slope data.

The LSI map was created from 4 main parameters that could be grouped based on its updating time: a) long period: slope map, lithological/ geological map; b) medium period: land cover map, and c) short period: precipitation data. Land cover map could be generated at least twice a year (based on the season), while precipitation needs monthly data. By updating its medium and short period data, the LSI map could be updated monthly. Considering data distribution time to public society, being a web-based GIS service could be worth.,

4. CONCLUSION

A new and high spatial resolution of landslide hazard map has been created by utilizing the data recorded from satellite (TerraSAR data and Sentinel 2A) as well as a geological map and precipitation data. By updating a weighting factor for each parameter based on landslide event over the area of study, more accurate map could be created using available data. Thus, this landslide-hazard map becomes a part of the recommendation for spatial planning that should be implemented by the local government.

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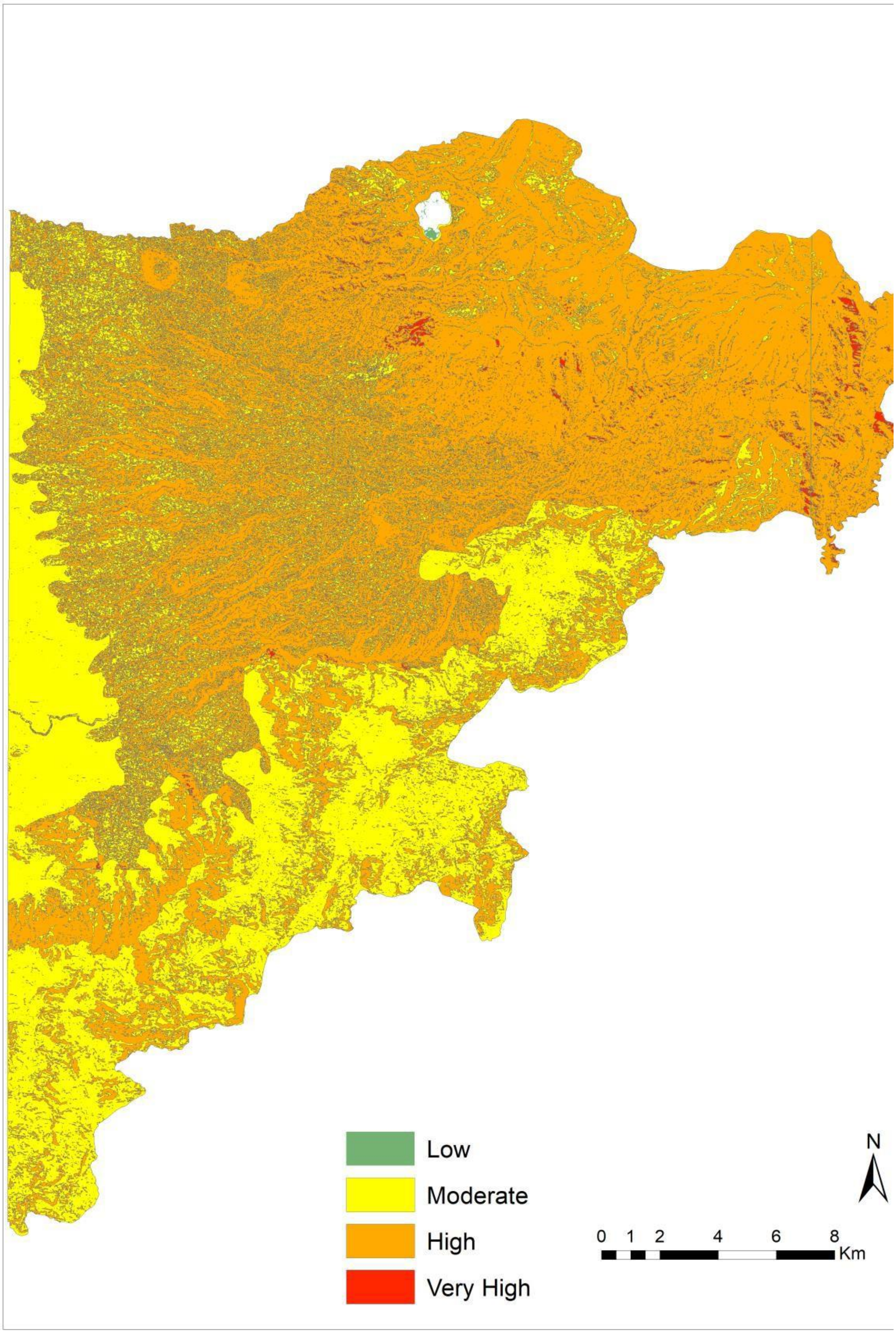
APPENDIX 1: Full Landslide Hazard Map



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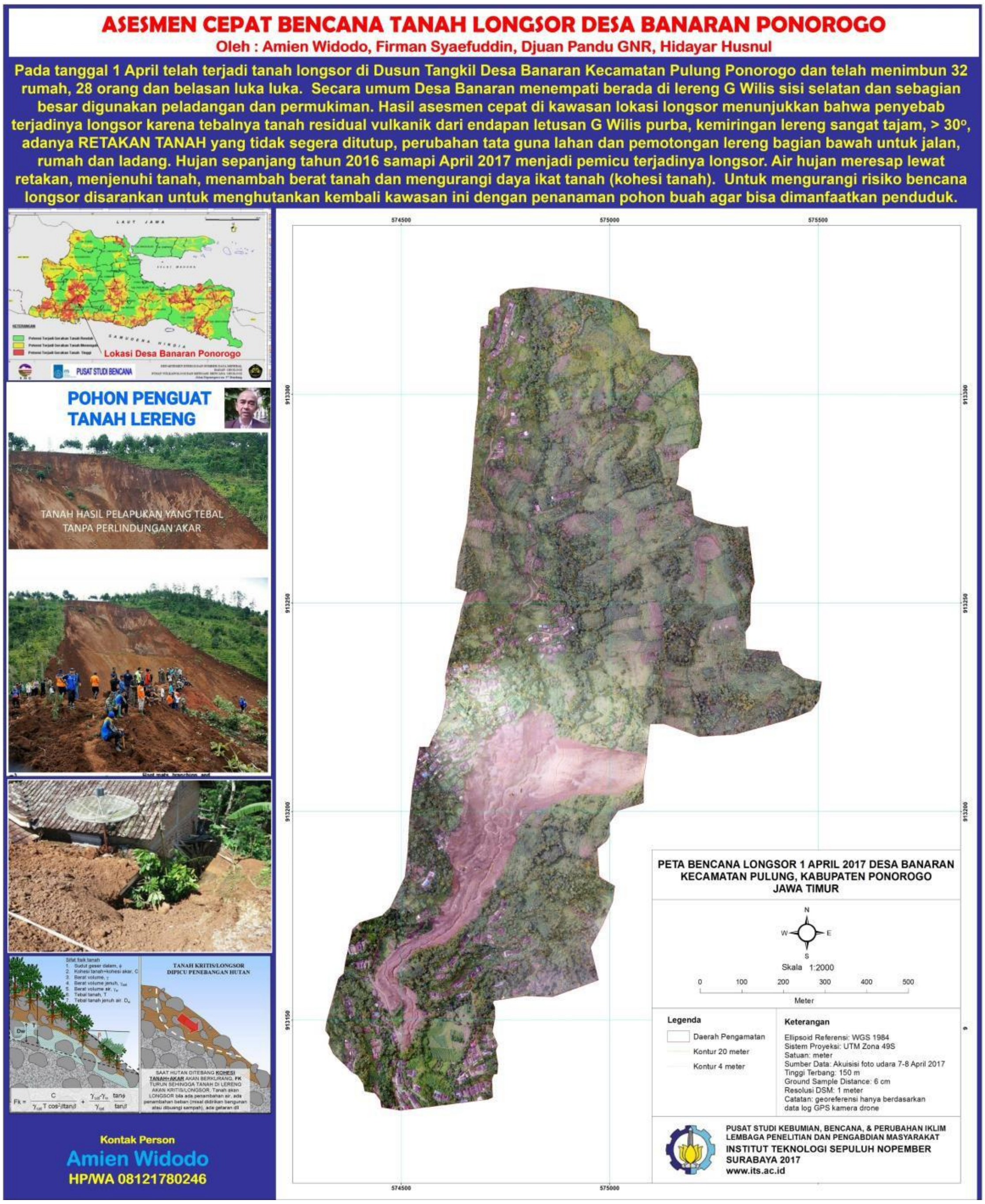
APPENDIX 2: Rapid assessment of landslides in Banaran, Ponorogo by ITS's team



APPENDIX 3: Field survey