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# 17 SEAGC

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## Rainfall-Triggered Landslide: from research to mitigation practice in Thailand

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**ABSTRACT:** Landslide is a serious treat to Thai society. Every 3 to 5 years large landslide is triggered by heavy rainfall. The northern and southern part is the most vulnerable part of the country to landslide hazard. This paper presents the researches done by Geotechnical Engineering Research and Development Center (GERD) which concentrating on the determination of the behavior of rainfall-triggered landslide by using Geotechnical method. It's found that it is possible to apply Geotechnical method for landslide risk management in large area with the link of using rainfall data from rain gauge or satellite image.

### 1. INTRODUCTION

Landslide is the natural disaster that affected the society in many ways. Geotechnical Engineering Research and Development Center (GERD), Kasetsart University has developed landslide database of Thailand which contains of almost 40 years of information on landslide events starting from 1970. From the database it was found that there are 2 types of landslide which can be classified based on the extensive of losses namely limited area landslide and large area landslide. Fig 1 shows the characteristic of each type of slide. It was found that more than 95% of limited area landslides are always caused by the disturbance of human activities which causing the change in landform or surface and underground water flow characteristics. On the other hand, large area landslide is natural and mainly caused by unusual large precipitation in the area. However, there are also many evidences that deforestation or agricultural process is the main cause of large area landslide. Fig 2 shows the location of recorded landslide events from the database. It can be seen that the landslide occurred mostly in the northern and southern part of the country. It's also found that the frequency of the landslide event is increasing sharply during the last decade starting from 1996. The assumptions for the cause of increasing number of landslide for the past decade are 1. Landslides naturally occur more often which might be related to the climate change 2. Mismanagement of land due to the increasing number of population and the needs of land for producing agricultural products, that force people to stay in the landslide hazard areas 3. Combination of first and second reason. Fig. 3 shows statistic data of landslide events that caused economic loss of greater than 100 million baht. Furthermore, Table 1 shows the recorded of economic and live losses.

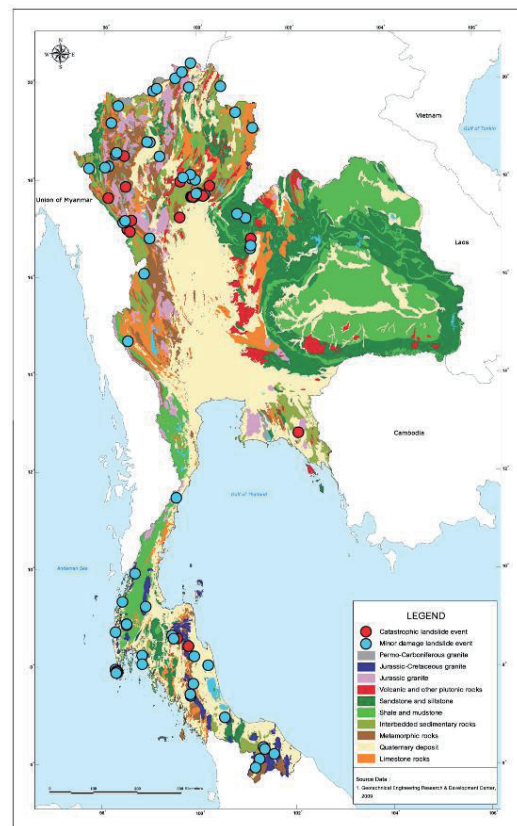


Figure 2 Landslide events in Thailand from 1970-2006 (GERD, 2006)

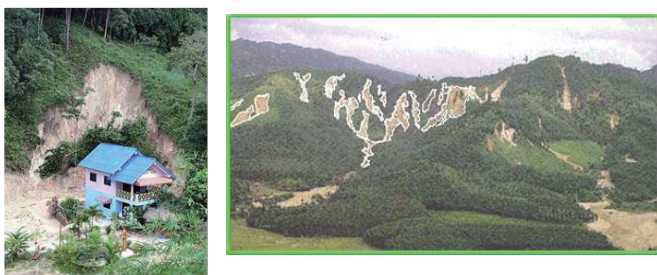


Figure 1 Limited and large area landslide (Department of Mineral Resources)

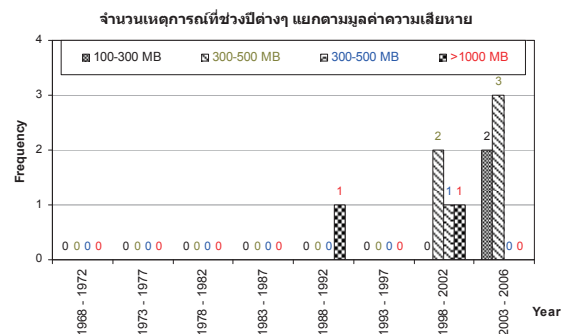


Figure 3 Direct damage cost of greater than 100 million baht from landslide events in Thailand (Soralump, 2007)

Table 1 Number of casualties from landslide events in Thailand since 1970 (Soralump, 2007)

Area	1970-2006		Average lost (37 year)	
	Lives	Economics	Lives	Economics
North	286	2,575,600,000.00	8	69,610,810.81
Central	1	300,000,000.00	0	8,108,108.11
South	247	1,010,000,000.00	7	27,297,297.30
Total	534	3,885,600,000.00	14	105,016,216.22

It is very important to understand the mechanics behavior of residual soil or weathered rock in order to understand the landslide behavior. Therefore, the classification of rock group that specifically related to landslide is needed at the first place. Similar type of rocks, based on their formation, age and statistical recorded of landslide, have been grouped together by Soralump et al. (2007) resulting in 8 rock groups. Soralump et al. (2007) is modified to be more accurate for sedimentary rock group in this paper and result in 10 rock groups instead which 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 3.04% Group 5: Sedimentary rock mainly sandstone, it has area of 17.55% Group 6 Sedimentary rock mainly shale and mudstone (18.79%) Group 7 Sedimentary rock, combination and interbedded or intercalated (7.17%) Group 8: Metamorphic rock has area of 6.3% Group 9: Quaternary sediment has area of 32.89% Group 10: Carbonate rock mainly limestone has area of 7.13%.

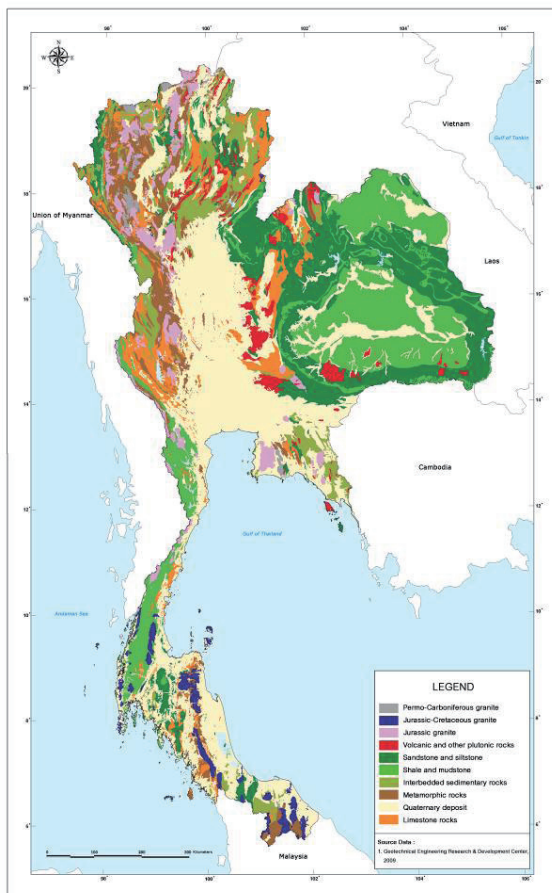


Figure 4 Rock groups related to landslide potential in Thailand

## 2. RAINFALL TRIGGERED

### LANDSLIDE- GEOTECHNICAL APPROACH

The behavior of rainfall-triggered landslide in the interested area is very important for landslide real time warning system. The key information that required for analyzing (by Geotechnical method) the changing in slope safety due to the change in soil moisture content from rainfall precipitation are:

1. The model of change in shear strength of soil in unsaturated zone due to the changing in soil moisture content (or metric suction), this characteristics of soil can be determined directly in laboratory by performing the direct shear test to the soil samples with various degree of saturation. Mairaing et al. (2005) has proposed this testing technique. In classical way, the above characteristics can be determined based on strength equation for unsaturated soil introduced by Fredlund (1978). This method required the determination of Soil Water Characteristic Curve (SWCC) in additional of effective strength parameters. Jotisankasa (2010) has investigated the unsaturated strength behavior of residual soil in Thailand based this theory.

2. The infiltration model of unsteady flow. The permeability of residual soil in unsaturated condition (K-Function) and also the rough information of underlain base rock permittivity are required. The infiltration behavior can also be determined by directly install tensiometers or moisture probes in various depth of residual soil in the target area in order to record the changing in degree of saturation of soil due to rainfall precipitation. However, many monitoring points may be required to represent the soil moisture behavior for the whole watershed.

3. The rainfall data, which are the rainfall intensity and its pattern, shall be determined. Direct measurement from automatic rain gauge or interpretation from satellite image can be used. With the wireless system, rainfall data from rain gauge can be sent to the monitoring hub for every 15 mins. As for the data from satellite interpretation, more time is required but still in the practical period.

4. In case of infiltration model, the knowledge of absorption and retention characteristic of land cover may be studied and incorporated into the model. This is a challenge in Geotechnical research.

Fig 5 shows the relationship of the analyses described above. The strength reduction characteristics can be used together with infiltration model based on the local rainfall pattern in order to investigate the changing in slope stability with time. Unsteady state flow of unsaturated soil should be considered to represent the more realistic infiltration behavior. Fig 6 shows the example work done by this concept. The rainfall pattern in study area were used in conjunction with the unsteady state flow, strength reduction behavior and stability model. Fig 7 shows the work example used for back analysis of slope failure due to intense rainfall in Ra Island located in the southern part of Thailand. The precipitation is as high as 300mm/day and after 1.5 hr the failure started to begin.

The method described above is suitable for the safety analysis of limited area slope where details slope configuration and engineering soil properties are well known. In order to practice this concept in the wider area to prevent the large area landslide, more afford was done by Soralump and Torwiwat (2009) and Torwiwat and Soralump (2009). Based on landslide rock group as described in last section, undisturbed samples of residual soil located in each rock group have been collected. The total number of over 514 soil samples has been tested for their engineering properties. 307 undisturbed soil samples have been specially tested their shear strength reduction behavior by KU-MDS shear testing method (Soralump and Torwiwat, 2009). Fig. 8 shows the example of strength reduction characteristic of 6 rock groups. The critical thicknesses at each degree of saturation of various slope angles are calculated. This critical thickness is then used to calculate the amount of water that could be contained and will give slope safety of 1.0.

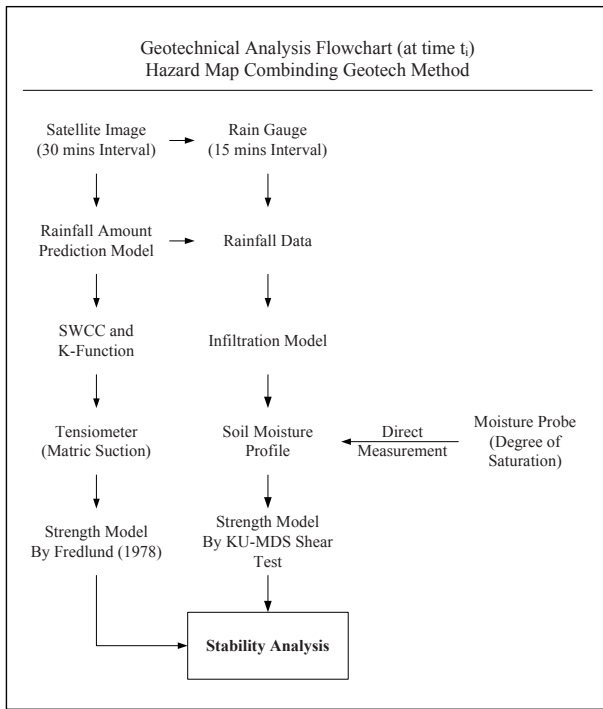


Figure 5 Geotechnical analysis flowchart for supporting the landslide real time warning system

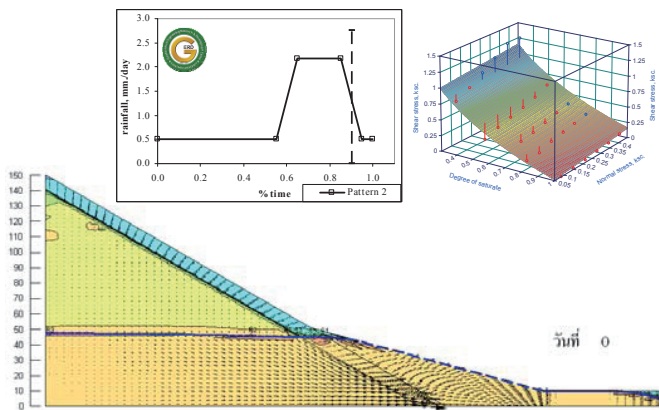


Figure 6 The modeling of rainfall triggered slope failure (Kunsuwan, 2005)

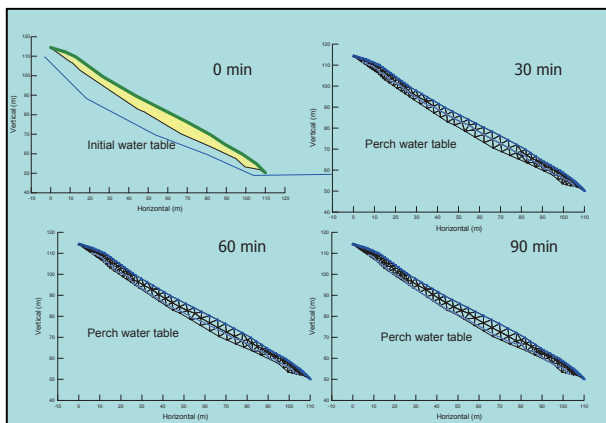


Figure 7 Infiltration model of actual landslide in Ra Island

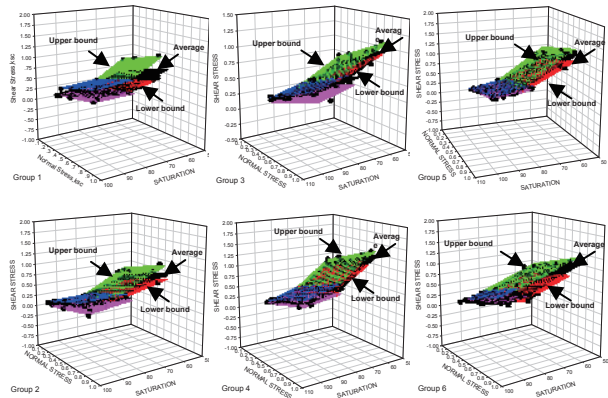


Figure 8 Strength reduction characteristic from increasing of soil moisture content (Soralump and Torwiwat, 2009)

This amount of water is called the Critical Moisture Content (CCM). In order to use this calculated value for landslide warning, CCM can be transformed into the unit of “mm” or the same unit of precipitation and will be used to compare with the Antecedent Precipitation Index value (Linsley et al., 1982) which calculated from rainfall records. The CCM will then be called the critical Antecedent Precipitation Index (API). Fig 9 shows the calculated critical API values for Thailand (DWR, 2008 and Torwiwat and Soralump, 2009). Since the use of API value for landslide and flood warning was initiated by Department of Water Resources, therefore these values are now used in practice for landslide warning in Thailand. However, the reduction of critical API values was used in order to cover various uncertainties. Proper uncertainty analysis using Monte Carlo simulation or FORM is under the research of the author.

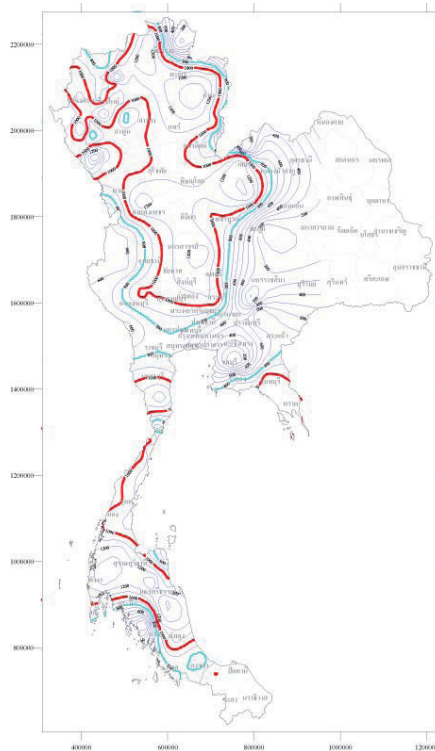


Figure 9 Critical API contour (DWR, 2008, Torwiwat and Soralump, 2009)

Fig 10 shows the application of the concept described above but done in area with map scale of 1:4,000. The work has been done for Patong Municipality by Asian Disaster Preparedness Center with the corporation with GERD and Department of Mineral Resources (DMR). It has been proved that with this map scale (1:4,000), it is

excellence to apply this approach since the detail investigation for engineering soil properties could possibly been done and the scale of topographic map is suitable for stability analysis.

The real time monitoring of landslide (and at the same time verification of the critical API value) can be done by using the concept proposed by Okada et al. (1992) as shown in Fig 11. The daily rainfall or smaller record is plotted with the API value which calculated based on the previous amount of rainfall precipitation, soil water holding capacity, evaporation etc. Note that this API value is the present API value at the time of consideration. The critical API value is shown as a red criterion line (Fig 12). If the curve went beyond this line, the landslide is likely to be occurred.

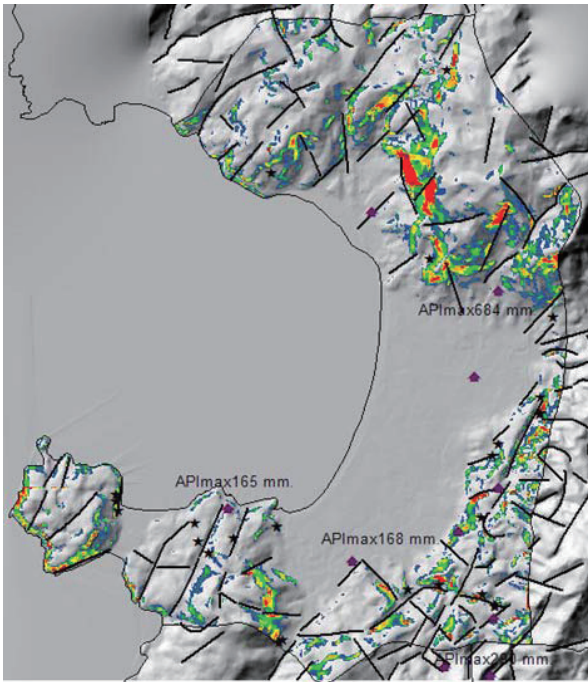


Figure 10 Critical API contour in Patong city, Phuket (ADPC, GERD and DMR, 2008, Sorulump, 2009)

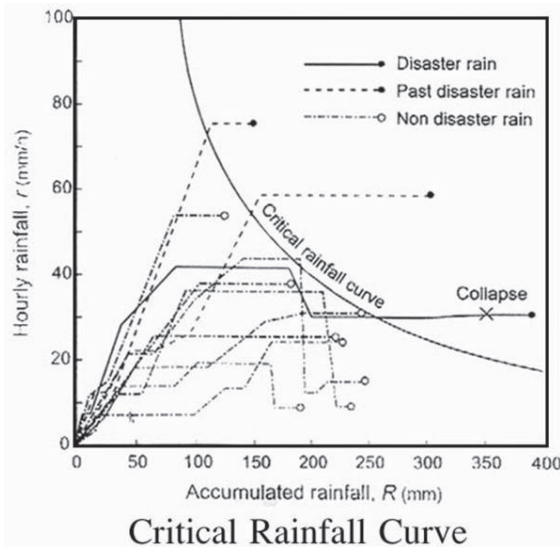


Figure 11 Critical rainfall Curve (Okada et al.,1992)

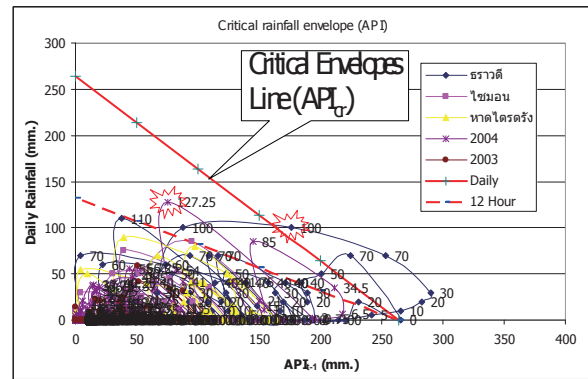


Figure 12 Verification of critical API value

### 3. Landslide hazard mapping

Landslide hazard map is one of the key information for landslide risk management, basically 4 approaches could be used to analyze hazard area: 1. weighting factor method 2. Geotechnical engineering method 3. the combination of both methods mentioned and 4. Logistic regression analysis or statistical method. Landslide hazard mapping of Thailand were done mostly by the technique of weighting factor method using GIS information. Table 2 shows the organizations that has produced landslide hazard map of Thailand. It can be seen that different factors were considered by different organizations. Factors considered are related directly their expertise. Geotechnical engineering approach was used by GERD in order to analyze the landslide hazard area, however this method is not fully appropriate to use in large area since many parameters are required for the analysis.

Table 2 Factors considered by various organizations for landslide hazard analysis

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

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

The combination method of weighting factor and Geotechnical engineering method could be done through the calculation of stability index or safety factor of slope in specific distance. This is depended on the grid size of the digital mapping. Fig 13 and 14 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.

It is possible to produce the real time or dynamic landslide hazard map by using the updated rainfall intensity contour map. The map can be produced by using the real time automatic rain gauge or the interpretation of satellite image for rainfall data. The degree of hazard can be updated through infiltration and stability model as described earlier or may be used to adjust the precipitation score if

weighting factor method is to be used. Fig 15 and 16 shows the application of this approach for Phuket, by using various return period of precipitation, various landslide hazard levels could be produced. Fig 15 shows the contour of 3-day accumulated rainfall analyzed from over 242 rain gauge stations. And with rainfall data date back for almost 40 years, it is possible to analyzed 3-days accumulated rainfall in specified return periods.

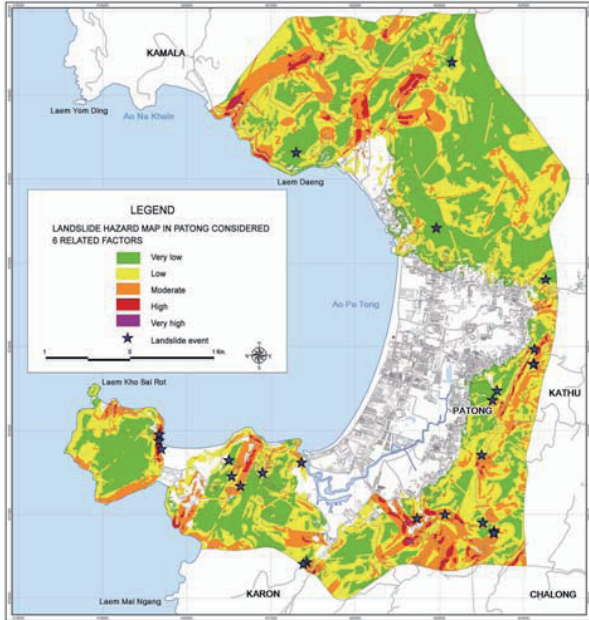


Figure 13 Landslide hazard map of Patong (ADPC, GERD and DMR, 2008)

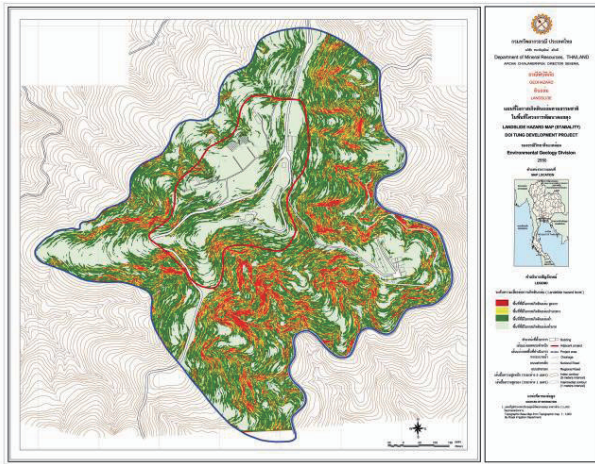


Figure 14 Landslide hazard map, Doi Tung (DMR, 2007 and Soralump et al, 2008)

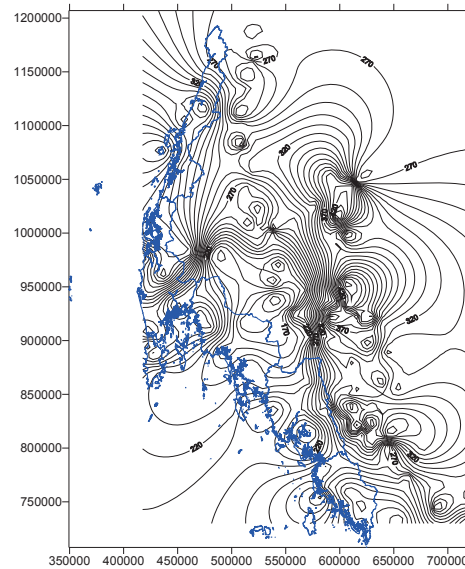


Figure 15 Contour of rainfall precipitation in southern part of Thailand

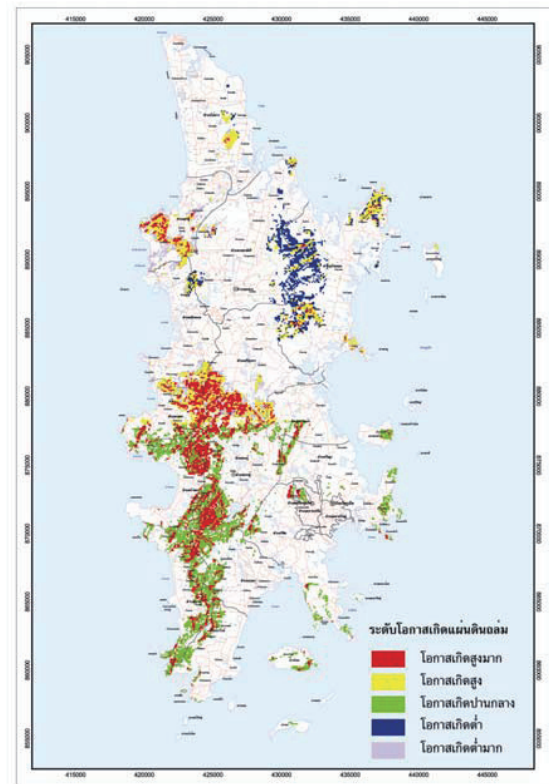


Figure 16 Landslide hazard map using different level of rainfall intensity

#### 4. 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 should be grouped based on geological group, engineering properties of geo-material of each group must be determined. Strength reduction model and infiltration model are important tools to calculate the amount of rainfall that may trigger landslide.

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 and triggering level of rainfall that might induce landslide.

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