Corporative of Geotechnical Approach for Landslide Susceptibility Mapping in Thailand

Suttisak Soralump

Geotechnical Engineering Research and Development Center (GERD)
Civil Engineering Department, Faculty of Engineering, Kasetsart University, Thailand
Email: fengsus@ku.ac.th , soralump_s@yahoo.com

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Keywords: landslide, landslide engineering, landslide hazard map, landslide susceptibility map

ABSTRACT: Geotechnical engineering approach for landslide risk analyses has been introduced for analyzing the landslide susceptible area and been adopted to use in various projects in Thailand. Since there are many factors that need to be considered, geotechnical engineering approach alone can not fully be used for analysis. Traditional method of weighting factor method is still need to be used for the analysis. The factor of slope and engineering properties of residual soil were represented by slope stability index or slope factor of safety and incorporate with others hard to model factor such as land use, linearment zone or drainage area. Geological rock group has been regrouped by Soralump and Kunsuwan (2006) to represent the possibility of landslide of each rock group. 8 rock groups have been classified and engineering properties of the residual soil of these rock groups have been investigated. Rainfall intensity map was also used to analyze the changing of landslide susceptible area of various return period of rainfall.

1 INTRODUCTION

Landslide susceptibility map of Thailand has been done mostly by weighting factor method. Various factors that indicated landslide potential were considered in the analyses, however the geotechnical engineering properties of residual soil such as strength reduction hasn’t been considered by any. In order to include this factor in the hazard mapping analysis, appropriate laboratory testing was designed to determine the properties that can indicate the landslide potential of each type of residual soil.

2 GEOLOGIC CONDITION OF LANDSLIDE IN THAILAND

Figure 1 shows geological map of Thailand which contains various group of rock. In order to study the effect of rock type on landslide hazard, similar type of rock, based on its formation, has been grouped together to obtain 8 rock group as shown in Figure 2. The 8 rock groups are Group 1: Carboniferous-Permian granite has area of 0.74% Group 2: Jurassic-Cretaceous granite has area of 1.84% Group 3: Jurassic granite has area of 4.55% Group 4: Volcanic rock and other intrusive rock such as basalt, andesine, diorite etc. It has area of 2.81% Group 5: Sedimentary rock such as sandstone and mudstone, it has area of 44.69% Group 6: Metamorphic rock has area of 6.12% Group 7: Quantanary sediment has area of 35.98% Group 8: Limestone has area of 3.26%. Since rock group 7 and 8 has very low potential of landslide, therefore they haven’t been considered in the study.

Considering the landslide events and their rock group, percent of landslide frequency of each rock group can be analyzed as shown in Figure 3. However, it will be more appropriate to consider the landslide frequency of each rock group based on their area as shown in Figure 4. From the figure, we can see that landslide has occurred mostly in the Jurassic granite, based on the unit area.

3 LANDSLIDE SUSCEPTIBILITY MAP OF THAILAND

Landslide susceptibility mapping in Thailand were mostly done by weighting factor method using GIS technique. Table 1 shows the organization that has produced landslide hazard map. It can be seen that different landslide susceptibility factors were considered by different organizations. Factors considered are related directly to the expertise of each organization. Geotechnical engineering method was used by Geotechnical Engineering Research and Development center (GERD), Kasetsart University, however that method is not fully appropriate to use in large area since details input required.

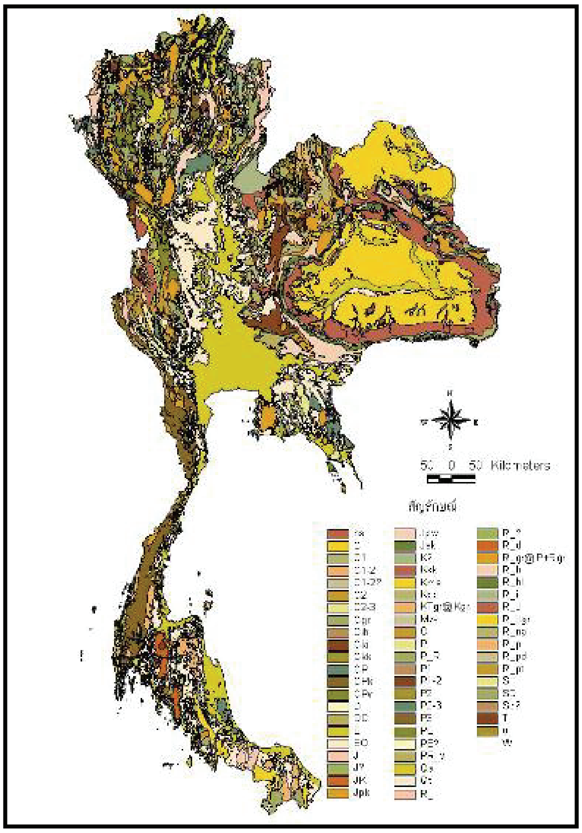


Figure 1: Geological map of Thailand (Department of Mineral Resources, 1987).

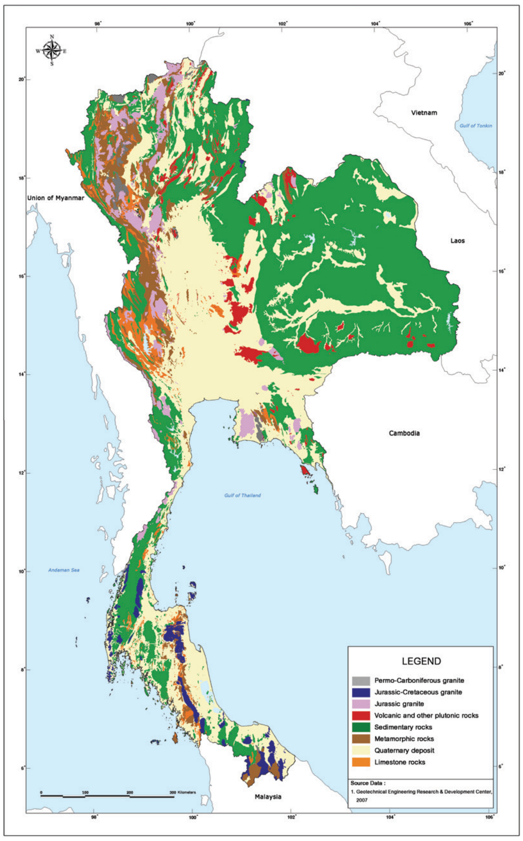


Figure 2: Landslide rock group of Thailand (Soralump et al., 2007).

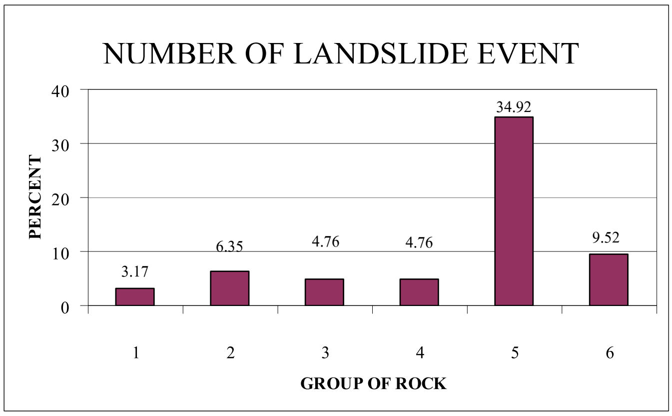
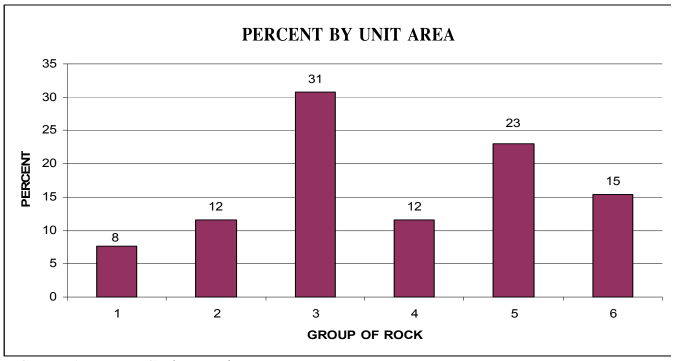


Figure 3: Number in percent of landslide events in Thailand classified by frequency of occurring in each rock group (Soralump et al., 2007).



Group 1 Permo-Carb. granite
Group 2 Jurassic-Cretaceous granite
Group 3 Jurassic granite
Group 4 Volcanic and other plutonic rock
Group 5 Sandstone, shale, mudstone, conglomerate and chert
Group 6 Metamorphic rock

Figure 4: Number in percent by unit area of landslide events in Thailand classified by frequency of occurring in each rock group (Soralump et al., 2007).

Table 1: Factors considered by various organizations for landslide susceptibility analysis.

Method/ Organization	FACTORS RELATED TO LANDSLIDE															
	ROCK TYPE	LANDFORM (SLOPE)	RAINFALL	RAINFALL 5 return	LANDUSE /LAND COVER	ELEVATION	GEOLOGY	TOPOGRAPHIC	THERMALOGY	INVENTORY	WATERSHED	DRAINAGE	WETNESS	SOIL DEPTH	GROUNDWATER	ENGINEERING SOIL PROPERTIES
1. Weighting factor																
1.1 *WICHAI (1995)*	✓	✓	✓		✓	✓										
1.2 DLD	✓	✓	✓		✓		✓									
1.3 FRC (KU)			✓				✓	✓	✓	✓						
1.4 DMR		✓	✓			✓	✓				✓	✓	✓			
1.5 Thassanapak (2001)	✓	✓	✓		✓	✓	✓					✓				
1.6 GERD (KU)	✓	✓	✓	✓	✓	✓	✓					✓				✓
2. Geotechnical																
2.1 GERD (KU)		✓	✓	✓	✓		✓						✓	✓	✓	

DLD : Department of Land Development
FRC : Foresty Reseach Center, Kasetsart University
DMR : Department of Mineral Resource
GERD : Geotechnical Engineering Research and Development Center, Kasetsart University

4 FACTORS CONSIDERED

This paper is presenting the method for corporation of geotechnical engineering data into landslide hazard map by using weighting factor method. This is part of the study project of Department of Mineral Resources and done by Geotechnical Engineering Research and Development Center, Kasetsart

University. The study area is in the 6 provinces in the Southern part of Thailand which has been affected by 2004 tsunami event. They are Phuket, Ranong, Trang, Phan-Gna, Satun and Krabi. Factors considered include: 1. Landform (slope and elevation) 2. Geologic condition (rock type and linearment zone) 3. Land use 4. Distance from surface water 5. Soil characteristics 6. Rainfall intensity and 7. Geotechnical engineering properties of residual soil. Factor 1 to 5 will not discuss in detail here since they are common factors considered for landslide hazard analysis. Rainfall intensity and geotechnical engineering properties factor is discuss below.

5 SIMULATION OF SHEAR STRENGTH LOSS IN RESIDUAL SOIL

In order to consider geotechnical engineering data for the landslide hazard analysis, three properties of residual soil were investigated: 1. strength reduction due to increasing of moisture content 2. soil plasticity and 3. grain size distribution. 220 landslides were investigated in the study area. 118 samples of residual soil were collected by KU-miniature sampler (Figure 5). The soil sampler was designed to ease the sampling of the residual soil especially in the landslide area (Mairaing et al., 2005). Since area ratio of the sampler is about 18 percent, x-ray analyses were done in this study to ensure the limited disturbance of soil samples (Figure 6).

Figure 5: KU-miniature sampler (Mairaing et al., 2005).

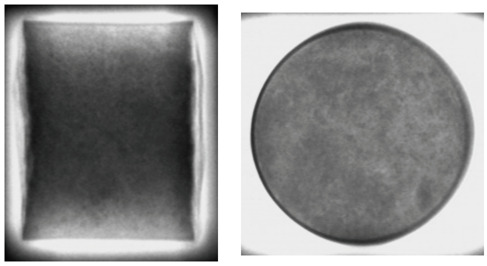


Figure 6: X-Ray analysis of soil disturbance from KU-miniature sampler.

Since there were quite a number of samples to be tested, the strength reduction due to the increasing of moisture content was studied by using Strength Reduction Index test (SRI) (Soralump, 2006). The test simulates the behavior of strength loss during the rainfall. The testing is done by comparing the effective shear strength of residual soil in natural moisture condition and in soaked condition. Soil strength was determined by direct shear testing. Constant normal stress was applied in all samples. The output of SRI is shown as the percent reduction of shear strength which is used an index for comparing the behavior of residual soil from different rock group. The effective shear strength will never used for stability analysis since the testing method is not accurate enough for detail analysis. Figures 7 and 8 shows the example of the result from SRI test. Beside the main output shown, during the soaking process, the collapse behavior of soil samples were monitor for future analysis (Figure 9).

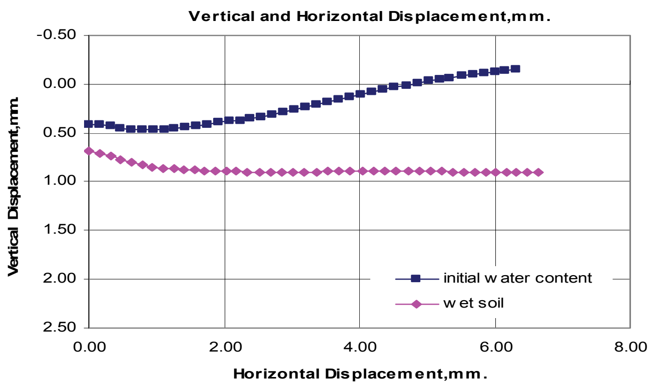


Figure 7: Strength reduction behavior from SRI test (Soralump et al., 2007).

Beside SRI test, plastic index test and grain size distribution analysis were also done. Based on rock group classification discussed above, the study area consists of rock group 2,3,5,7 and 8. Group 7 and 8 is not considered since it has low landslide hazard potential. As for rock group 2, 3 and 5, the dominate rock type are granite, pebbly mudstone, shale and sandstone or siltstone. Therefore, the rock type factor, considering in the landslide hazard mapping analysis of this study, was considered 4 rock types based on dominate rock. The results of SRI test, PI value and grain size distribution analysis of residual soil of those rocks were used to compare the landslide hazard potential. The results of those analyses are shown in Figure 10 to 12.

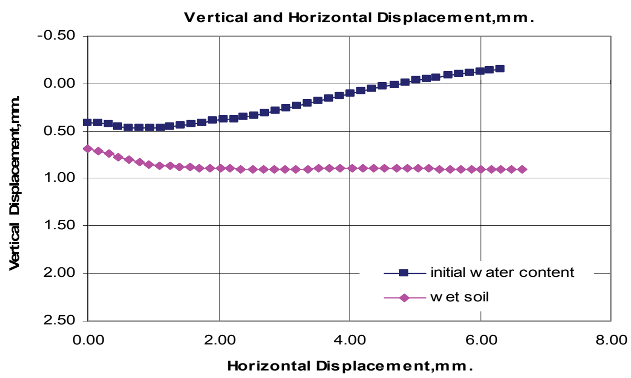


Figure 8: Change in vertical displacement from SRI test (Soralump et al., 2007).

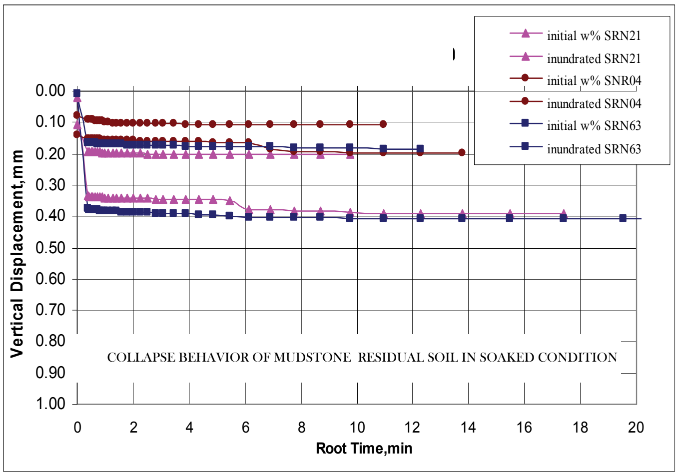


Figure 9: Collapse behavior of mudstone residual soil after soaked (Soralump et al., 2007).

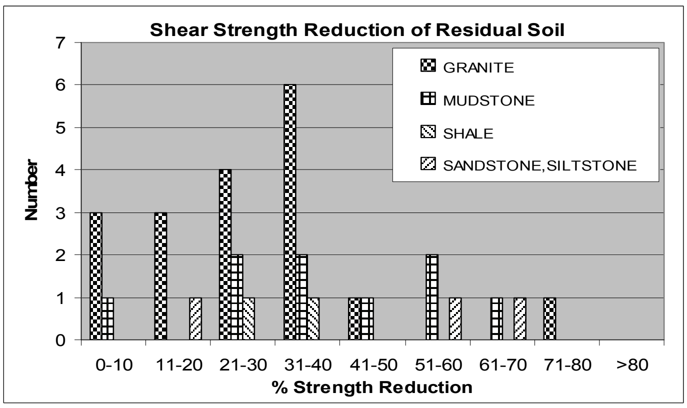


Figure 10: Percent of shear strength reduction of residual soil of various rock type from SRI test.

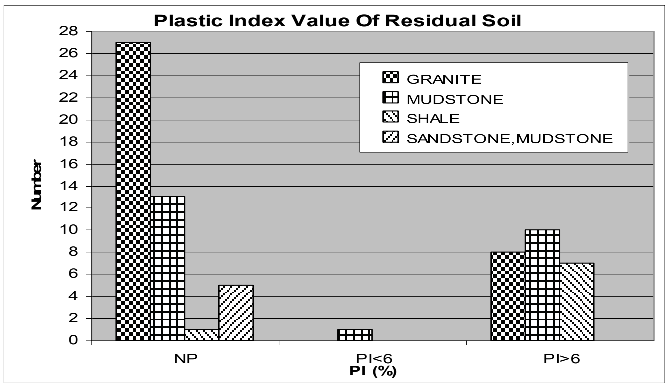


Figure 11: Plastic index value of various type of residual soil.

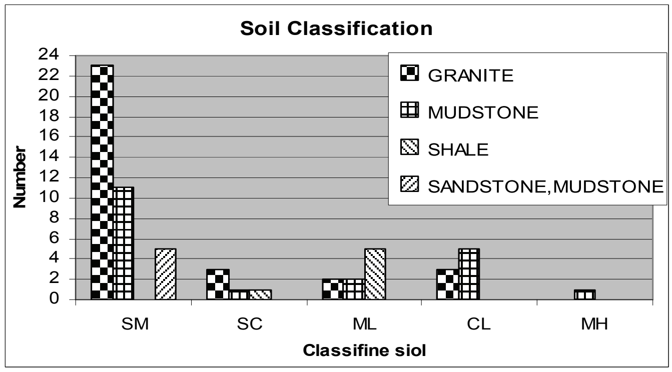


Figure 12: Soil classification of residual soil.

From the results shown above, the ranking of rock type based on potential of landslide hazard was done as shown in Table 2. This ranking was used to produce landslide hazard map in the studied area. Figure 13 shows the engineering soil properties map of Phuket.

Table 2: Ranking of landslide potential properties.

Unstable Soil Ranking	Rock Type	PI	Wet Sieve Analysis	USCS	Percent Strength Reduction
1	Sandstone	NP	Uniform grade	SM	>50%
2	Granite	NP	Well grade	SM	<50%
3	Mudstone	NP&PI>6	Gap grade	SM&CL	20%-70%
4	Shale	PI>6	Gap grade	ML	20%-40%

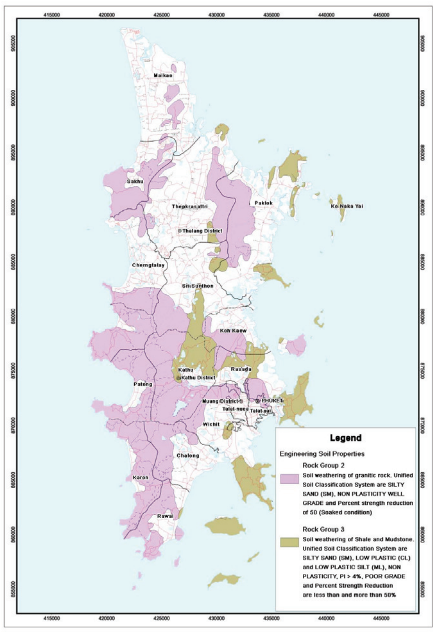


Figure 13: Engineering soil properties of Phuket.

More direct method could be done by calculation of stability index or safety factor of slope in specific distance. This is depended on the grid size of the digital mapping. However, the shear strength parameters shall be determined by the standard shear testing and that required more time and effort. Specific landslide related factors in particular area could be used as well such as the effect of slope cutting for road construction or the surface drainage etc. Fig 14 and 15 shows the application of this approach for Patong (Phuket) and Doi Tung (Chiangrai). The verification of the hazard mapping shows that each study area has different dominant factors that triggered landslide. Such as seen in Patong where lineament zone controlled the failure but in Doi Tung, the cut slope for road way controls.

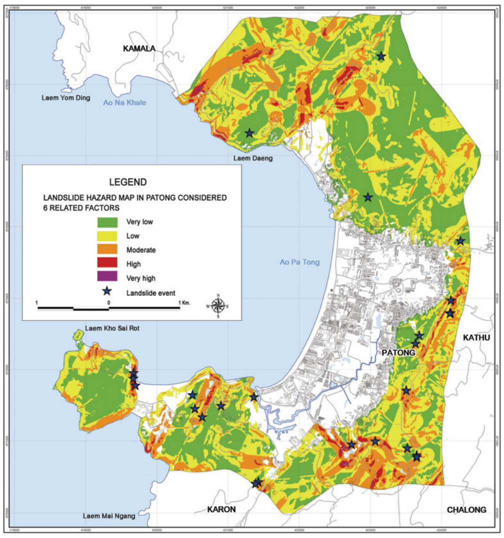


Figure 14: Landslide hazard map of Patong (ADPC, GERD and DMR, 2008).

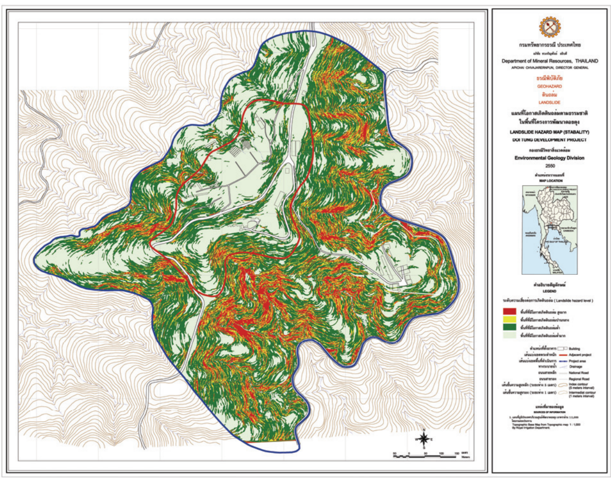


Figure 15: Landslide hazard map, Doi Tung (DMR, 2007 and Soralump et al, 2008).

6 TRIGERRING FACTOR AND HAZARD AREA ANALYSIS

The classification of hazard area has been done in GIS based. 50 by 50 meter grid size was used for each layer of information. The engineering soil properties factor was classified for different level of hazard as discussed in the previous section. Finally rainfall intensity factor was also considered. Rainfall precipitation data (about 20-30 years period)were obtained from 242 rain gauge stations in southern provinces in order to calculate 3 days accumulated rainfall in target area with various return period: 1, 5, 10, 20, 50 and 100 year (Figures 16-17). The variation of calculated accumulations within the study area was used to assign hazard range with various return periods of precipitation.

Finally, after all factors have been analyzed to obtain landslide hazard level, all factors was compared in order to obtain appropriate weight by using weighting factor method. This procedure is an expert opinion method. Table 3 shows the result of weighting factor procedure. The weights and scores shown in Table 3 were applied to each grid cell in GIS in order to get the landslide hazard level of each grid cell. This process was done for all grid cells. Figure 18 shows the landslide hazard map of Phuket using 1 year return period of accumulated rainfall. As for other higher rainfall intensity (greater return period), when applied those in the landslide hazard model, the larger hazard area is obtained. Therefore, the landslide warning area shall be depended on the rainfall intensity at which we measure during the rainfall. 5 landslide hazard maps were then produced. The critical 3 days accumulated rainfalls of each rain gauge stations were calculated from the rainfall prediction analyses. The example of Phuget landslide hazard map and critical 3 days accumulated rainfall data is shown in Figure 19. For convenient, various hazard areas calculated from various rainfall intensity or return periods can be plotted into one hazard map as shown in Figure 20.

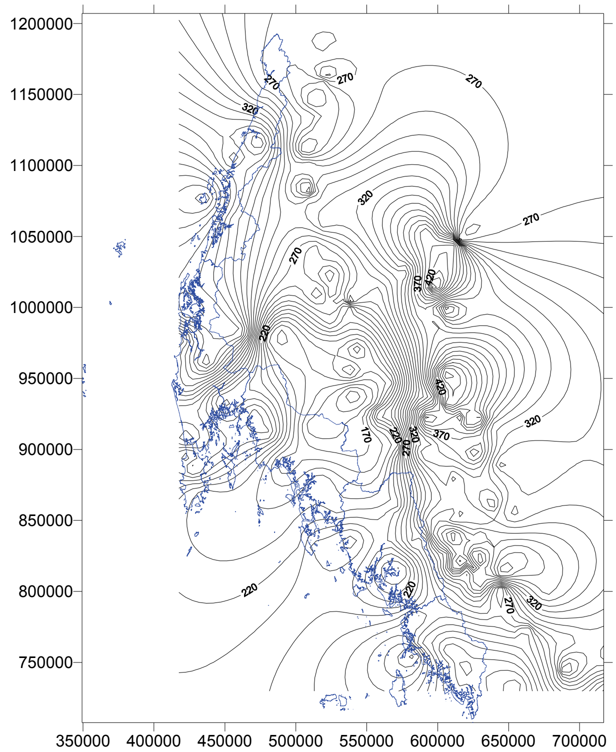


Figure 16: Contour of rainfall precipitation in southern part of Thailand.

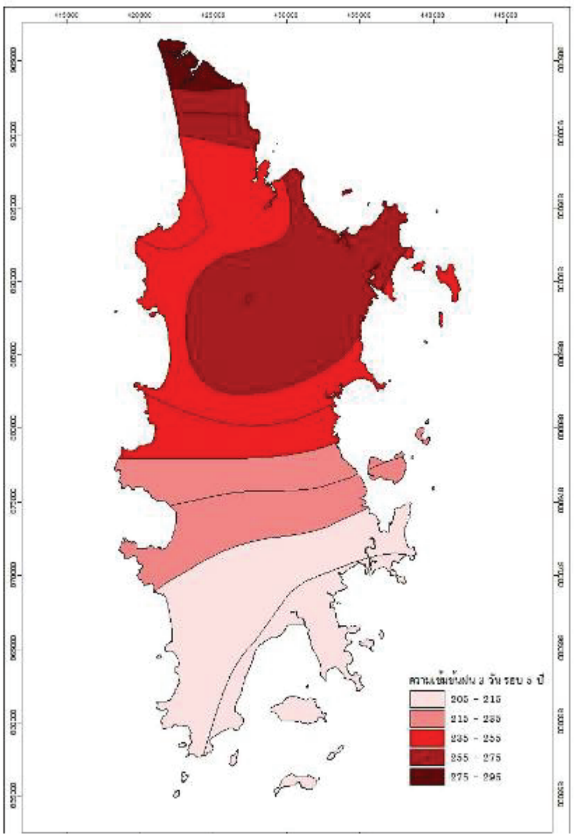


Figure 17: Contour of 3 day accumulate rainfall for 1 year return period.

Table 3: Weighting and rating used for making landslide hazard map of Phuket and others 6 provinces.

Parameter	Weight Value: Parameter	Weight Value: Sub-parameter	Rating Value: Description		Rating (1-5)
1. Geology	5				
1.1 Rock Type		3	A. Granite Rock		5
			B. Shale/Mudstone		4
			C. Sandstone/Siltstone		3
			D. Quartzite, Sandstone and Siltstone		2
			E. Limestone/Dolomite		1
1.2 Lineament zone		2	A. Area inside lineament zone		5
			B. Area outside lineament zone		1
2. Landform	4				
2.1 Slope (%)		3	A. >70%		5
			B. 50-70%		4
			C. 30-50%		3
			D. 15-30%		2
			E. 0-15%		1
2.2 Elevation (meter)		1	A. >400 m		5
			B. 300-400 m		4
			C. 200-300 m		3
			D. 100-200 m		2
			E. 0-100 m		1
3. Surface drainage	2		A. Area inside surface drainage zone		4
			B. Area outside surface drainage zone		1
4. Soil characteristics	2		A. Gravel loam/Gravelly sand		5
			B. Sand		4
			C. Sandy loam		3
			D. Clayey loam/loam		2
			E. Clay, Mud		1
5. Land use and land cover	3		A. Agriculture area		4
			B. Urban and built-up area		3
			C. Other deforestation		2
			D. Forest area		1
6. Rainfall intensity	5		Return period 1	Return period 1,5,20,50,100 years	
			A. >203 mm.	>857 mm.	5
			B. 161-203 mm.	651-827 mm.	4
			C. 119-161 mm.	446-651 mm.	3
			D. 77-119 mm.	240-446 mm.	2
			E. 35-77 mm.	35-240 mm.	1
7. Engineering soil properties (in term of parent rocks)	4		A. Weathered Sandstone/Siltstone		5
			B. Weathered Granite Rock		4
			C. Weathered Shale/Mudstone		3
			D. Weathered Quartzite, Sandstone and Siltstone		2
			E. Weathered Limestone/ Dolomite		1

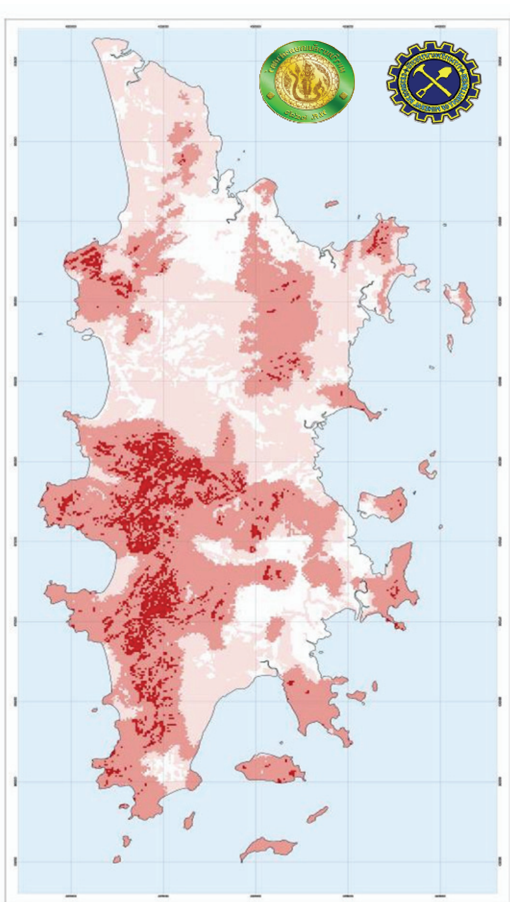


Figure 18: Landslide hazard map of Phuket considering 1 year return period 3 days accumulate rainfall.

Return Period	Station				
	A	B	C	D	E
1	131	120	124	137	141
5	286	236	281	220	205
20	419	336	416	290	260
50	507	402	505	337	297
100	574	452	572	373	324

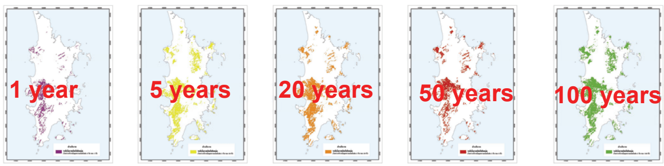


Figure 19: Critical 3 days accumulated rainfall calculated for each rain gauge station and for different level of hazard map.

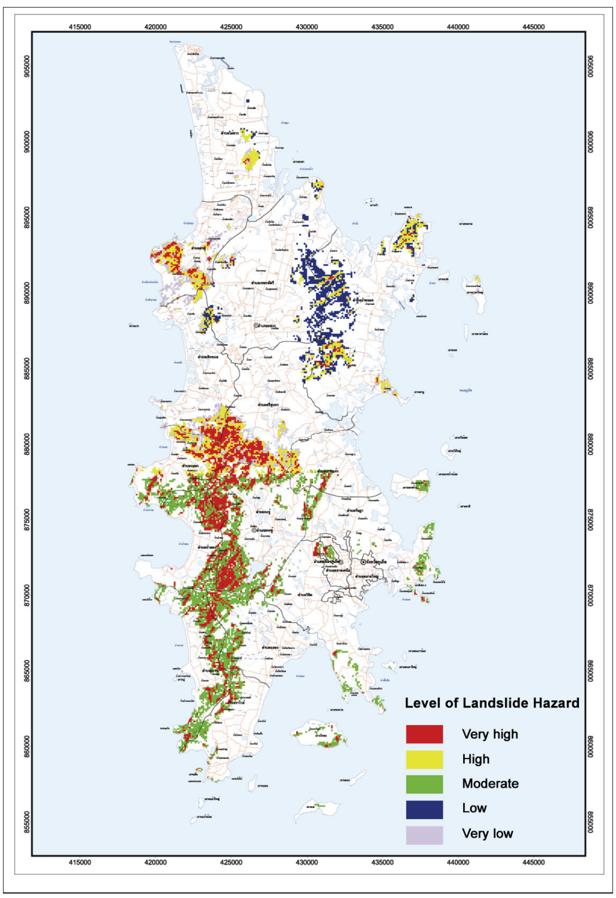


Figure 20: Landslide hazard map using different level of rainfall intensity.

7 CONCLUSIONS

Rainfall-triggered landslide is proved to be manageable if warning criteria and hazard area can be supplied from research field. In turn, in order to obtain those data for large area, comprehensive geotechnical testing shall be done. Area was grouped based on geological group, engineering properties of geo-material of each group must be determined.

Landslide hazard is sensitive to various factors that might be different in different area. There is no one solution to solve all for this problem. Therefore, the landslide hazard map of Thailand is just a guideline to get the idea of landslide hazard for the whole country. However, for landslide management, detail analyses are required in specific site. It has been proved that with the scale of 1:4,000, it is possible to apply the detail geotechnical analysis to obtain the hazard area.

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