Landslide Risk Management of Patong City: Demonstration of Geotechnical Engineering Approach

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ABSTRACT: Patong city located in Phuket province which is in the southern part of Thailand, it is one of most desire tourist destination in Thailand. The development of the city occasionally caused flooding and landslide. Landslide risk management program is introduced by Asian Diaster Preparedness Center (ADPC) under RECLAM II project. Geotechnical approach was used to produce landslide susceptibility map and landslide risk map. Buildings in the landslide hazard area were classified into various risk classes. Man made factors such as the road, area of prohibition by law and others have been considered as a factor for landslide hazard mapping. Engineering practice handbooks were specification technique that will minimize the triggering of landslide. Critical API was calculation and the appropriate warning method was adapted for local personnel to use as critical for landslide warning. All the works mentioned were closely done together with the Patong Municipality in order to customize these mitigations for the person who are in charge. The project is perhaps the first landslide risk mitigation project in Thailand.

1 INTRODUCTION

Landslide is one of natural hazard that affected Thailand. The direct economic lost due to landslide is calculated to be equal to 100 million Baht per year and the return period of large area landslide is once in every 3-5 years (Soralump, 2010).

Patong beach, located in Phuket province, is one of the famous tourist destinations in Thailand. This beautiful beach is surrounded by the mountain range. Since the city is expanding, the use of steep slope area on the mountain is unavoidable. This causes the disturbance to the environment and sometime triggers the landslide. Asian Disaster Preparedness Center (ADPC) together with The Norwegian Geotechnical Institute (NGI) had the responsibility for execution of Regional Capacity Enhancement for Landslide Impact Mitigation program (RECLAIM) which the funding was provided by the Royal Norwegian Embassy in Bangkok. Department of Mineral Resources and Kasetsart University were asked by ADPC to take responsibility for the implementation which decided to demonstrate the landslide mitigation in Patong.

2 STUDY AREA

Patong Municipality is approximately 16 square kilometers in area and located on the west coast of Phuket Island. Population mostly consists of tourists and Muslim communities living in areas near the beach. However, after the tsunami event the development tends to move higher on the mountain. Changing of the land use and land cover caused the landslide in the area (Pungsuwan, 2006) such as shown in Figure 1.

Table 1 shows some event of landslide records gathered by Patong municipality, it shows that most of the landslide has triggered by excessive rainfall.

Figure 1: Na Nai roadside landslide events on October 25, 2007**.**

Table 1: Landslide records gathered by Patong Municipality.

No.	date	location	Triggering factor
1	October 19, 2001	Various places	Heavy rainfall
2	October 21, 2003	50th anniversary Rd.	Cut slope and Heavy rainfall
3	October 14, 2004	Na Nai village	Blockage of drainage and Heavy rainfall
4	October 14, 2004	Kalim village	Inappropriate drainage and Heavy rainfall
5	October 25, 2006	Na Nai Rd.	Cut slope non protection and Heavy rainfall
6	July 15, 2007	50th anniversary Rd.	Under construction
7	September 5, 2008	50th anniversary Rd.	Drainage
8	September 19, 2009	Kathu-Patong Rd.	Heavy rainfall

3 GEOLOGICAL CHARACTERISTICS

Geological characteristics of Patong include formation of granite in Cretaceous Era and modern beach sediments in Quaternary period. Granite rock is found to be in moderately to highly weathered condition with various sets of joint and fracture. Left lateral strike-slip fault has found mostly with their strike lies between north-east to south-west direction. Department of mineral resources has interpreted the geologic structures of Patong as shown in Figure 2 (Department of Mineral Resources, 2006).

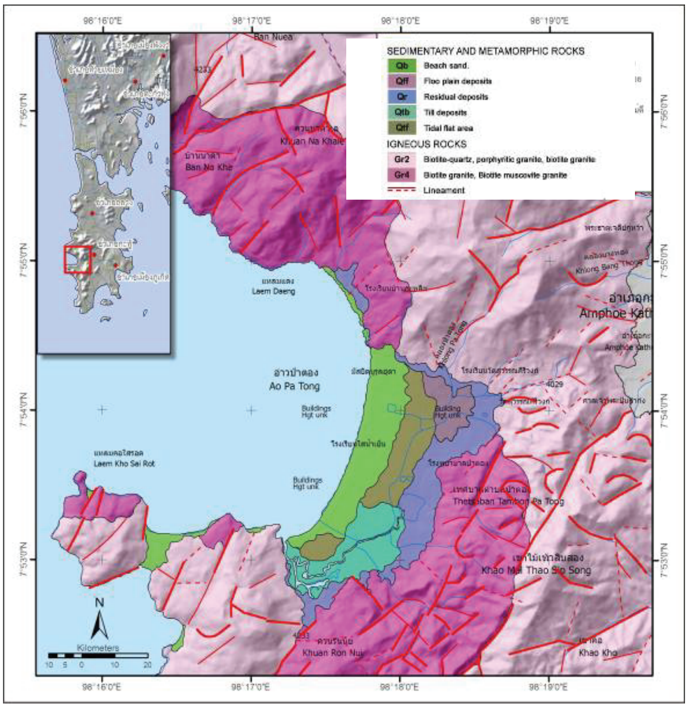


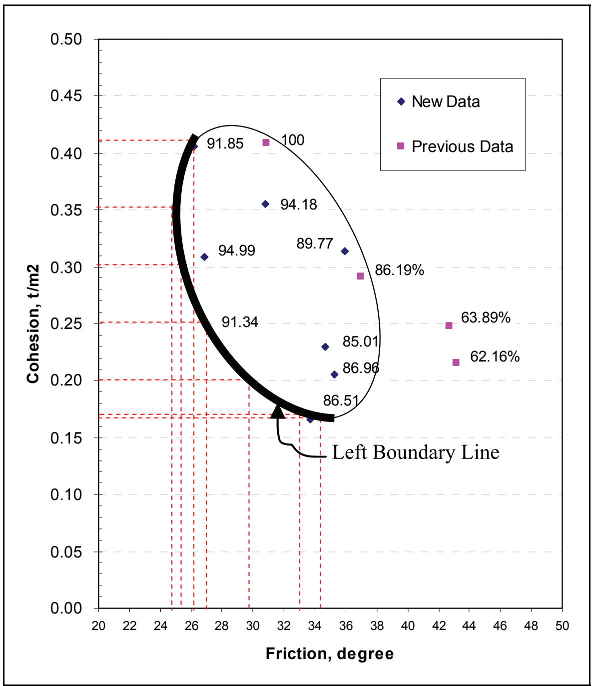
Figure 2: Geological characteristics, Patong (Department of Mineral Resources).

4 SLOPE STABILITY ANALYSIS

Multi-Stage Direct Shear Test were done using the residual soil samples collected in the study area as well as the data gathered from previous study (Soralump and Torwiwat, 2007). Finally, soil data from 12 locations were used for the analysis in this study. The drained direct shear tests were done to the soaked (almost saturated) samples. In order to ensure the drained behavior, pressure sensor, capable of measuring both positive and negative pressure, was embedded in the top cap to monitor the change in pore pressure. The excess pore pressure is only exist during consolidation stage but not the shearing stage. This can be concluded that the soil sample is sheared under fully drained condition. The results of strength parameter (c',ϕ') are clearly shown that cohesion value has tendency of increasing when the degree of saturation is getting higher (Figure 3).

Slope stability analyses were done by KUslope computer program developed by Kasetsart University (Isaroranit, 2001). The geometry of the mountain slope was studied to select the appropriate cross section for the analysis. The cross section of slope above Na Nai village shown in Fig.4 were used as a typical section for analyses.

The analyses were done with various angle of slope from 14 to 40 degrees of both natural (one bench) and cut slope. Since the strength parameters vary based on degree of saturation, therefore the slope analysis were done by trial a pair of strength parameters along the left boundary line shown in Figure 3 to obtain the possible lowest F.S.. The results are summarized in Fig 5. The results show that the factor of safety of cut slope has lower value than the natural slope as expected. The critical slope angle that the cutting might trigger the landslide is 17.1 degree in which corresponding to FS equal to 1.3. Therefore, any construction cutting (1H:2V) in the natural slope with slope angle greater than 17.1 degree, those cut slopes need to be analyzed and the counter measures need to be considered.



Cohesion	0.168	0.170	0.200	0.250	0.300	0.350	0.410
Degree	34.5	33.0	29.6	27.0	25.2	24.8	26.1

Figure 3: Boundary of strength parameters used for the analyses.

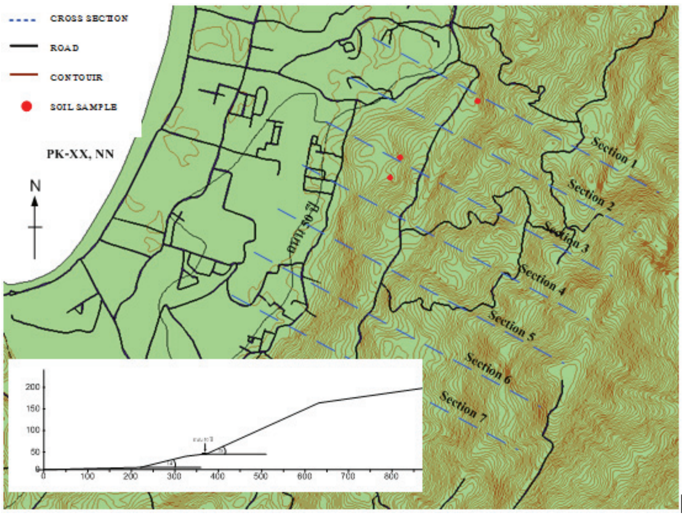


Figure 4: Typical section for analyses.

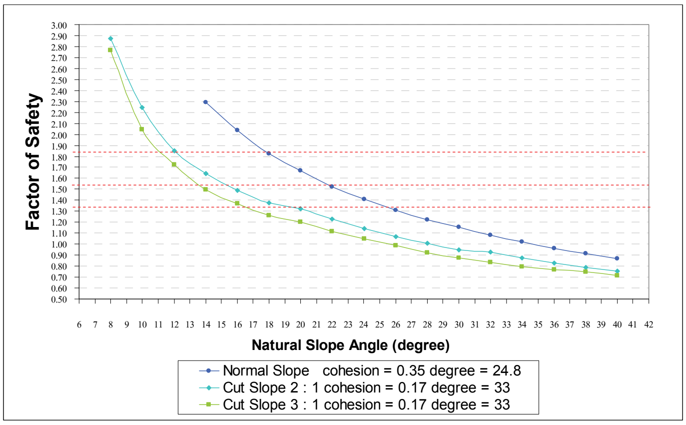


Figure 5: Factor of safety of cut and natural slope.

5 LANDSLIDE SUSCEPTIBILITY MAP

The landslide susceptibility area is analyzed using weighting factor method. 8 major factors listed below were considered in the analysis including the safety factor calculated from geotechnical method explained in the previous section.

1. Factor safety and slope angle relationship
2. Rock mass structure & slope angle relationship (Later neglected)
3. Lineament zone
4. Rock type (Later neglected)
5. Distance from road
6. Elevation
7. Land use and land cover
8. Surface drainage zone

The factor of rock mass structure and rock type were neglected since the detail analysis found that there is less correlation of those factors with previous landslide. In determining the numerical rating for landslide potential of each 6 parameters, an area of 5x5 square meters grid cell has been employed for the analysis by GIS program. The weight-rating value of each parameter is determined in each square grid cell of each derivative map. Table 2 shows the weighting value of the parameters, considering weighted matrix method based on expert assessments as shown in Table 3. Finally the scores of weight-rating in each 5x5 square meters grid cell is obtained from the summation of weight-rating values of each derivative map to obtain the landslide susceptibility map. The map of each influencing factors is shown in Figure 6.

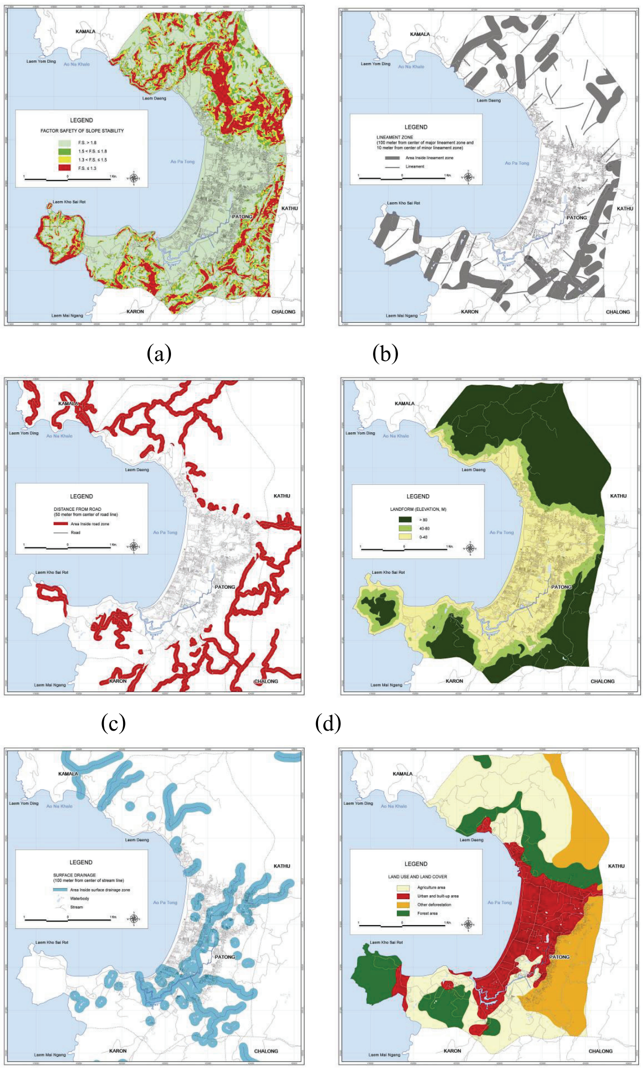
Table 2: Weights and rating values used for the analyses.

Parameter	Weight Value	Rating Value	
		Description	Rating (1-5)
1. Factor safety and slope angle relationship	1.875	A. F.S.≤ 1.3 (≥26 degree) B. 1.3 < F.S. ≤ 1.5 (22≤ slope< 26 degree) C. 1.5 < F.S. ≤ 1.8 (18≤ slope< 22 degree) D. F.S. >1.8 (< 18 degree)	5 3.66 2.33 1
2. Lineament zone	1.625	A. Area inside lineament zone B. Area outside lineament zone	5 1
3. Distance from road	1	A. Area inside road zone B. Area outside road zone	5 1
4. Elevation	1	A. >80 m B. 40-80 m C. 0-40 m (Not include slope < 10^{O})	1 3 5
5. Surface drainage	1	A. Area inside surface drainage zone B. Area outside surface drainage zone	5 1
6. Land use and land cover	1	A. Agriculture area B. Urban and built-up area C. Other deforestation D. Forest area	5 3.66 2.33 1

Table 3: The weighing process.

Factors	1	2	3	4	5	6	Total score	Weight
1		3	3	3	3	3	15	1.875
2	1		3	3	3	3	13	1.625
3	1	1		2	2	2	8	1
4	1	1	2		2	2	8	1
5	1	1	2	2		2	8	1
6	1	1	2	2	2		8	1

The results of the analysis are shown in Figure 7. The landslide susceptibility classes are classified as shown in Table 4. It clearly shows in Figure 7 that the actual events are matched with the moderate to high landslide susceptibility area from the result of analysis with the matching of 78.2 percent. Table 5 shows the suggestion for land development act, proposed to Patong Municipal which will be used as a guideline for the future enforcement.



(a) (b) (c) (d) (e) (f)

Figure 6: Factors used in GIS. a. Factor of safety classification b. Lineament zone c. Distance from road d. Elevation e. Surface drainage area f. Land use and land cover.

Table 4 Landslide classification based on score.

Score	Landslide Potentials Classes	pixel	Area (m^2)	%
31.6-37.5	Very high potential	408	10,200.00	0.07
25.6-31.5	High potential	13,054	326,218.36	2.27
19.6-25.5	Moderate potential	102,359	2,555,706.73	17.76
13.6-19.5	Low potential	237,269	5,904,230.18	41.03
0-13.5	Very low to nil potential	224,914	5,594,591.66	38.88
	Total	578,004	14,390,946.93	100

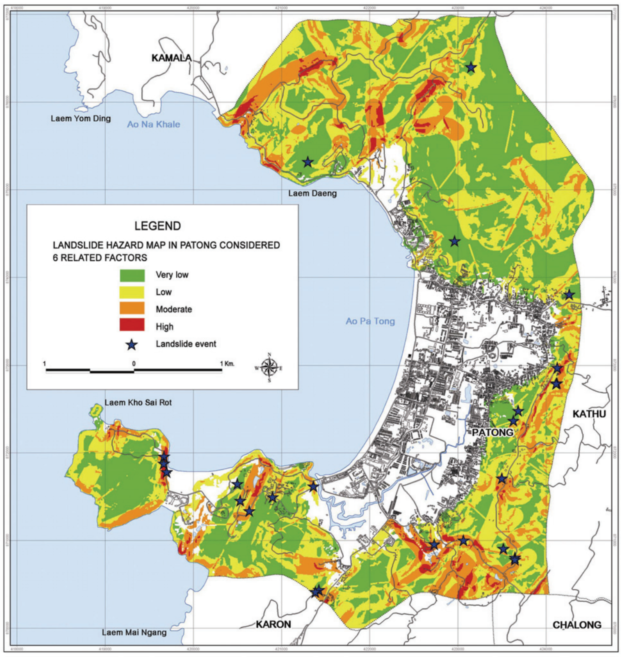


Figure 7: Landslide susceptibility map.

Table 5: Recommendations for slope cutting at various level of landslide susceptibilities.

Action	Landslide Hazard Level			
	High	Medium	Low	Very Low
Geotechnical engineer required	√	√		
Geologist required	√			
Land cover control	√	√		
Drainage management	√	√		
Control of the angle of cut slope	√	√	√	√

6 LANDSLIDE RISK MAP

Since risk is a function of hazard and consequence. Therefore, in order to develop risk mapping, the consequence area from landslide need to be estimated. Buildings location and their data were obtained from taxation map provided by Patong City. The hazard levels were classified based on landslide susceptibility map produced as discussed earlier. The affected area at the toe slope area was estimated to be equal to the height of the slope above the toe based on Finlay et al. (1999). Fig. 8 shows the boundary of affected area at the toe of the slope. The buildings were classified into levels based on their vulnerability due to landslide. The number of population at risk (PAR) is estimated from the census data in the taxation map.

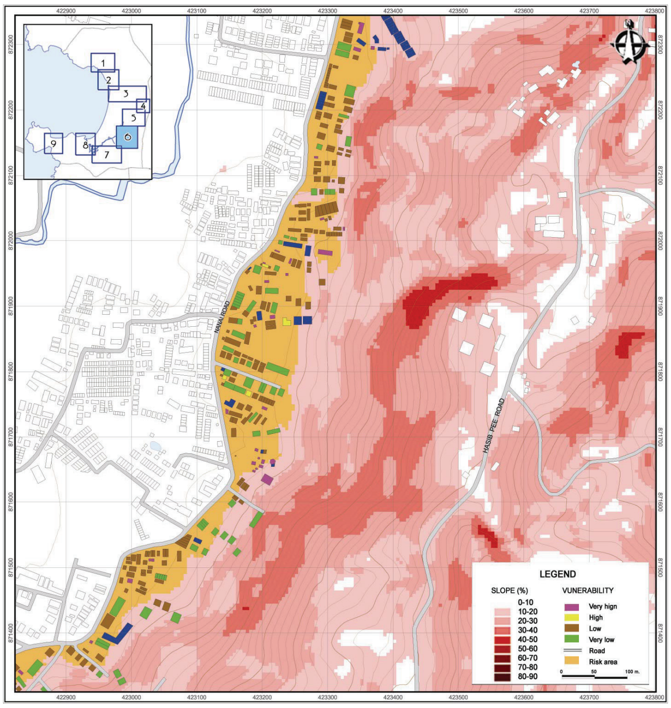


Figure 8: Part of landslide risk map in Patong.

7 API MAP

Landslide disaster management will be incomplete if lack of warning system. The past studies found that the accumulated rainfall and current precipitation has great influence in rainfall-triggered landslide. This is consistent with the use of the API concept (Antecedent Precipitation Index). The API represents the moisture of the soil at any time using the values measured by rain gauge. The critical API is determined by calculating the critical moisture content in soil layer that will cause the soil layer to fail. Factor of safety was analyzed by infinite slope stability and with soil strength parameter of c' = 0.35 ksc., $\phi' = 24.8^{o}$, the unit weight of soil (γ_d) = 1.41 t/m^3 , Gs = 2.65, void ratio (e) = 0.89, degree of saturation (Sr) = 93% and the porosity of the soil (n) = 0.471. The calculation was done according to equation 1 and the critical thickness is determined from Equation 2. The result is shown in Figure 9 and Figure 10. The critical API map is shown in Figure 11.

$$F.S. = [1 - r_u(1+\tan^2\beta)]\frac{\tan\phi'}{\tan\beta} - \frac{1}{\sin\beta\cos\beta}\frac{c'}{\gamma H_{cri}} \quad (1)$$

when $F.S.$ = Factor of safety for infinite slope
r_u = Pore pressure ratio $u/\gamma H$
β = Slope angle
γ = Unit weight of sliding mass
H_{cri} = Critical depth (m)

$$API_{cr} = n \cdot S_{r,cr} \cdot T_{cr} \quad (2)$$

when API_{cr} = critical API (mm.)

n = porosity

$S_{r,cr}$ = percent critical of saturation

T_{cr} = critical depth (m)

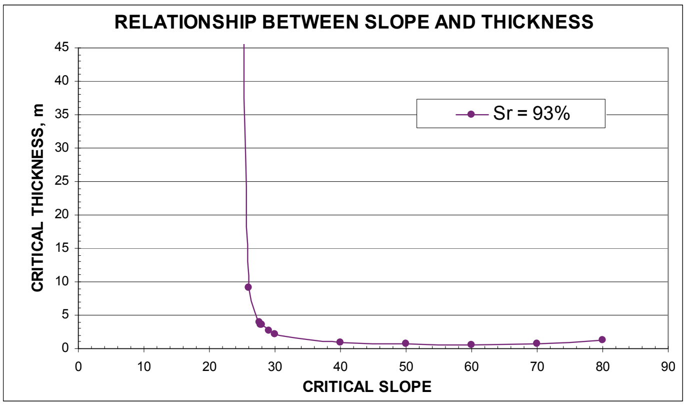


Figure 9: The relationship between the critical thickness and slope angle.

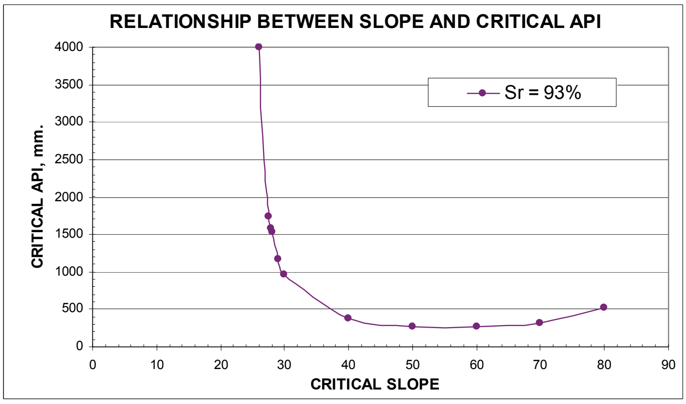


Figure 10: The relationship between critical API and critical slopes angles.

8 WARNING BY RAINFALL

Using critical API for landslide warning is required to install rain gauge stations to present monitor rainfall in the area for calculating the API at time t. (API_t) (Equation 3) (Soralump and Thowiwat, 2010). Figure13 to 16 compare between the warning method using 3 days accumulated rainfall data and API value in which the later giving a longer time period prior to landslide events. However, as seen in Fig.16, it shows that a landslide event occurred before the calculated critical API value, therefore more real time wireless rain gauge system was installed as shown in Figure 17 and the Alert-Alarm-Action criteria were set for practical purpose.

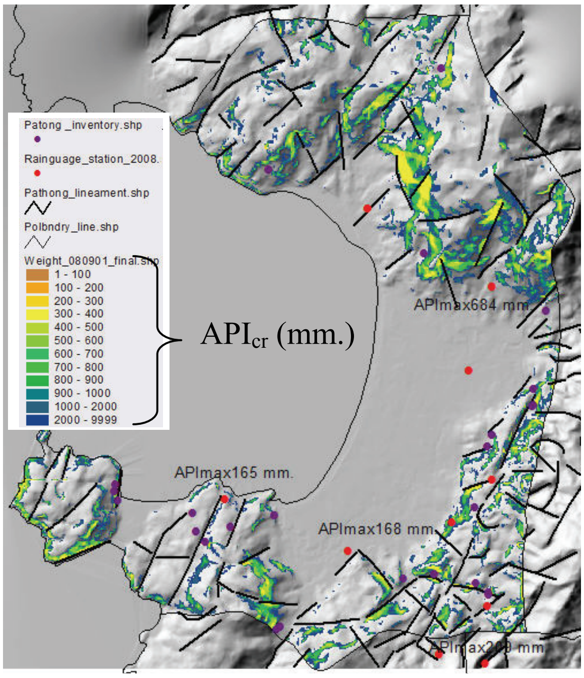


Figure 11: Critical API map.

$$API_t = (K_t \times API_{t-1}) + P_t \quad (3)$$

when API_t = API on 't' day (mm)

API_{t-1} = API on 't-1' day (mm)

P_t = Precipitation on 't' day (mm)

K = recession constant API constant (K =< 1.0 and usually 0.85-0.98)

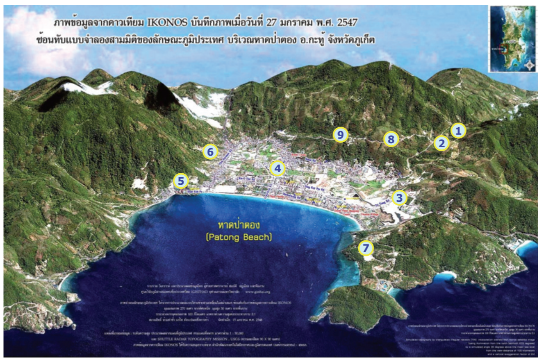


Figure 12: Position of rain gauge stations. (Landscape scenarios: GISTHAI).

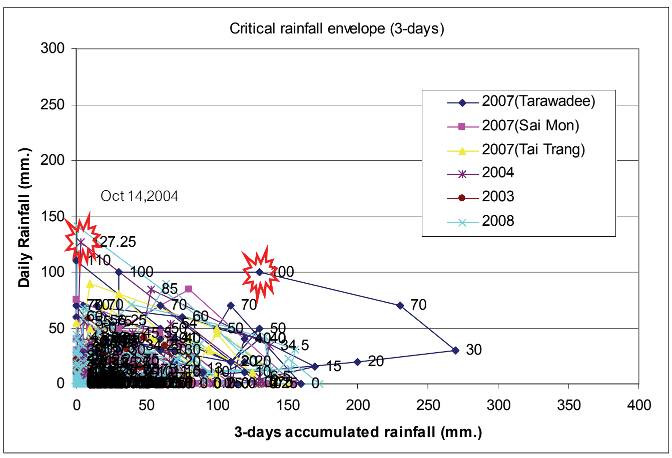


Figure 13: 3 days accumulated rainfall and daily rainfall relationship.

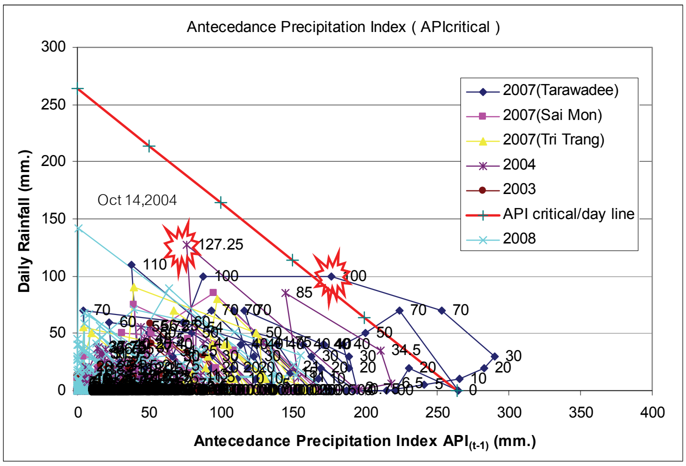


Figure 14: API value and daily rainfall.

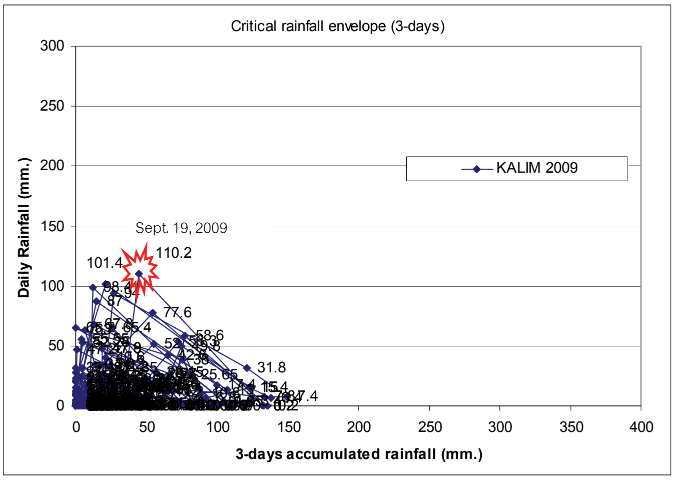


Figure 15: 3 days accumulated rainfall showing the landslide events in 2009.

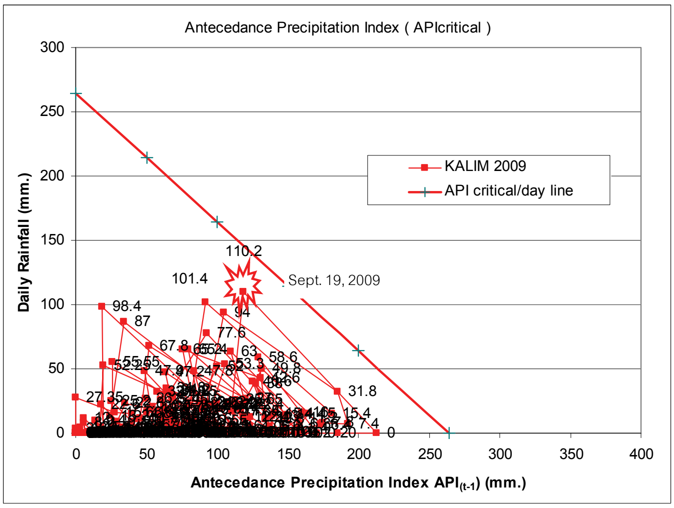


Figure 16: API graph showing the landslide event in 2009.

9 CONCLUSION

Geotechnical approach is found to be useful in landslide risk management in Patong, Phuket. Hazard and risk mapping together with the landslide warning system using rainfall data were produced and set up based on geotechnical data and analyses.

Figure 17: Wireless rain gauge system.

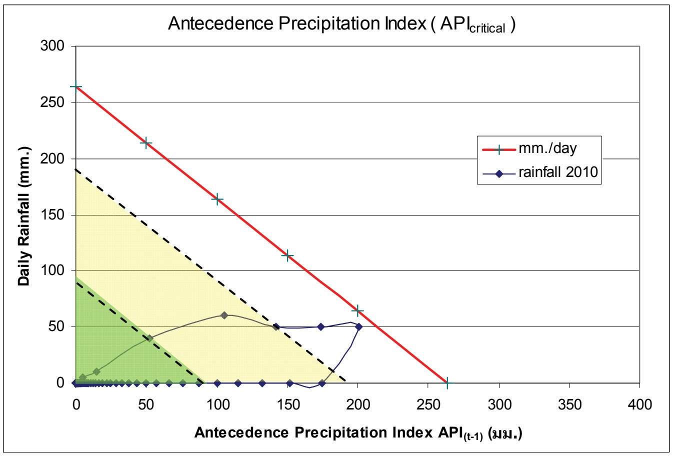


Figure 18: Alert Alarm Action criteria.

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