Multi-Disaster Risk Analysis of Klaten Regency, Central Java, Indonesia

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ABSTRACT

Klaten Regency is located in Central Java Province, Indonesia, ranked as 19th most susceptible area in Indonesia. Among of many disasters those take place in Klaten are floods, landslides, and earthquake, which cause damages and loss of lives. Unfortunately, some areas in Klaten Regency are also very vulnerable to the disasters that often contribute severe damage and loss. This paper presents result of risk analysis due to floods, landslides and earthquake disaster at Klaten Regency. Several parameters or criteria are utilized to describe the level of the disaster intensities. The flood susceptibility parameters are the Topographic Wet Index (TWI), Normalized Difference Vegetation Index (NDVI), permeability and roughness, as proposed by Kafira, et al. (2015). The landslide susceptibility are the geology, slope, elevation, distance from fault, distance from rivers, rainfall and land use, as suggested by Thearith (2009) whereas the earthquake susceptibility was referred to FEMA P-154 by using the S_s and S_1. The vulnerability and risk analysis are carried out by referring to the parameters as stipulated by the Chief Regulation of the National Board of Disaster Management No.2 Year 2012 (*Perka Badan Nasional Penanggulangan Bencana-BNPB*), concerning the parameters being used for the vulnerability analysis, i.e. population density, poverty ratio, land use, and level of Gross Regional Domestic Product. Further spatial analysis of the risk performs the multi-disaster risk map as a combination between the floods, landslides and earthquake disaster risk in Klaten Regency. The established multi-disaster risk map shows the risk level in the Klaten Regency, i.e., 16.31% at very low risk, 33.01% at low risk, 34.49% at medium risk, at 14.22% high risk and 1.97% at very high risk.

Keyword: Susceptibility, vulnerability, multi-disaster risk, national regulations

1 GENERAL DESCRIPTION

1.1 Background

Klaten Regency is located in the southern area of Java Island and considered very vulnerable to disasters such as floods, landslides, earthquake, volcanic eruption and draughts. Based on the Indonesian Disaster Risk Index, Klaten Regency is ranked as 19th of most susceptible area in the country with risk index of 106 or high category (National Board for Disaster Management, 2011). The 5.9 magnitude of tectonic earthquake on 27 May 2006 has caused 29,989 houses collapsed and 69,984 houses were heavily damage. The loss as caused by flood occurrence in 2014 was approximately IDR 262,000,000, whereas from landslide occurrence in the same year was approximately IDR 424,000,000 (National Board for Disaster Management, 2015). The high intensity of disaster susceptibility and

vulnerability of some area in the Klaten Regency has made the authority to realize the necessity of providing disaster risk information system for the whole regency. Among of many types of disasters those may take place in Klaten Regency, the floods, landslides and earthquake disasters are considered in the multi-disaster risk analysis.

1.2 Susceptibility, Vulnerability, and Risk

Susceptibility is defined as a hazard that may take place in a certain frequency (probability) and location (National Board for Disaster Management, 2012). Hazard analysis is an initial step of susceptibility analysis comprising of determination approach (through estimation and familiarization the tendency) of the disaster (Westen, 2005). The governing equation of the susceptibility analysis is shown in the Equation (1) as follows.

$$SI = \sum_{i=1}^{n}\left(W_{s,i} \times S_{s,i}\right) \qquad (1)$$

where SI is the susceptibility index, $W_{s,i}$ is the weight of susceptibility parameter at i, and $S_{s,i}$ is the score of susceptibility sub-class parameter at i.

The vulnerability is a characteristic of a group or individual situation that affect their capacity to anticipate, cope with, resist, and recover from the impact of natural disaster hazard (Blaikie, et al., 1994). The equation that is used to analyse vulnerability level of disaster is explained in Equation (2) as follows.

$$VI = \sum_{i=1}^{n}\left(W_{svi} \times S_{svi}\right) \qquad (2)$$

where VI is the vulnerability index, $W_{s,i}$ is the weight of vulnerability parameter at i, and $S_{s,i}$ is the score of vulnerability sub-class parameter at i.

Based on the National Board for Disaster Management (*Badan Nasional Penanggulangan Bencana, BNPB*) Chief Regulations No.4 Year 2008 (National Board for Disaster Management, 2008), disaster risk is loss potency that induced by disaster on an area and time period in the form of death, injury, illness, threatened lives, the loss of sense of security, evacuation, wealth damage or loss, and disruption of community activity. In determining the hazard risk level zone, the susceptibility map and vulnerability map were established utilizing Equation (3) as suggested by Sopheap (2007).

$$Risk = (0.7 \times SI) + (0.3 \times VI) \qquad (3)$$

where $Risk$ is the risk index.

2 SUSCEPTIBILITY PARAMETERS

2.1 Flood Susceptibility Parameters

Flood is a phenomenon of increasing water discharge that occur in the river, if the water discharge increases but the river capacity could not convey the discharge, the river water would overflow out from the river (Juandi, 2007). The new technology availability in measuring the surface height (such as the Global Positioning Systems/GPS, Synthetic Aperture Radar/SAR, and radar) has helped in providing the topographical data in high resolution (Manfreda, et al., 2011). By the increasing Digital Elevation Model (DEM) data availability, there has been strong suggestion to develop hydro geomorphology model that based on DEM (Nardi, et al., 2006; Samela, et al., 2016). The *Topographic Wet Index* (*TWI*), *Normalized*

Difference Vegetation Index (*NDVI*), permeability and roughness are parameters for describing the flood susceptibility (see Table 1). The *TWI* was the derived data from DEM in the steady condition, and used the accumulation function of flow and slope (Moore, et al., 1993 in Yang, et al., 2005). Topography is an important factor in determining the spatial pattern of saturated areas, as the key to understand soil diversity and the hydrology process the watershed has went through. The *TWI* has been widely used in determining the wetness in the watershed, by assuming that the surface water level height comply its surface gradient (Grabs, et al., 2009).

Table 1. Score and weight of flood susceptibility

Parameter	Score	Weight
Topographic Wet Index (*TWI*)		
-2 to 6.6	1	
6.6 to 8.57	2	
8,57 to 11,16	3	0.584
11.16 to 14.56	4	
>14.56	5	
Normalized Difference Vegetation Index (*NDVI*)		
-0.23 to -0.005	1	
-0.005 to 0.19	2	
0.19 to 0.5	3	0.065
0.5 to 0.63	4	
>0.63	5	
Permeability level (Geology)		
High (Pendul Diorite, Dacite, Mandalika Rck.)	1	
Medium (Merapi volcanic rock, Wonosari Punung F[1]., Wungkal Mt.F[2]., Old Merapi Rck[3]., Semilir F., Kebobutak F.)	2	0.248
Slow (old Alluvium, Alluvial deposit)	3	
Roughness level		
Forest, bushes, moor, farm		
Rocky surface, grasses, shoal		
Freshwater, swamp, forest		0.103
Rain fed/irrigated field, farm		
Building, settlement		

[1]F = Formation
[2]Mt. F = Mountain Formation
[3]Rck = Rocks

The *TWI* equation was developed by Beven and Kirkby (1979) on Equation (4).

$$TWI = ln\left(\frac{\alpha}{\tan\beta}\right) \qquad (4)$$

where α is slope, and β is the flow accumulation on the upslope.

The vegetation density condition, surface moisture, and the object brightness recorded in the image could be identified from the digital interpretation of the remote sensing image data of Landsat 8 (Jamil, 2013). The *NDVI* is image calculation used to find the best greenness level of vegetation area. The *NDVI* is a mathematical combination of red band and *NIR (Near-Infrared Radiation)* band which has been long used as the indicator of vegetation condition and existence (Lillesand & Kiefer, 1993) on the Equation (5).Image used in this study was the Landsat 8 image on June 22, 2016 that was downloaded from USGS.

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (5)$$

where *NIR* is the *Near-Infrared Radiation* for a cell (Band 4) and *Red* is the red band for the cell (Band 3).

Another important factor other than topography that affects the flood susceptibility is permeability of soil/rock arrangement of the area based on its composition (Kafira , et al., 2015). The permeability is a measure of ease of the water to move, depend on the pores size of the rock/soil density and types (Widiyatmoko, et al., 2015).

2.2 Landslides Susceptibility

Landslide susceptibility is a function of slope, geology, elevation, distance from fault, distance from river, rainfall, and land use as shown in Table 2 (Kafira , et al., 2015). According to Foumelis, et al (2015), one of the most influential factors in determining landslide susceptibility is slopes, which gives direct effect to the shear stress in an unconsolidated soil, and indirectly influence the surface water velocity or the saturation degree. Slope parameter is often used in preparation of landslide susceptibility map because it is directly related to the slope stability (Pratiwi, et al., 2016; Khodadad & Dong-Ho, 2015; Mouchel, 2013; Pourghasemi, et al., 2012; Gemitzi, et al., 2011, Thearith, 2009; Sopheap, 2007; Foumelis, et al., 2004; Koukis & Ziourkas, 1994). The land elevation influences landslide occurrence, in which the land with high elevation usually consists of cohesive formation such as limestone, where high rainfall may trigger the landslide occurrence (Kouli, et al., 2010). Land elevation is an inducing factor of landslide, for it may control some geological and geomorphological processes (Gritzner, 2001).

Table 2. Score and weight of landslide susceptibility

Parameter	Score	Weight
Geology		
Merapi volcanic rocks, Dacite, Old Merapi volcanic rocks, Mandalika Formation, Alluvial deposit	1	
Pendul Diorite, Wonosari Punung Formation, Gamping Wungkal Formation	2	0.365
Semilir Formation	3	
Kebobutak Formation, old Alluvium	4	
metamorphic rocks	5	
Slope		
flat (<5°)	1	
sloping (5-15°)	2	
quite steep (15-30°)	3	0.167
steep (30-45°)	4	
very steep (>45°)	5	
Elevation		
<21 m	1	
21-25 m	2	
25-32 m	3	0.131
32-47 m	4	
>47 m	5	
Distance from fault		
>2000 m	1	
1000-2000 m	2	0.112
<1000 m	3	
Distance from river		
>200 m	1	
100-200 m	2	0.124
<100 m	3	
Rainfall		
<1900 mm/year	1	
1900-2000 mm/ year	2	
2000-2100 mm/ year	3	0.051
2100-2200 mm/ year	4	
>2200 mm/ year	5	
Land use		
Forest, bushes	1	
Rocky surface, grasses, shoal	2	
Freshwater, pond, swamp	3	0.049
Building, settlement	4	
Rain fed/irrigated field, farm	5	

It is mentioned that the probability of landslide occurrence increases with distance proximity from fault, which affects not only the rock material structure, but also the permeability of the land and furthermore contributes slope instability (Kanungo, 2006). The distance proximity from river or drainage channel is an important factor in controlling the landslide (Gokceoglu and Aksoy in Foumelis, et al., 2004). This is because the change in soil formation which is caused by the erosion may lead to landslide, similarly that of

the high infiltration level in the slope adjacent to the river. Rainfall become a consideration in determining the landslide susceptibility because rain makes the rock/soil condition to be more saturated, which potentially lead to landslide (Khodadad & Dong-Ho, 2015). The land utilization is a human activity-related factor that influences the landslide occurrence (Gemitzi, et al., 2011). The land utilization may also be a triggering factor for the landslide occurrence (Montgomery, et al., 2000), particularly the woody vegetation where strong and big root may influence the slope stability.

2.3 Earthquake Susceptibility

Earthquake is vibrations that detected from the earth surface which is a result from seismic waves caused by sudden release of the energy that sourced from inside the earth (Hunt, 2007). The susceptibility level of earthquake is assumed to be uniform, in case of Klaten Regency is on the moderate level of Peak Ground Acceleration (PGA) at 0.25 to 0.70g (National Board for Disaster Management, 2012). This study referred to the FEMA P-154 (FEMA, 2015) with parameter S_S and S_1 as shown in Table 3.

Table 3. Score and weight of earthquake susceptibility

Earthquake-prone zone	Classification of response spectrum value		Score	Weight
	S_S (g)	S_1 (g)		
Low	<0.25	<0.10	1	
Medium	0.25-0.50	0.10-0.20	2	
Quite high	0.50-1.00	0.20-0.40	3	1
High	1.00-1.50	0.40-0.60	4	
Very high	>1.50	>0,60	5	

There are two important parameters in earthquake consideration, i.e. the S_S and S_1 parameters that are determined based on response spectrum velocity of 0.2 second and 1 second in the seismic ground motion with 2% probability of exceedance (Badan Standardisasi Nasional, 2012). Values of S_S and S_1 are calculated based on the attenuation function or ground motion prediction equations which are considered appropriate in describing the seismicity zone. The S_S and S_1 response spectrum velocity values are obtained by entering the coordinate point to the Research and Settlement Development Centre of Ministry of the Public Works (Ministry of Public Works and Housing, 2011)

2.4 Multi-disaster Vulnerability

The vulnerability is divided into two categories, i.e. the earthquake, and flood and landslide. Rainfall is the important triggering factor affecting the flood and

landslide occurrence (Tauhid, 2017). Therefore, the vulnerability weights for flood and landslide are assumed to be similar (see Table 4).

Table 4. Score and weight of multi-disaster vulnerability.

Parameter	Score		Weight	
	F&LS[1]	EQ[2]	F&LS[1]	EQ[2]
Social Vulnerability				
Population density (60%)				
<500 people/km²	1	1		
500-1000 people/km²	2	2		
>1000 people/km²	3	3	0.40	0.40
Poverty ratio (40%)				
<20%	1	1		
20-40%	2	2		
>40%	3	3		
Economy Vulnerability				
Gross Regional Domestic Product Level				
<IDR 100 million				
IDR 100-300 million			0.25	0.30
>IDR 300 million				
Physical/Environment Vulnerability				
Land Utilization				
Rocky surface, grasses, shoal, shrubs	1	0		
Freshwater, pond, swamp	2	0	0.35	0.30
Farm, forest, rain fed/irrigated field	2.5	0		
Building, settlement	3	3		

[1]F&LS = Flood and Landslide
[2]EQ = Earthquake

2.5 Multi-disaster Risk

The multi-disaster risk determines all risks from several hazards by considering the interaction between hazard probability and vulnerability which involve multi-hazard and multi-vulnerability (Carpignano, et al., 2009 in Gallina, et al., 2015). The development of multi-disaster risk map should be derived from the calculation of risk indexes of all threats as shown in Table 5 (National Board for Disaster Management, 2012). It is seen from Table 5 that the flood, landslide, and earthquake have the same weight, of 0.1064.

The weights of flood, landslide, and earthquake used simple mathematical calculation as shown in Equation (6). The weights were 0.35 for flood and landslide, and 0.30 for earthquake.

Multi-disaster Risk = (0.35×*flood risk*)

(0.35 × *landslide risk*) + (0.30× *earthquake*)   (6)

Table 5. Multi-threat Weight (National Board for Disaster Management, 2012)

No	Threat Type	Weight
1	Flood	0.1064
2	Earthquake	0.1064
3	Tsunami	0.0638
4	Building and Settlement Fires	0.0638
5	Draught	0.0638
6	Extreme weather	0.0638
7	Landslide	0.1064
8	Volcano eruption	0.1064
9	Abrasion and extreme waves	0.0638
10	Land and forest fire	0.0638
11	Technology failure	0.0638
12	Social conflict	0.0638
13	Epidemic and disease outbreaks	0.0638

3 RESULTS AND DISCUSSION

3.1 Flood Disaster Susceptibility

The combination result of each flood susceptibility parameter with Equation (1) and its classification seven categories according to Natural Breaks (Jenks) method is shown in Appendix 1. At least 5% of the area within each district is affected by high susceptibility on flood disaster (see Figure 1(a)). It can be seen from Figure 1(a) that several districts, i.e. Wedi, Cawas, Trucuk, Gantiwarno, and Karangdowo, are laid on the high and very high susceptibility. This is considered common since these districts are located along the river branch where the slope is very mild.

3.2 Landslide Disaster Susceptibility

Classification that resulted from the combination between the landslide susceptibility parameters five parameters of Natural Breaks (Thearith, 2009) method and Equation (1) shown in Figure 1(b) Appendix 2 performed a sensible classification. Chalkias , et al. (2014) has evaluated the landslide susceptibility classification method, and stated that among the methods, the Natural Breaks (Jenks) is the most effective method. Based on the event data from National Board for Disaster Managemen (2015), most of the location of the event were in medium, high, and very high susceptibility, mostly found in districts of Bayat, Kemalang, Wedi, and Gantiwarno, with weak geological condition and slope condition of >15°. A comparison between Thearith (2009) and Indonesian regulation is presented in Table 6.

The method as proposed by National Board for Disaster Management did not explain the mapping

techniques since it utilized the seismic ground hazard map from the National Geology Agency of Ministry of Energy and Mineral Resources. The landslide susceptibility map according to National Board for Disaster Management (2012) is shown in Appendix 3. Table 7 shows a comparison between the method from Thearith (2009) and National Board for Disaster Management (2012). There are significant differences between each class of the two methods. This may be caused by the condition that the data was very limited (only 2014 and 2015).

Table 6. Comparison on landslide susceptibility classification based on National Board for Disaster Management (2012) and Thearith (2009)

Chief Regulation of National Board for Disaster Management No. 2 Year 2012			
Seismic Ground Hazard Map (Guide from National Geology Agency)	Landslide class classification (3 classes)		
	Low	Medium	High
	Very low – low susceptibility zone	Medium suscepti bility zone	High susceptibility zone
Thearith (2009)			
Geology Slope Elevation Fault Distance River Distance Land Utilization Rainfall	Landslide class classification (5 classes)			

Very Low	Low	Medium	High	Very high
Susceptibility Index Classification with Natural Breaks (Jenks)				
<1.4	1.4-1.6	1.6-1.9	1.9-2.2	>2.2

Table 7. Comparison on classification of landslide affected area from Thearith (2009) and National Board for Disaster Management (2012)

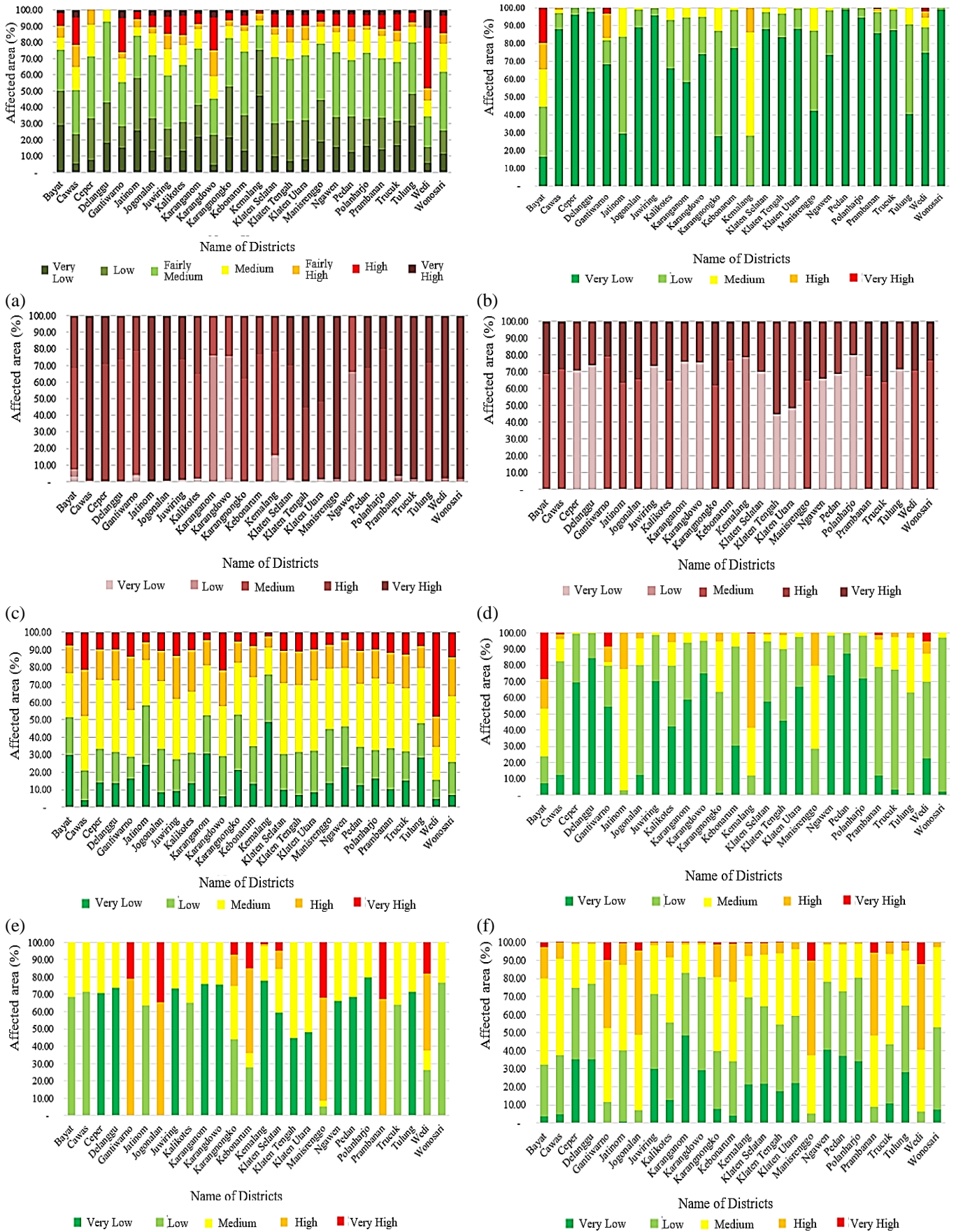| Class	Thearith (2009)		National Board for Disaster Management (2012)	
	Percentage (%)			
Very low	64.51	86.16	69.34	96.41
Low	21.65		27.07	
Medium	9.71	9.71	2.75	2.75
High	2.78	4.13	0.84	0.84
Very high	1.35		-	
Total	100	100	100	100

Figure 1. District-based (a) floods susceptibility, (b) landslides susceptibility, (c) flood and landslides vulnerability, (d) earthquake susceptibility (e) flood risk, (f) landslide risk, (g) earthquake risk, (h) multi-disaster risk

3.3 Earthquake Disaster Susceptibility

The points with highest S_S and S_1 were located in the Cucukan Village, Prambanan District; with each consecutively were 1.426 and 0.524. Meanwhile the points with lowest S_S and S_1 which were 0.772 and 0.321, took place in the Sidoharjo Village, Polanharjo District. The mapping result that was based on the S_S and S_1 (FEMA P-154) are shown in Appendix 4. It can be seen from Figure 1(d) that the most severe damage due to the earthquake in May 27th, 2006 took place at the districts of Prambanan, Gantiwarno, Jogonalan, and Wedi; which was included in the high susceptibility class. The highest number of collapsed house which was 7,292 houses was in the Gantiwarno District, due to its soil condition which was in the soft soil category, where as it caused the amplification of earthquake energy.

3.4 Multi-disaster Vulnerability

The result from combining the parameters of vulnerability map was divided into 5 classes with Natural Breaks referred to National Board for Disaster Management Chief Regulations No. 2 Year 2012. Appendix 5 and 6, and also Figure 1(c) show the affected area (in %) of each district for the flood and landslide vulnerability and for the earthquake vulnerability respectively.

3.5 Flood Risk

The flood risk map in Klaten Regency as shown in Appendix 7 was established from the combination of flood susceptibility (Appendix 1) and multi-disaster vulnerability (Appendix 5) by applying Equation (3). According to Natural Breaks (Jenks) method, the results were classified into five categories, and then the flood risk level in each district is presented in Figure 1(e).

3.6 Landslide Risk

The landslide risk map in Klaten Regency as shown in Appendix 8 was resulted from the combination of landslide susceptibility (Appendix 3) and multi-disaster vulnerability (Appendix 6), applying Equation (3). Same method of Natural Breaks (Jenks) was also utilized, and the risk level of each district is presented in Figure 1(f).

3.7 Earthquake Risk

The earthquake risk map in Klaten Regency as shown in Appendix 9 was resulted from the combination of earthquake susceptibility (Appendix 4) and multi-disaster vulnerability (Appendix 6), applying Equation (3). Figure 1(g) presents the earthquake risk level at each district. It is seen from Figure 1(g) that the riskiest area took place in Bayat district, which is confirmed with 27 March 2006 earthquake occurrence.

3.8 Multi-disaster Risk

The risk maps of flood, landslide, and earthquake were then combined by utilizing Equation (6), and the multi-disaster risk map was obtained (see Appendix 10). Figure 1(h) shows the affected area (in %) of the multi-disaster risk.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The combination of flood risk, landslide risk, and earthquake risk generated a multi-disaster risk map, in which the result was 16.31% has very low risk, 33.01% low risk, 34.49% medium risk, 14.22% high risk, and 1.97% has very high risk. Whereas the very high risk of multi-disaster is found in the districts of Jogonalan, Gantiwarno, Manisrenggo, and Wedi.

4.2 Recommendations

The more detailed descriptions on both susceptibility and vulnerability parameters taking into account the local community perception are still subjects of interests. This is due to the fact that in real practice, the livelihood of the local community may affect the weighting of each parameter and similarly the developed equation. However, such consideration must be initially introduced through some lesson learns those have been took place in the past history.

The susceptibility, vulnerability, multi-disaster risk maps may be dynamics that the frequent update by taking into account the disaster occurrences is advisable.

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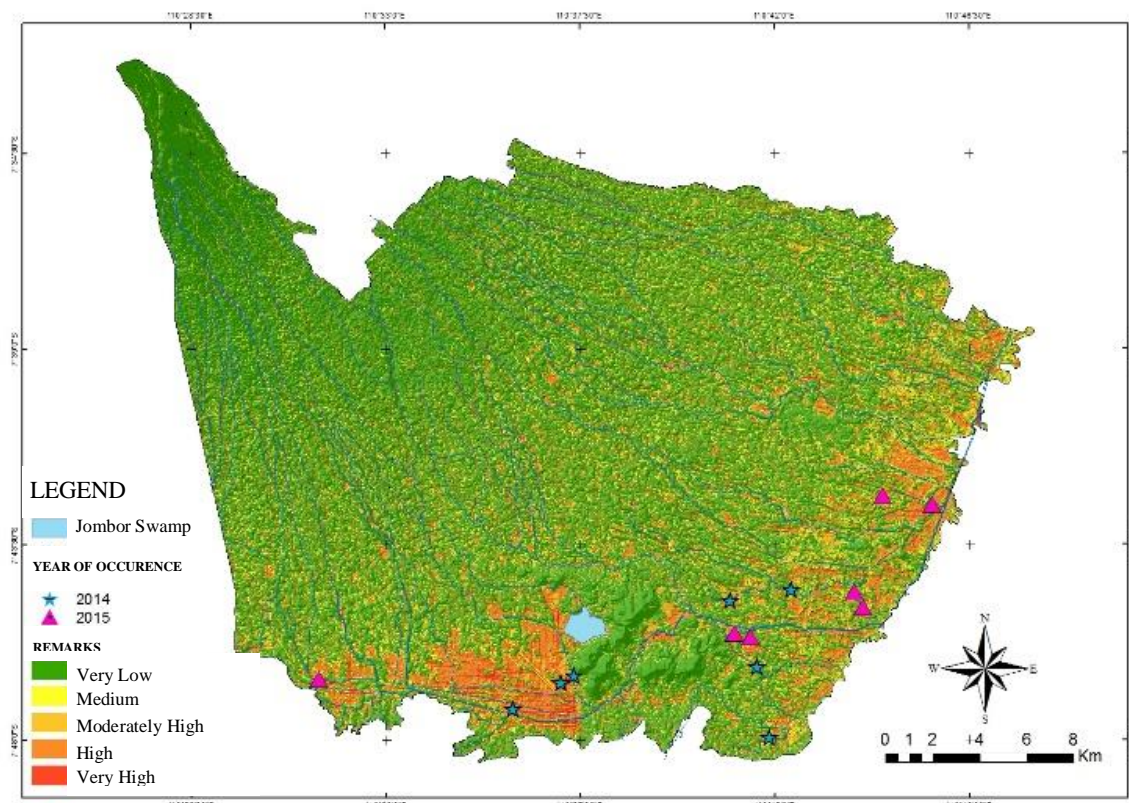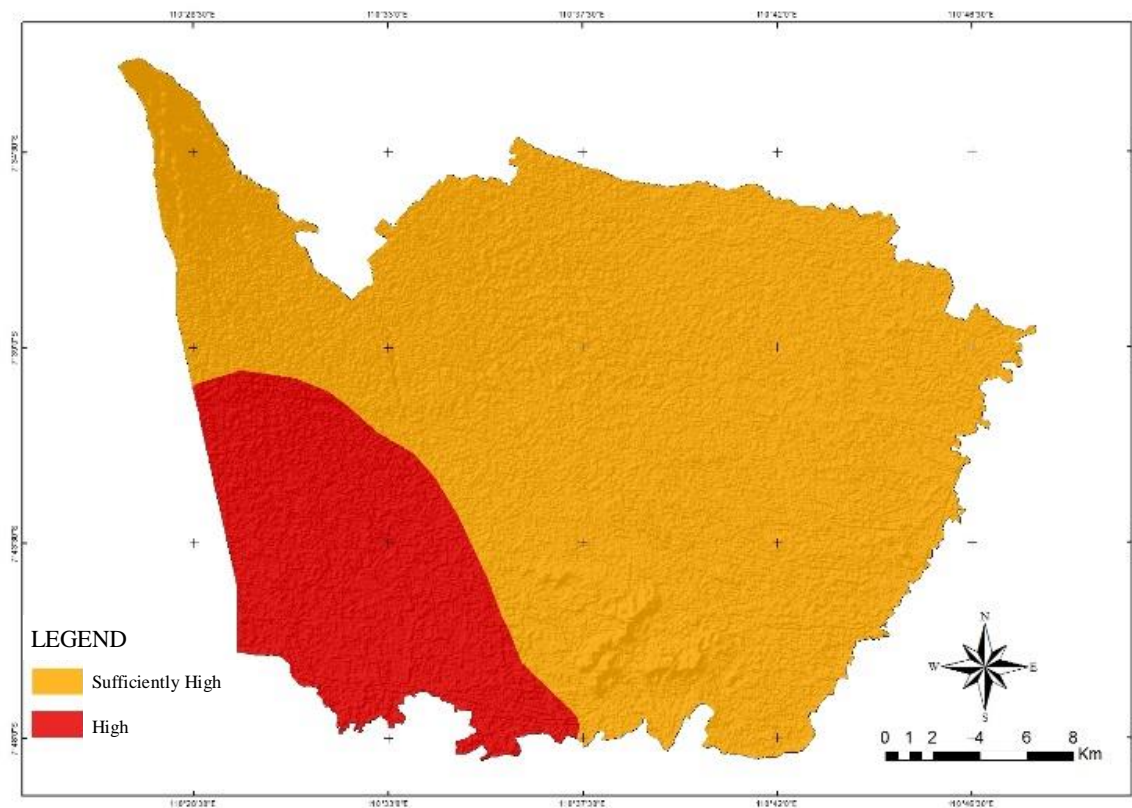
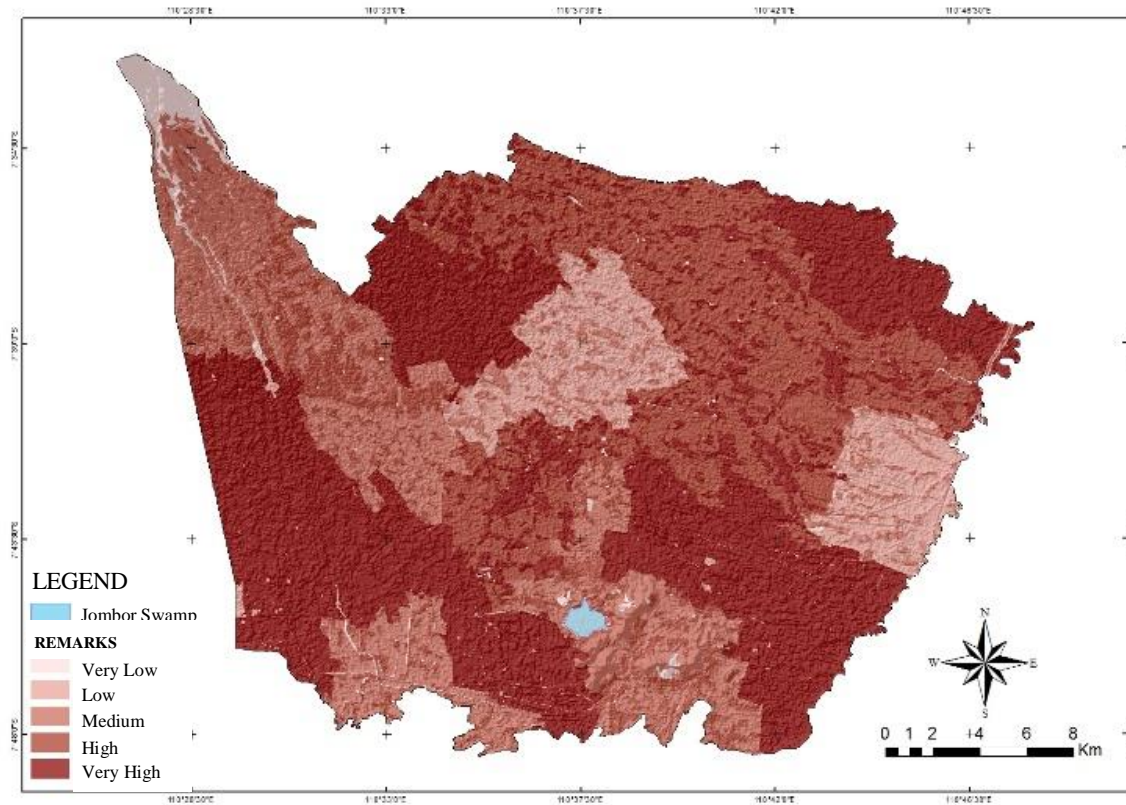Appendix 1. Flood susceptibility map
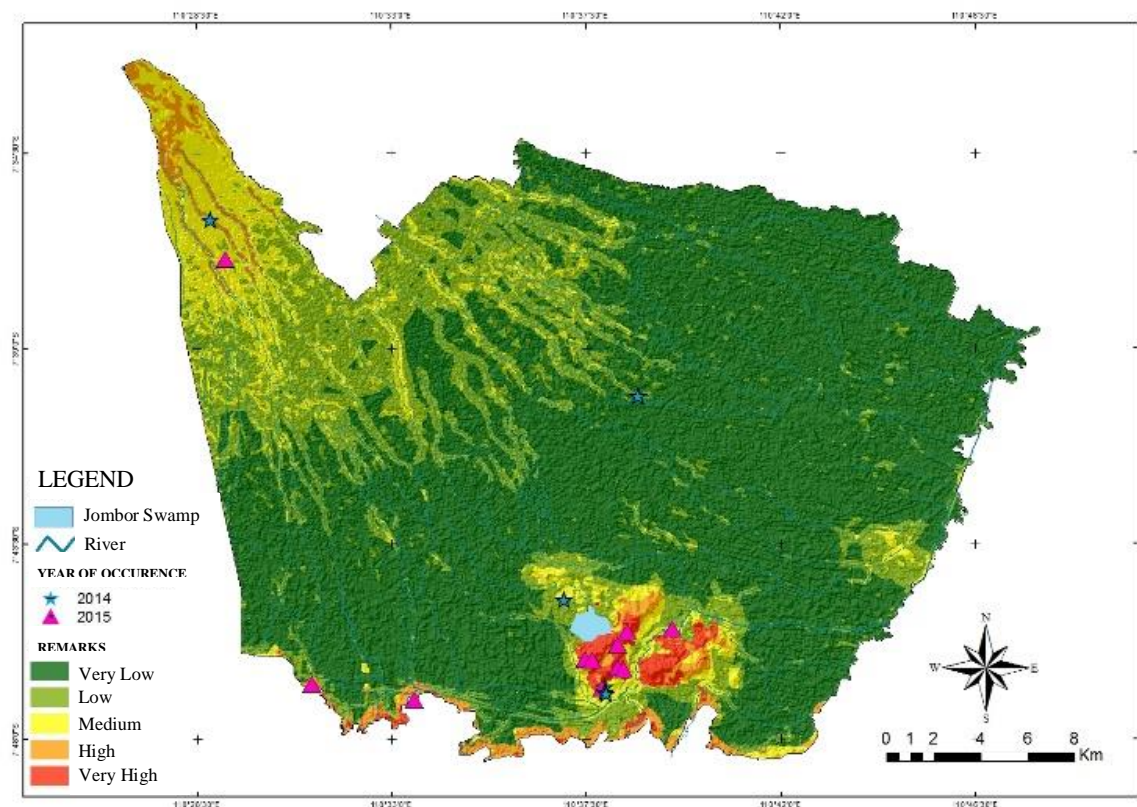
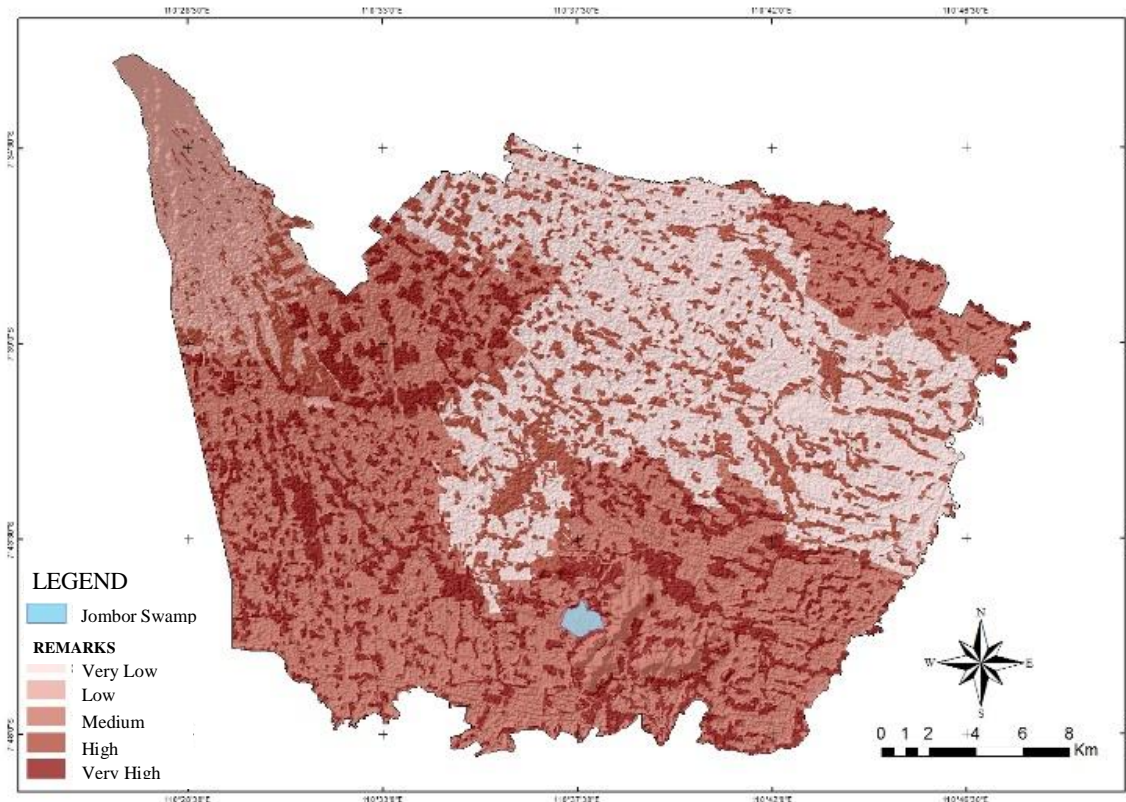Appendix 2. Landslide susceptibility map (Thearith, 2009)
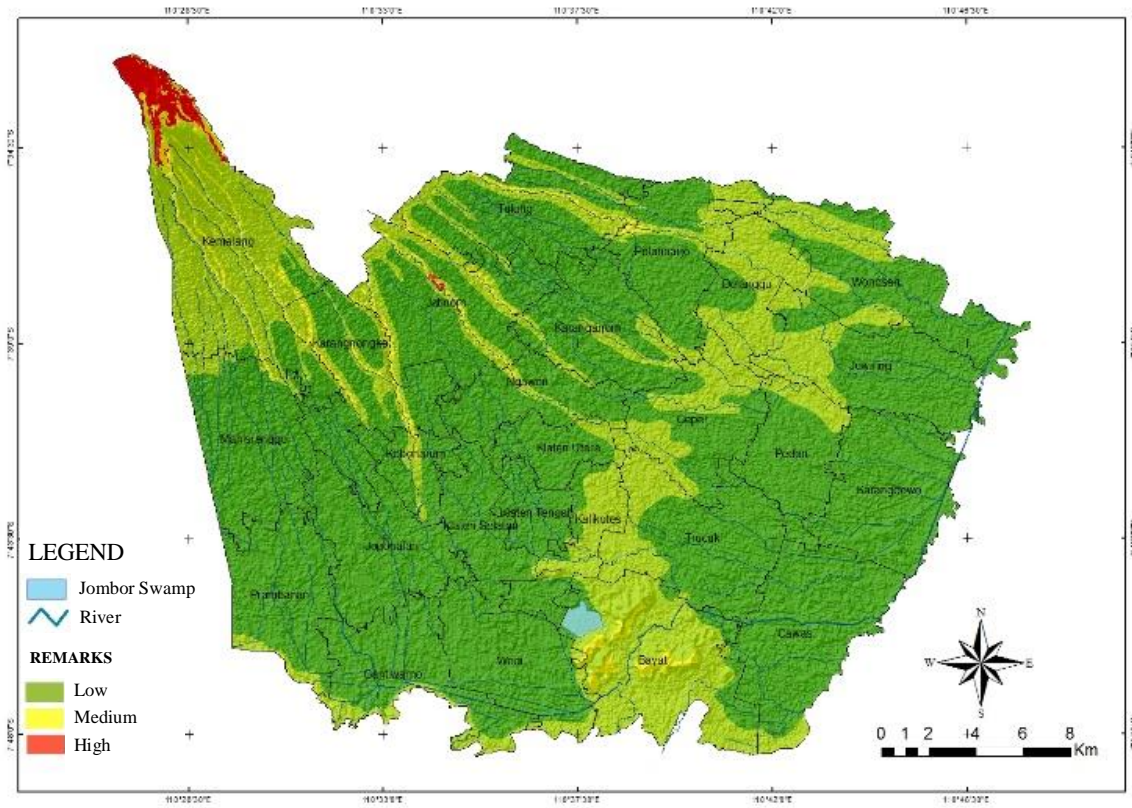
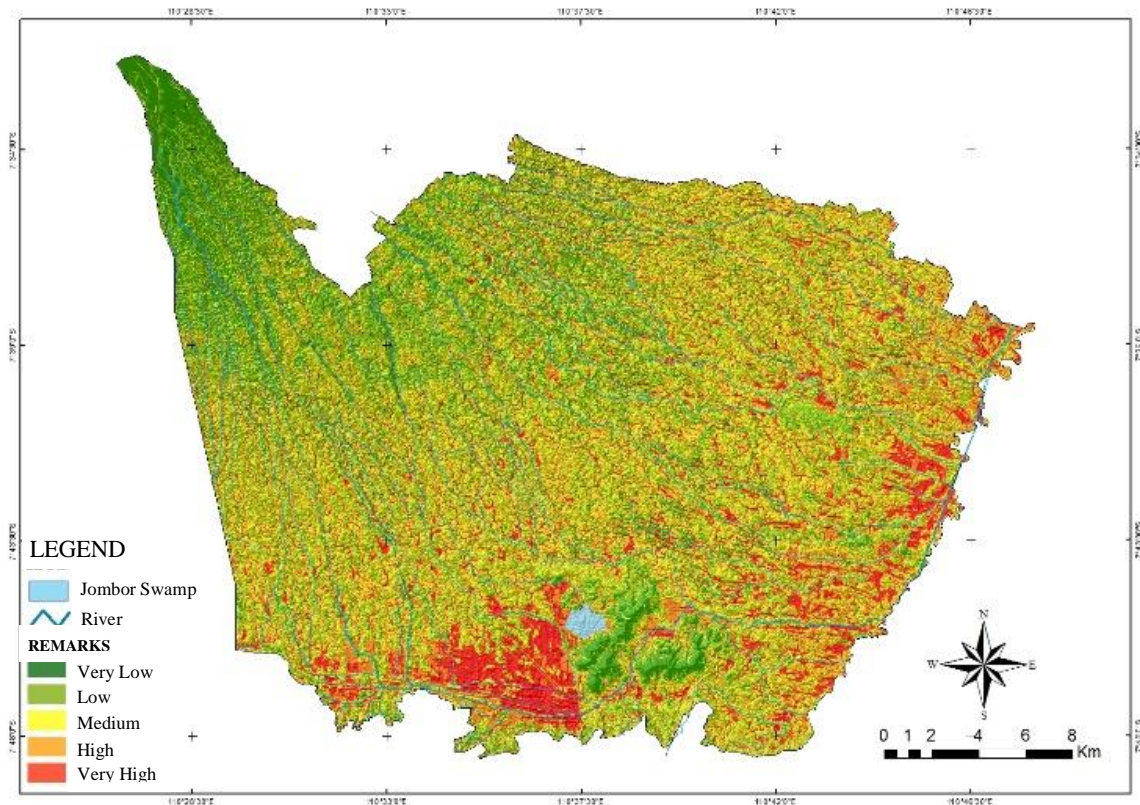Appendix 3. Landslide susceptibility map (BNPB, 2012)
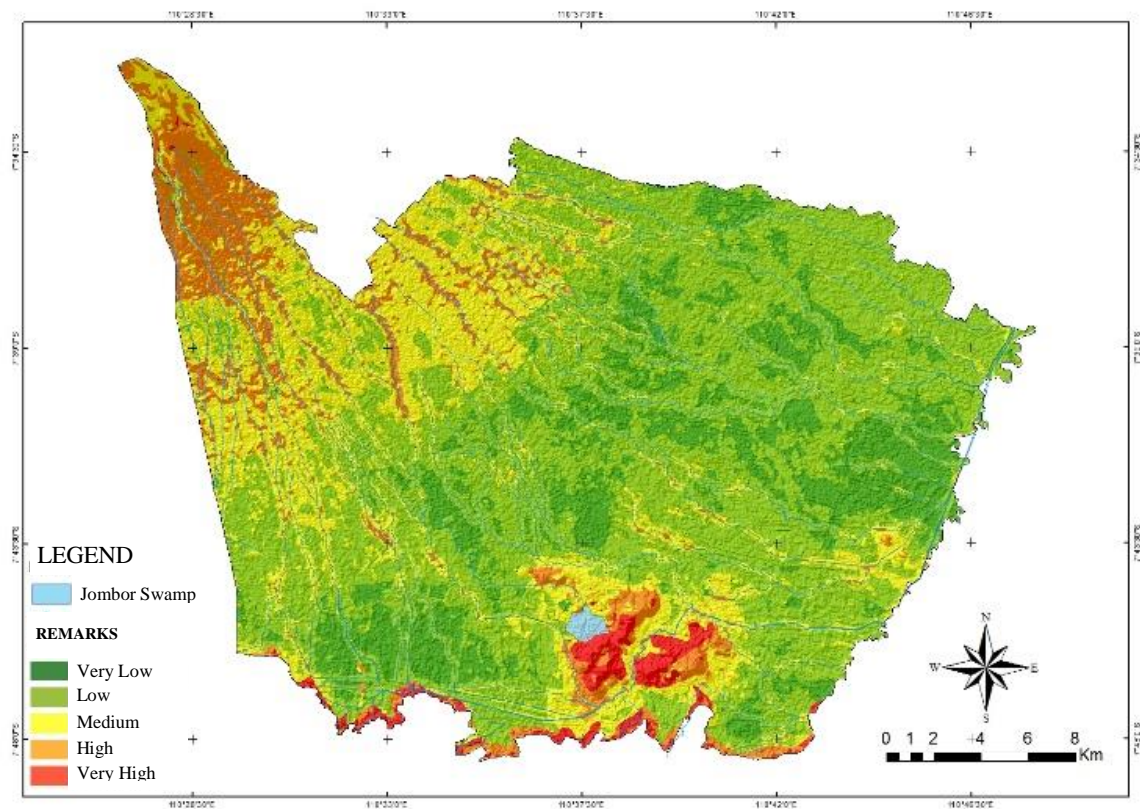

Appendix 4. Earthquake susceptibility map

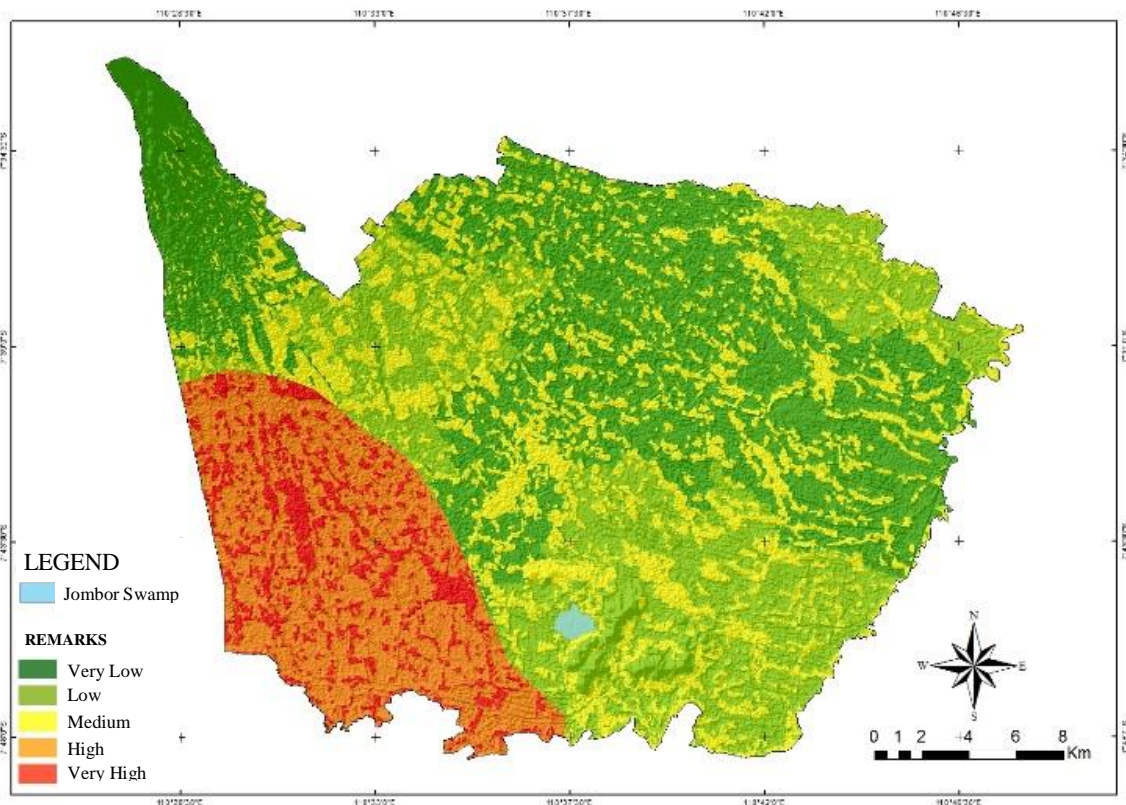Appendix 5. Flood and landslide vulnerability map

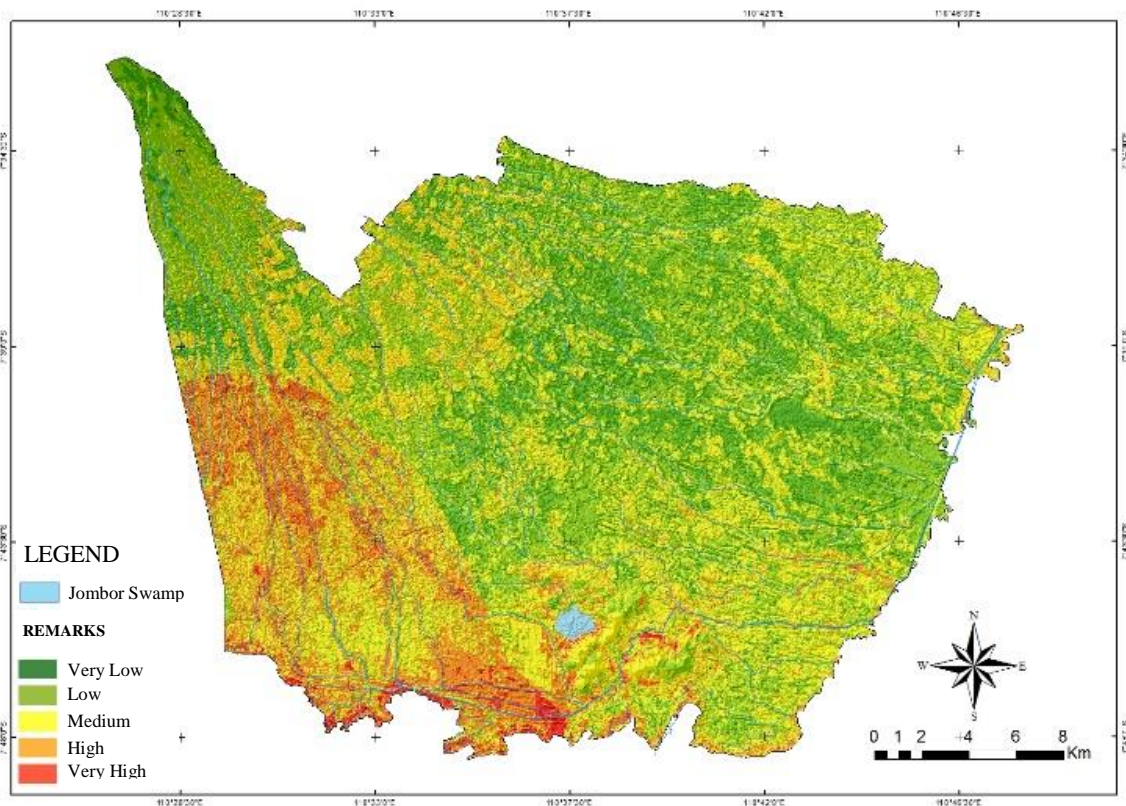Appendix 6. Flood and landslide vulnerability map

Appendix 7. Flood risk map

Appendix 8. Landslide risk map

Appendix 9. Earthquake risk map

Appendix 10. Multi-disaster risk map