THESIS

EVALUATION OF LANDSLIDE SENSITIVE AREAS
FOR CUT SLOPE IN PHUKET

DAMRONG PUNGSUWAN

GRAUDATE SCHOOL, KASETSART UNIVERSITY
2006

THESIS APPROVAL

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THESIS

EVALUATION OF LANDSLIDE SENSITIVE AREAS FOR CUT SLOPE IN PHUKET

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This study attempted to improve a method of determination of landslide susceptibility map and evaluated landslide sensitive areas for cut slope in Phuket island. The improvement of landslide susceptibility map was made by introducing engineering soil properties parameter, RMR and SMR parameters for weighting factor analysis. The evaluation of landslide sensitive areas for cut slope was evaluated by weighting factor method and logistic regression analysis.

The field investigation was done in 87 areas and located in 14 watersheds. Data collected in each area included a field estimation of strength of intact rock, joint spacing, joint condition, degree of weathering, ground water condition and joint orientation. These were used for evaluation of RMR and SMR factors. Descriptions of slope condition were collected for determination of landslide probability by logistic regression analysis.

The results of weighting factor method shows that RMR and SMR factors have slight effect on landslide hazard map. However, RMR and SMR value show direct relation with the prediction of landslide for slope cutting. As for rainfall intensity factor, the landslide potential map that considered 1 year return period of rainfall gives large difference compared to the map that used concept of 5 return periods of rainfall. Furthermore, landslide potential classes done by cumulative frequency analysis gives more realistic result than using equal range of score concept. Nevertheless, the cumulative frequency analysis of total score shows limited accuracy due to limited and slightly biased data. Finally, RMR and SMR values show significant effect on landslide probability of failure when analyzed by logistic regression data. The significant outcome of the research is the map showing the sensitive areas for slope cutting, produced by weighting factor analysis and logistic regression analysis.

Student's signature

Thesis Advisor's signature

2 / Nov / 2006

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Damrong Pungsuwan

September 2006

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EVALUATION OF LANDSLIDE SENSITIVE AREAS FOR CUT SLOPE IN PHUKET

INTRODUCTION

General Introduction

Landslides have become one of the major natural disasters over the past few years in our country. It is the most common natural hazard and threatening condition for people in mountainous area. Even when it happens away from the inhabited area, landslide can be a significant hazard and has a serious economic impact by blocking roads and river (Akbar, 1998).

In Thailand, many groups of researcher studied about the landslide occurrences and have developed landslide susceptibility map. The landslide susceptibility map is used for a hazard management. In order to develop the map property, factors related to slope instability need to be studied. Slope instability processes are the product of local geomorphic, hydrologic, and geologic conditions; modification of these conditions by geodynamic processes, vegetation, land use practices, human activities and frequency and intensity of precipitation and seismicity (Soeters and Van Westen, 1996). Recently, Geographic Information System (GIS) application is a powerful analysis tool to handle spatial data. Since the landslide hazard zonation is very much related to spatial information e.g. topography, geology, land cover, rainfall etc, GIS can be effective in analyzing these factors at various locations of a given area (Rajbhandari, 1995). This research is focused on the process of combining engineering soil properties and weighting factor method by using GIS application. An important thing in evaluating the hazard associated with the failure of landslide induced by cut slope is the probability of failure.

The development on Phuket island is rapidly growth and requires more infrastructure such as transportation route, resort projects, residential and commercial buildings. Building those structures in mountain area can trigger landslide. Therefore, this study is also focused on the determination of sensitive area for cut slope in Phuket.

Statement of Problems

The stability of cut slope on mountainous area is a major concern to the developed area as well as for the safety of those staying in these areas. Any kind of slope failure may lead to disruption in traffic, socio-economic activities, loss of property, injuries or sometimes even deaths of humans and/or livestock, and environmental degradation. Moreover, humans trigger landslide by carelessly cutting a slope for construction, especially at the toe slope.

Therefore, an assessment of the stability conditions in mountainous area is quite important especially as granitic and mudstone soil is the most common soil found in Thailand and has the highest rate of landslide (Geotechnical Engineering Research and Development Center, 2006). Several techniques can be used to evaluate landslide potential area such as infinite slope analysis, weighting factor method and logistic regression method. The slope mass rating (SMR) technique has been found to be quite useful where it can be practiced, and is effectiveness in interpreting stability and recommending control measures. The technique is based on the well established rock mass rating (RMR) technique. The RMR and SMR technique has been used earlier in many mining and engineering projects related to tunnels and cut slope.

In order to improve the landslide susceptibility map by weighting factor method, it is necessary to improve the parameter to predict landslide such as engineering soil properties factor, RMR and SMR factors.

Objective of Research

The objectives of this study are:

1. Determine the sensitive areas of landslide and cut slope failure due to urban development in Phuket area by combination engineering soil properties factor into weighing factor method using GIS application.
2. Develop and verify landslide susceptibility caused by cut slope failure by using field investigation data.
3. To propose a method in calculating probability of cut slope failure and to combine into landslide hazard map by using field investigation data.

Scope of Research

1. Study area located in Phuket province.
2. Engineering parameters of slope material were determined by rock mass classification method and used the analyzed data from previous study.
3. GIS application was used for data analysis.

LITERATURE REVIEW

Landslides

Varnes (1978) defined term Landslide “the movement of a mass of rock, debris or earth down a slope”. The criteria used in classification of landslides presented in emphasizing type of movement and type of material. The names for the type of materials are rock, debris, and earth. The movement has been divided into fall, topples, slides, spreads, and flows, as shown in Fig 1. This scheme considers fall, slides, and flows in bedrock, soils and unconsolidated deposits. The moisture content increases from rockfall to debris flow, and ultimately, a very wet debris flow grades into a very turbid stream.

A landslide is the mass movement, usually sudden, of soil and debris down a steep slope. Landslides can be triggered by heavy rainfall, earthquake or undercutting of the base of slopes by river (Ian Davis and Gupta, 1989).

The term landslide is defined as outward and downward movement of mass, consisting of rock and soil due to natural or manmade factors. High intensity rainfall triggers many landslides (Fauziah, 2004).

The processes involved in slope movements comprise a continuous series of events from cause to effect. Varnes (1978) provided a list of the causes of slides follows Varnes's distinction that the three broad types of landslide processes are which that increase shear stresses, contribute to low strength, and reduce material strength.

Varnes (1978) classified landslides according to the type of movement undergone on the one hand and the type of materials involved on the other (Fig 1). Types of movement were grouped into falls, slides and flows. The materials concerned were simply grouped as rocks and soils. Obviously, one type of slope failure may grade into another; for example, slides often turn into flows. Complex slope movements are those in which there is a combination of two or more principal types of movement. Multiple movements are those in which repeated failures of the same type occur in succession, and compound movements are those in which the failure surface is formed of a combination of curved and planar sections.

Falls are very common. The moving mass travels mostly through the air by free fall, saltation or rolling, with little or no interaction between the moving fragments. Movements are very rapid and may not be preceded by minor movements. A rockfall event involves a single block or group of blocks that become detached from a rock face; each block may be a falling block behaving more or less independently of other blocks. Blocks may be broken during the fall. There is temporary loss of ground contact and high acceleration during the descent, with blocks attaining significant kinetic energy. Blocks accumulate at the bottom of a slope as scree deposit. If a rockfall is active or very recent, then the slope from which it was derived is scarped. Frost thaw action is one of the major causes of rockfall.

Toppling failure is a special type of rockfall, which can involve considerable volumes of rock. The danger of slope toppling increases with increasing discontinuity angle, and steep slopes in vertically jointed rocks frequently exhibit signs of toppling failure.

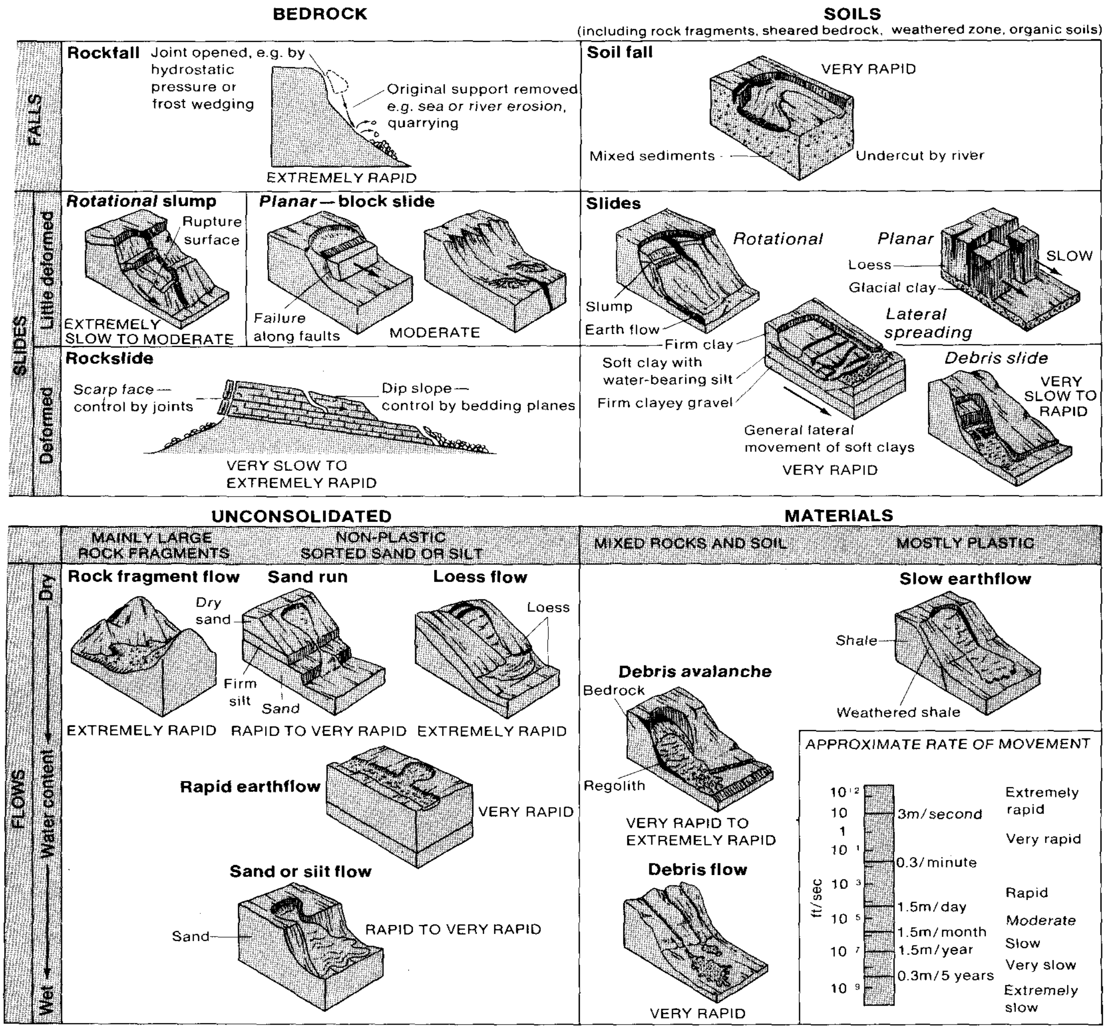


Figure 1 Landslide type
Source: Varnes (1978)

In slides, the movement results from shear failure along one or several surfaces, such surfaces offering the least resistance to movement. The mass involved may or may not experience considerable deformation. One of the most common types of slide occurs in clay soils, where the slip surface is approximately spoon-shaped. Such slides are referred to as rotational slides (Fig 2). They are commonly deep-seated (depth/length ratio = 0.15—0.33). Backward rotation of the failed mass is the dominant characteristic, and the failed material remains intact to the extent that only one or a few discrete blocks are likely to form.

Although the slip surface is concave upwards it seldom approximates to a circular arc of uniform curvature. For instance, if the shear strength of the soil is lower in the horizontal than vertical direction, the arc may flatten out; if the soil conditions are reversed, then the converse may apply. What is more, the shape of the slip surface is very much influenced by the existing discontinuity pattern.

Rotational slides usually develop from tension scars in the upper part of a slope, the movement being more or less rotational about an axis located above the slope. The tension cracks at the head of a rotational slide are generally concentric and parallel to the main scar. Undrained depressions and perimeter lakes, bounded upwards by the main scar, characterize the head regions of many rotational slides.

When the scar at the head of a rotational slide is almost vertical and unsupported, then further failure is usually just a matter of time. As a consequence, successive rotational slides occur until the slope is stabilized. These are retrogressive slides and they develop in a headward direction. All multiple retrogressive slides have a common basal shear surface in which the individual planes of failure are combined. Non-circular slips occur in overconsolidated clays in which weathering has led to the development of quasi-planar slide surfaces, or in unweathered structurally anisotropic clays. Both circular and non-circular shallow rotational slips tend to form on moderately inclined slopes in weathered or colluvial clays.

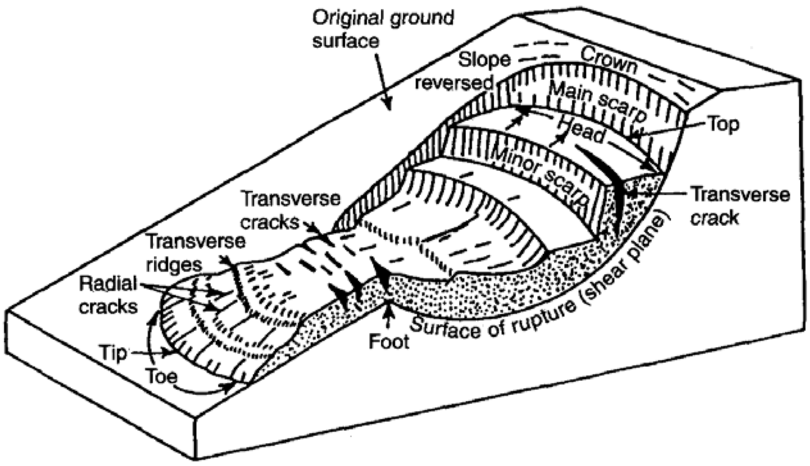


Figure 2 The main features of a rotational slide
Source: Varnes (1978)

Translational slides occur in inclined stratified deposits, the movement occurring along a planar surface, frequently a bedding plane. The mass involved in the movement becomes dislodged because the force of gravity overcomes the frictional resistance along the potential slip surface, the mass having been detached from the parent rock by a prominent discontinuity such as a major joint. Slab slides, in which the slip surface is roughly parallel to the ground surface, are a common type of translational slide. Such a slide may progress almost indefinitely if the slip surface is sufficiently inclined and the resistance along it is less than the driving force. Slab slides can occur on gentler surfaces than rotational slides and may be more extensive.

According to Skempton and Hutchinson (1969), compound and translational slides develop in clay deposits when rotation is inhibited by an underlying planar feature, such as a bedding plane or the base of a weathered boundary layer. Translational slides tend to be more superficial than compound slides, being governed by more shallow inhomogeneities. Clay that is subjected to part rotational, part translational sliding is often distorted and broken. Block slides may develop in the more lithified, jointed deposits of clay, blocks of clay first separating and then sliding on well-defined bedding, joint or fault planes. Slab slides are characteristic of more weathered clay slopes of low inclination. Material moves en masse with little internal distortion.

Weathered mantle and colluvial materials are particularly prone to slab failure, which rarely occurs with depth/length ratios greater than 0.1. If a sufficient number of overlapping slips develop, they may form a shallow translational retrogressive slide. Failures that involve lateral spreading may develop in clays, quick clays and varved clays. This type of failure is due to high pore water pressure in a more permeable zone at relatively shallow depth, dissipation of pore water pressure leading to the mobilization of the clay above. The movement is usually complex, being predominantly translational, although rotation and liquefaction, and consequent flow may also be involved. Such masses, however, generally move over a planar surface and may split into a number of semi-independent units. Like other landslides, these are generally sudden failures, although sometimes movement can take place slowly.

Rock slides and debris slides are usually the result of a gradual weakening of the bonds within a rock mass and are generally translational in character. Most rock slides are controlled by the discontinuity patterns within the parent rock. Water is seldom an important direct factor in causing rock slides, although it may weaken bonding along joints and bedding planes. Freeze—thaw action, however, is an important cause. Rock slides commonly occur on steep slopes and most are of single rather than multiple occurrence. They are composed of rock boulders. Individual fragments may be very large and may move great distances from their source. Debris slides are usually restricted to the weathered zone or to surficial talus. With increasing water content debris slides grade into mudflows. These slides are often limited by the contact between the loose material and underlying firm bedrock.

In a flow the movement resembles that of a viscous fluid (Bishop, 1973). In other words, as movement downslope continues, intergranular movements become more important than shear surface movements. Slip surfaces are usually not visible or are short-lived, and the boundary between the flow and the material over which it moves may be sharp or may be represented by a zone of plastic flow. Some content of water is necessary for most types of flow movement, but dry flows can and do occur. Consequently, the range of water content in flows must be regarded as ranging from dry at one extreme to saturated at the other. Dry flows, which consist predominantly of rock fragments, are simply referred to as rock fragment flows or rock avalanches and generally result from a rock slide or rockfall turning into a flow. They are generally very rapid and short-lived, and are frequently composed mainly of silt or sand. As would be expected, they are of frequent occurrence in rugged mountainous regions, where they usually involve the movement of many millions of tonnes of material. Wet flows occur when fine-grained soils, with or without coarse debris, become mobilized by an excess of water. They may be of great length.

Progressive failure is rapid in debris avalanches and the whole mass, either because it is quite wet or is on a steep slope, moves downwards, often along a stream channel, and it advances well beyond the foot of a slope. Lumb (1975) reported speeds of 30 m s for debris avalanches in Hong Kong. The main characteristics of many slips that occur in the residual soils (mainly decomposed granite) of Hong Kong are the rapid fall of debris (once movement starts the whole mass separates from the main slope within minutes) and the shallow depth of the slide, usually less than 3 m. The ratio of thickness to length of the scar is usually less than 1.5. There is rarely any prior warning that a slip is imminent. The prime cause of failure is direct infiltration of rainwater into the surface zones of slopes, leading to soil saturation and its loss of effective cohesion. Debris avalanches are generally long and narrow, and frequently leave V-shaped scars tapering headwards. These gullies often become the sites of further movement.

Debris flows are distinguished from mudflows on the basis of particle size, the former containing a high percentage of coarse fragments, while the latter consist of at least 50% sand-size or less. Almost invariably, debris flows follow unusually heavy rainfall or the sudden thaw of frozen ground. These flows are of high density, perhaps 60 to 70% solids by weight, and are capable of carrying large boulders. Like debris avalanches, they commonly cut V-shaped channels, at the sides of which coarser material may accumulate as the more fluid central area moves down-channel. Debris may move over many kilometres.

Mudflows may develop when a rapidly moving stream of storm water mixes with a sufficient quantity of debris to form a pasty mass. Because such mudflows frequently occur along the same courses, they should be kept under observation when significant damage is likely to result. Mudflows frequently move at rates ranging between 10 and 100m min and can travel over slopes inclined at 1° or less, although they usually develop on slopes with shallow inclinations, that is, between 5 and 15°. Skempton and Hutchinson (1969) observed that mudflows also develop along discretely sheared boundaries in fissured clays and varved or laminated fluvio-glacial deposits where the ingress of water has led to softening at the shear zone. Movement involves the development of forward thrusts due to undrained loading of the rear part of the mudflow, where the basal shear surface is Inclined steeply downwards. A mudflow continues to move down shallow slopes due to this undrained loading which is implemented by frequent small falls or slips of material from a steep rear scarp on to the head of the moving mass. This not only aids instability by loading but it also raises the pore water pressures along the back part of the slip surface (Hutchinson and Bhandari, 1971; Bromhead, 1978).

An earthflow involves mostly cohesive or fine-grained material, which may move slowly or rapidly. The speed of movement is to some extent dependent on water content in that the higher the content, the faster the movement. Slowly moving earthflows may continue to move for several years. These flows generally develop as a result of a build-up of pore water pressure, so that part of the weight of the material is supported by interstitial water with consequent decrease in shearing resistance. If the material is saturated, a bulging frontal lobe is formed and this may split into a number of tongues, which advance with a steady rolling motion. Earthflows frequently form the spreading toes of rotational slides due to the material being softened by the ingress of water. Skempton and Hutchinson (1969) restricted the term 'earthflow' to slow movements of softened weathered debris, as forms at the toe of a slide. They maintained that movement was transitional between a slide and a flow, and that earthflows accommodated less breakdown than mudflows.

Factors Affecting Landslide

Landslides in Relation to Geomorphology (Landform: Slope angle, elevation)

Mehortra, Sarkar and Dharmaraju (1992) analyzed that maximum number of landslides occur in the slope category of 31^o-40^o followed by slope category 21^o-30^o. These slope categories in the field have been found to consist predominantly of moderate to highly weathered rock types frequently jointed and fractured as well. Incidence of landslides have been found to be much less on the rocky slopes generally steep, falling in the category of 51^o-60^o more than 60^o.

The change of slope gradient may be due to natural or artificial interference i.e. to the undermining of the foot of the slope by stream erosion or by excavation. Exceptionally, the change of slope gradient may be produced by tectonic processes, by subsidence or uplift. The increase in slope gradient provokes a change of stress in the rock mass; the equilibrium is then distributed by the increase in shear stress. Upon the relief of lateral stress the rocks on the slope loosen and facilitate the penetration of water (Zaruba and Mencel, 1967).

Varnes (1984) noted that steepness of slope in relation to the strength of slope forming materials was very important: for zoning purposes, slope inclination was often grouped into range of degrees or percentages. He also pointed out that the interrelation between slope gradient and stability was not simple and that the steeper slope might not always be those most likely to fail. Many steep slopes of competent rock were more stable as compared to gentle slopes of weak material. The complex relationships between relative frequency of landslides, slope and lithology could be statistically examined.

The data suggested that while steeper slopes provided greater potential energy to induce failure, they were also indicative of higher strength materials. This trade-off between increased driving force and increased strength appeared to reduce the importance of slopes that were steeper than this threshold should be influenced to a greater degree by the remaining factors that affect landslide susceptibility.

Landslides in Relation to Geology (Lithology, Structural geology)

Lee and Min (2001) stated the landslide occurrence value was higher in granite gneiss and leucocratic gneiss areas, and was lower in quartz mica schist and biotite gneiss areas.

Khantaprab (1993) conducted a study on November 1988 landslides in southern Thailand and proposed the geology factors influencing the landslides. The areas underlain by granitic terrain with residual soil of weathered granite had higher landslides.

Landslides in Relation to Surface Drainage zone

It is observed that the incidence of landslides are more in areas having drainage density values between 3-4 km/km^2 characterized by medium to coarse texture having infiltration more or equal to runoff. The areas designated as low having drainage density values less than 3.0 km/km^2 and characterized by coarse texture with infiltration more than runoff. The frequency of landslides has been found to be comparatively much less in areas having drainage density values more than 4 km/km^2 having fine to medium texture (Mehrotra, Sarkar and Dharmaraju, 1992).

Landslides in Relation to Soil Characteristics

Collins and Znidarcic (2004) stated the relations between soil and rainfall parameters and the cause of failure for slopes subject to infiltration. Coarse-grained soils and high infiltration rates lead to the development of positive pore water pressures and failure will be caused by seepage forces within the slope. Fine-grained soils and low infiltration rates do not lead to the development of positive pore pressures and failure will more often occur due to the decrease in shear strength caused by the loss of suction. In general, shallower failures are associated with the development of positive pore pressures, while deeper failures are associated with a loss in suction. However, it should be noted that the failure depth is governed not only by the strength characteristics, but also by the hydraulic characteristics of the soil and that both should be investigated in performing detailed analyses.

Landslides in Relation to Land use and Land cover

Varnes (1984) stated effect of vegetation on slope stability appears to be complex in that depending on local conditions of soil depth, slope and type of vegetation, a vegetative cover in some ways definitely promotes stability and in other ways it may not.

Greenway (1987) also stated in the same way that vegetation that may be growing on a slope has traditionally been considered to have an indirect or minor effect on stability; and it is usually neglected in stability analysis. This assumption is not always correct and for certain forested slopes with relatively thin soil mantles has shown significantly in error.

The relationship of landslide activities with various land use types in the Himalayan region, India. The agricultural lands have occupied the maximum area and have also shown maximum proneness to landslide. The high rate of landslide event in this category of land use could be due to its locations commonly preferred by local people either in old/dormant slide area or close to populated areas where ill planned construction activities have already taken place. The barren and sparsely vegetated areas have shown more frequent occurrences of landslides as compared to thickly and moderately vegetated areas possibility due to insufficient growth of secondary vegetation on the slope and the ground (Mehrotra, Sarkar and Dharmaraju, 1992).

Landslides in Relation to Rainfall Intensity

Precipitation causes an increase or risk in the water level and increases the pore water pressure within the rock or soil. This action greatly reduces the shearing strength of the soil. This same water or an increase in moisture content adds weight to the mass and lubricates the slip planes. The actions will increase the chances for the down slope movement of the landslide mass.

Rain and melt water penetrate into the joints producing hydrostatic pressure; the increase in pour-water pressure in soil induces a change of consistence, which in turn causes a decrease of cohesion and internal friction. Recurrent sliding movement generally occurs in the years of usually high rainfall (Zaruba and Mencel, 1967).

Summerfield (1991) said that raindrops possess kinetic energy by virtue of their mass and velocity. Although the impact velocity of raindrops varies depending on the droplet size, wind speed and turbulence, raindrops of maximum size under normal conditions of around 6 mm diameter have an impact velocity of about 9 m/s. At this speed, rain drops can directly move particles more than 10 mm across and coarser material can be dislodged by the removal of down slope support provided by finer sediment. Rain splash erosion can occur wherever vegetation does not entirely cover the ground, although it is a more potent erosive agent in environments where there is little or no vegetation cover. Both slope gradient and surface characteristics influence the effectiveness of rain splash erosion. Experimental studies have shown that on low angle slope at 5^{o} only about 60% of the particles dislodged by the raindrop impacts move down slope but this percentage increases with gradient reaching 95% on 25^{o} slopes. It also appears that rain splash erosion is more effective on sandy surfaces than those containing a high proportion of clay and silt-sized material, apparently because the presence of finer particles contribute to cohesion.

Landslide Hazard Map in Thailand

Samran (1984) studied the rainfall erosivity-factor, R in Universal Soil Loss Equation, USLE, for mountainous areas in northern Thailand from automatic record rainfall intensity. He reported results that rainfall erosivity-factor, R indicated highly significant relationships between rainfall factor and rainfall amount in terms of annual, seasonal and monthly basis. And annual, wet seasonal and monthly rainfall had highly significant relationships with elevation and aspect.

Pantanahiran (1994) conducted research to identify landslide areas and to develop a predictive landslide model using various parameters from a limited data base. Pipun and Kiliwong areas in Thailand were selected for model development and validation, respectively. Information obtained from topographic maps and remotely sensed data were used in this study. The predictive model was formulated using logistic regression under TIN and GRID modules in ARC/INFO and SAS software. Land use/land cover and landforms were the primary factors affecting landslides in the study areas. The sensitive areas in Pipun occur at an elevation of 400-600 m which had slopes of 16-30°. In addition, approximately 75% of all landslides in Pipun occurred within 140 m of a stream channel. Eight parameters including elevation, aspect, vegetations (TM4), flow accumulation, soil characteristics (Brightness), soil moisture (Wetness), slope, and flow direction were selected as significantly contributing to the model. The logistic model was represented by the equation:

$$
\begin{aligned}
Y = {} & 1.8914 - 0.00281(\text{Elevation}) + 1.4215(\text{Adjusted aspect}) \\
& - 0.00505(\text{TM4}) + 0.00073(\text{Flow accumulation}) \\
& - 0.0042(\text{Brightness}) - 0.00504(\text{Wetness}) + 0.00698(\text{Slope}) \\
& - 0.00165(\text{Flow direction})
\end{aligned}
$$

and $P = 1/(1 + \exp(-Y))$ is the estimated probability (P) of landslide presence at a given cell.

The results indicated that the predictive model correctly classified 82% of the landslides at a 0.4 cutoff probability.

Table 1 The landslide potential and the rang of probability

Landslide Susceptibility Classes	Range of probability
Very low to nil susceptibility to landslide	0-20
Low susceptibility to landslide	21-40
Moderate susceptibility to landslide	41-60
High susceptibility to landslide	61-80
Very high susceptibility to landslide	80-100

Source: Pantanahiran (1994)

Auathaveepon (1995) reported application of satellite data on classification of landslide risk area in Amphoe Phipun, Changwat Nakhon Si Thammarat. Also the total of 226 square grid selected each 1x1 square kilometer corresponding with active landslide which occurred in 1989. The slope, landform, geological characteristics, soil characteristic, rainfall and landuse were investigated as independent variable coinside with appearant landslide on sattellite image. The relationships between the percentage of landslide and independent variables were formulated by stepwise method. The best multiple regression equation is

$$\text{Log } Y = 1.3285 - 0.0101(\text{Slope}) - 0.1021(\text{Landform}) + 0.9178(\text{Land use}) + 0.5189(\text{Geology}) - 0.8939(\text{Soil}) + 0.3213(\text{Rainfall})$$

in which the coefficient of determination (R^2) is equal 0.6538.

For landslide susceptibility study Department of Land Development used weighting factor index. Five factors such as rock type, slope, land use, soil properties and rainfall precipitation intensity were identified as the main factors governing slope instability in Thailand.

Table 2 The detailed descriptions of different weighted factor values

Parameter	Weight Value	Rating Value		Score
		Description	Rating	
1. Rock type	10	1. Sedimentary rock 2. Sandstone/Shale 3. Limestone/Dolomite/Pyrite 4. Metamorphic of Igneous rock/Quartzite 5. Granite/Slate	1 2 3 4 5	1x10=10 2x10=20 3x10=30 4x10=40 5x10=50
2. Slope (%)	9	1. 0-8% 2. 8-16% 3. 16-35% 4. 35-50% 5. >50%	1 2 3 4 5	1x9=9 2x9=18 3x9=27 4x9=36 5x9=45
3. Land used and Land cover	8	1. Forest 2. Grassland/Deforest 3. Vacant land/Orchard 4. Agriculture 5. Open area	1 2 3 4 5	1x8=8 2x8=16 3x8=24 4x8=32 5x8=40
4. Soil properties	7	1. Fine grain soil +deep 2. Medium +deep/ Fine grain soil +intermediate 3. Fine grain soil +shallow/ Coarse grain soil +deep 4. Medium + intermediate 5. Coarse grain soil +shallow	1 2 3 4 5	1x7=7 2x7=14 3x7=21 4x7=28 5x7=35
5. Rainfall intensity	6	1. < 1,800 mm/yr 2. 1,801-2,100 mm/yr 3. 2,101-2,400 mm/yr 4. 2,401-3,200 mm/yr 5. 3,201-4,000 mm/yr	1 2 3 4 5	1x6=6 2x6=12 3x6=18 4x6=24 5x6=30

Source: Department of Land Development (1996)

Table 3 The landslide potential and the rang of total score

Landslide Susceptibility Classes	Range of Score
Very low to nil susceptibility to landslide	40-72
Low susceptibility to landslide	73-104
Moderate susceptibility to landslide	105-136
High susceptibility to landslide	137-168
Very high susceptibility to landslide	169-200

Source: Department of Land Development (1996)

Naramngam (1996) applied GIS and factor of safety (F.S.) in determining landslide risk area sub-watershed Klong Kathu and Klong Dindaeng of Tapi watershed, Changwat Nakhon Si Thammarat. The F.S. value was calculated using the equations proposed by Mairaing, Abe, Gray and Megahan, Gray and Leiser, Wu et al. and Coppin and Richards. Applicability and efficiency of those equations were evaluated based on the concided value (CV) representing percentage of the overlaps in terms of size and location of landslide area between actual and simulated landslide maps. The most feasible equation in determining and mapping landslide risk area is Wu et al.'s equation when soil depth was given at 1.5 m. and 2.0 m.

Chalermpong (2002) conducted to identify landslide risk area and communities that might be affected by landslides in the East-Coast Gulf Watershed. Landslide statistics and factors were investigated. The landslide risk factors were employed together with the geographic information system to prepare, analyze, and map landslide risk area. The land use map, geology map, and soil group map were used to analyses landslide risk.

Junkhiaw (2003) applied the technique of geographic information system and Artificial Neural Network (ANN) to create modal flash flood and landslide risk area. The modal was conducted under the influence parameters such as the topographical, geomorphology, land use characteristics, and hydrometeorology. The Phuket Island was the study area. High level hazard of landslide was found on granite mountain.

Thaijeamaree (2003) studied the landslide behaviors for Nam Kor Watershed, Nam Kor subdistrict, Lom Sak district, Phetchabun Province. The studies were done by field survey on landslide area, field tests, and laboratory tests such as strength. Finite Element Method on soil slope during heavy rainfall was performed using these test results for infiltration analyses. The relationship of rainfall patterns and the stability of slope gave the critical rainfall causing landslide. This report found direct shear test showed when the moisture content of the samples increased, the shear strengths decreased. These relationships can establish the critical rainfall envelope when the Factor of Safety (FS.) is equal to unity. With the various rainfall patterns from 1-14 raining days, the critical rainfall envelope can be established and used as future warning levels for the villager.

Table 4 The detailed descriptions of different weighted factor values

Parameter	Weight Value		Rating Value		Score
	Weight	Sub	Description	Rating	
1. Geology	5				
1.1 Rock type		3	A. Igneous rocks	5	5x3=15
			B. Sedimentary rocks	3	3x3=9
			C. Metamorphic rocks	1	1x3=3
1.2 Lineament zone		2	A. Inside lineament zone	3	3x2=6
			B. Outside Lineament zone	1	1x2=2
2. Landform	4				
2.1 Slope (%)		3	A. >70%	5	5x3=15
			B. 50-70%	4	4x3=12
			C. 30-50%	3	3x3=9
			D. 15-30%	2	2x3=6
			E. 0-15%	1	1x3=3
2.2 Elevation-m		1	A. >401 m	5	5x1=5
			B. 301-400 m	4	4x1=4
			C. 201-300 m	3	3x1=3
			D. 101-200 m	2	2x1=2
			E. 0-100 m	1	1x1=1
3. Surface drainage zone	2		A. Inside	2	2x2=4
			B. Outside	1	1x2=2
4. Soil characteristics	2		A. Gravel loam/Gravelly sand	5	5x2=10
			B. Sand	4	4x2=8
			C. Sandy loam	3	3x2=6
			D. Clayey loam/loam	2	2x2=4
			E. Clay, Mud	1	1x2=2
5. Land used and Land cover	3		A. Agriculture area	4	4x3=12
			B. Urban and build-up area	3	3x3=9
			C. Other deforestation	2	2x3=6
			D. Forest area	1	1x3=3
6. Rainfall intensity (mm)	5		A. > 2,826 mm/yr	3	3x5=15
			B. 2,726-2,825 mm/yr	2.5	2.5x5=12.5
			C. 2,626-2,725 mm/yr	2	2x5=10
			D. 2,476-2,675 mm/yr	1.5	1.5x5=7.5
			E. 2,325-2,475 mm/yr	1	1x5=5

Source: Thassanapak (2001)

Table 5 The landslide potential and the rang of total score

Landslide Susceptibility Classes	Range of Score
Very low to nil susceptibility to landslide	21-33
Low susceptibility to landslide	34-45
Moderate susceptibility to landslide	46-58
High susceptibility to landslide	59-70
Very high susceptibility to landslide	71-82

Source: Thassanapak (2001)

Study susceptibility of landslide by Thassanapak (2001) use weighted factor index. The influencing parameter of geology including rock types and lineament zone, slope gradient and elevation, surface drainage zone, land use and land cover, soil characteristics, and rainfall intensity were identified as the main factors governing slopes instability in Phuket Thailand.

Kunsuwan (2005) studied the landslide behavior for Khlong Krating, Khlong Takhian and Klong Thung Phen, in Chantaburi sub-basin during the heavy rainfalls and floods in 1999 and 2001. The hazard map was created by the relationships between the rainfall patterns, rainfall duration, return period, the slope stability and the critical rainfall envelop in order to use for landslides warning. The results showed that the failure slopes were on the area of 25-35 degree slopes and the depth of 2.5-3.5 meters. The soil profiles were on the weathered granite rock with high natural moisture contents. The shear strength of soil decreased with increase of the degree of saturation. The study of the distribution of the sediment carried from the landslide areas along the rivers found that the sediment of rocks decreased with increasing of the distance from the source. The critical F.S. occurred right after the end of heavy rainfall. The correlation of the slope stability analyses with the historical rainfall data lead to landslide critical rainfall envelope of the F.S. equal to 1.1.

General Method of Evaluating Landslide Hazard Zonation.

Definition of Hazard Zonation

To differentiate between the terms hazard; and risk, following definitions (given by Varnes, 1984) have become generally accepted:

NATURAL HAZARD (H): The probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area.

VULNERABILITY (V): The degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is exposed on a scale from 0 (no damage) to 1 (total loss).

SPECIFIC RISK (Rs): The expected degree of loss due to a particular natural phenomenon. It may be expressed by the product of H and V.

ELEMENT AT RISK (E): The population, properties, economic activities, including public services, etc. at risk in a given area.

TOTAL RISK (Rt): The expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon. It is therefore the product of specific risk (Rs) and elements at risk (E).

Hazard Assessment

Disaster result from vulnerable conditions being exposed to a potential hazard. Therefore, the first step in taking any mitigation measures is to assess the hazard. Hazard assessment aims to come to grips with: (a) the nature, severity and frequency of the hazards; (b) the area likely to be affected; and (c) the time and duration of impact. (Ian Davis and Gupta, 1989)

Landslide Hazard Zonation

Landslide hazard is commonly shown on maps, which display the spatial distribution of hazard classes (landslide hazard zonation). Zonation refers to " the division of the land in 'homogeneous' areas or domains and their ranking according to degrees of actual/potential hazard caused by mass movement" (Varnes, 1984).

Anbalagan (1992) stated that Landslide Hazard Zonation (LHZ) map depicts the division of land surface in to zones of varying degree of stability based on the estimated significance of the causative factors in inducing instability. He pointed out the usefulness of the LHZ map as follow.

The LHZ maps are useful for the following purposes

l. LHZ map help the planners to choose favourable location for site development schemes such as building and road construction. Even if the hazardous areas can not be avoided altogether, their recognition in the initial stages of planning may help to adopt suitable precautionary measures.

2. As the LHZ map delineates the areas into zones of varying degree of stability, the environmental regeneration measures can be initiated in high hazard areas by adopting suitable mitigation measures.

Mapping Scale

Van Westen (1994) stated selection of the working scale for a slope instability analysis project is determined by the purpose for which it is executed. He followed the scale of analysis presented in the International Association of Engineering Geologists monograph on engineering geological mapping (IAEA, 1976) in his study of landslide hazard zonation in Andes of Colombia. The scales are
National scale (< 1: 1,000,000) Synoptic or regional scale (< 1:100,000) Medium scale (1:25,000 - 1:50,000) Large scale (1:5,000 - 1: 10,000)

Mapping Framework of Landslide

Einstein (1988) introduced the framework of mapping landslide in to five levels

1. State of nature map
2. Danger maps
3. Hazard maps
4. Risk maps
5. Landslide management maps

Hazard Mapping Analysis

Van wester (1993) stated in his publication that the most straightforward type of hazard map is a landslide inventory map displaying present and past landslides. Assessment of the area extent of landslides and their evolution in the recent past can be made with the use of multi-temporal photo interpretation and geomorphological fieldwork.

The report stated that the prediction of hazard in areas presently free of landslides requires different methods, based on the assumption that hazardous phenomena that have occurred in the past can provide useful information for the prediction of occurrences in the future. Therefore, mapping these phenomena and the factors thought to be of influence is very important in hazard zonation. He cited the two general approaches used for such mapping

1. Many of the geomorphology-based hazard zonation studies can be called hazard mapping studies, since the hazard is basically assessed in the field during mapping. This method is also called direct approach (Hansen, 1984).

2. Indirect methods calculate the importance of the combinations of parameters occurring in landslide locations, and extrapolate the results to landslide-free areas with similar combinations, mostly by statistical techniques (Hansen, 1984)

The report cited Hartlen and Viberg (1988) who differentiated between relative hazard and absolute hazard assessment techniques. The relative hazard assessment techniques differentiate the likelihood of occurrence of mass movements for different areas on the map, without giving exactly exact values.

Absolute hazard maps display an absolute value for the hazard, either as a factor of safety or a probability of occurrence. A combination is also possible, indicating the probability that the factor of safety is below one.

Absolute hazard assessment techniques can be divided into three main groups (Carrara, 1983; Hartlen and Viberg, 1988):

1. White box model, based on physical models (slope stability and hydrological models) also referred to as deterministic models;
2. Black, box models, not based not on physical models but on statistical analysis;
3. Grey box models, based partly on physical models and partly on statistics.

Principles of Hazard Zonation

According to Varnes (1984) Landslide Hazard Zonation is still in a stage of experimentation. He has indicated at least three basic principles or fundamental assumptions that have guided all zonation studies.

1. The past and present are keys to the future
2. The main conditions that cause landslide can be identified
3. Degree of hazard can be estimated

General Trend in Landslide Hazard Zonation Techniques

A large amount of research on hazard zonation has been done over the last 30 years as the consequences of and urgent demand for slope instability hazard mapping. Several types of landslide hazard zonation techniques have been developed in which Van westen (1994) has listed the summary of the various trends in the development of techniques as follow

Type of landslide analysis	Main characteristic
A. Distribution analysis	Direct mapping of mass movement features resulting in a map which gives information only for those sites where landslides have occurred in the past
B. Qualitative analysis	Direct, or semi-direct, methods in which the geomorphological map is renumbered to a hazard map or in which several maps are combined into one using subjective decision rules, based on the experience of the earth scientist
C. Statistical analysis	Indirect methods in which statistical analysis are used to obtain predictions of the mass movement hazard from a number of parameter maps
D. Deterministic analysis	Indirect methods in which parameter maps are combined in slope stability calculations

E. Landslide frequency analysis	Indirect methods in which earthquake and/or rainfall records or hydrological models are used for correlation with known landslide dates, to obtain threshold values with a certain frequency

Data Required for Input in GIS for Landslide

Van Westen (1994) pointed out the list of various input data needed to assess landslide hazard at regional, medium and large scale. The list is extensive, and only in a ideal case will all type of data be available. However, the amount and type of data that can be collected, determine the type of hazard analysis that can be applied ranging from qualitative assessment to complex statistical methods.

The data layer needed to analyze landslide hazard can be subdivided into five main groups; geomorphical; topographic; engineering geological or geotechnical; land use; and hydrological data. A data layer in a GIS can be seen as one digital map, containing one type of data composed of one type of element (points, line, units) and having one or more accompanying Tables. The layers that have to be taken into account vary for different environment.

Phases of Landslide Hazard Analysis Using GIS (Van westen, 1993)

The following phases can be distinguished in the process of mass movement hazard analysis using GIS:

1. Choice of working scale and the methods of analysis which will be applied;
2. Collection of existing maps and reports with relevant data;
3. Interpretation of Images and creation of new input maps;
4. Design of the data base and definition of the way in which data should be collected and stored;
5. Fieldwork to verify the photo-interpretation and to collect relevant quantitative data;
6. Laboratory analysis of soil and rock samples for classification;
7. Digitizing of maps and attribute data;
8. Validation of the entered data;
9. Manipulation and transformation of the raw data to a form which can be used in the analysis;
10. Analysis of data for preparation of hazard maps;
11. Evaluation of the reliability of the output maps and inventory of the errors which may have occurred during the previous phases.
12. Final production of hazard maps and adjoining reports.

Weighting Factor Method

A numerical rating system or a weight-rating system is based on the theory of logical combination. A weighting or a measure of relative importance, must be assigned each influencing factor. Each influencing factor was subdivided into subclasses and given index numbers. Although the index numbers are for identification only, the subclasses should be arranged in a logical sequence, such as from gentle to steep or small to large. The product of these factors was the potential of the area indicated susceptibility to landslide.

A simplified formula to predict the susceptibility to landslide is defined as follows;

$$M_t = M_1W_1+M_2W_2+ M_3W_3+ M_4W_4+\ldots\ldots\ldots\ldots+ M_nW_n$$

Where M_t = Total scores
M = Value of the importance factor
W = Value of subclasses of the importance factor

Rock Mass Qualitative System

Rock masses have been described from the earliest geological maps onwards. The descriptions of the rocks were initially in lithological and in other geological terms. With increasing knowledge of geology, geological features and the influence of geology on engineering the amount of information to be included in a description for geotechnical purposes increased, leading to sets of rules for the description or characterization of a rock mass geotechnically. Parallel with this development, a movement took place in mining and engineering geology to combine the characterization of a rock mass with direct recommendations for tunnel support. This resulted in rock mass classification systems. The systems were developed primarily empirically by establishing the parameters of importance, giving each parameter a numerical value and a weighting. This led, via empirical formulae, to a final rating for a rock mass. The final rating was related to the stability of the underground excavation. In systems that are more elaborate, the rating was also related to the support installed in the excavation and to stand-up times. The success of classification systems in underground excavations resulted in classification systems also being used for slopes. Classifications systems have been designed following many different calculation methods and also the used parameters and their influence on the final result differ widely from system to system. This obviously sets some question marks to the validity of classification systems. The correlation between the results of some systems is often quoted to prove that the systems do work, but also this on detailed investigation seems not to be so convincing.

Rock Mass Rating

In 1973 Bieniawski introduced the Geomechanics Classification also named the Rock Mass Rating (RMR), at the South African Council of Scientific and

Table 6 Rock mass rating

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4-10 MPa	2-4 MPa	1-2 MPa	For this low range - uniaxial compressive test is preferred
		Uniaxial comp. strength	>250 MPa	100-250 MPa	50-100 MPa	25-50 MPa	5-25 MPa / 1-5 MPa / < 1 MPa
	Rating		15	12	7	4	2 / 1 / 0
2	Drill core Quality *RQD*		90%-100%	75%-90%	50%-75%	25%-50%	< 25%
	Rating		20	17	13	8	3
3	Spacing of discontinuities		> 2 m	0.6-2 . m	200-600 mm	60-200 mm	< 60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous
	Rating		30	25	20	10	0
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10-25	25-125	> 125
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1,-0.2	0.2-0.5	> 0.5
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300-400	200-300	100-200	< 100
Friction angle of rock mass (deg)	> 45	35-45	25-35	15-25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1-3 m 4	3-10 m 2	10-20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1-1.0 mm 4	1-5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip-Dip 45-90°	Drive with dip-Dip 20-45°	Dip 45-90°	Dip 20-45°
Very favourable	Favourable	Very favourable	Fair
Drive against dip-Dip 45-90°	Drive against dip-Dip 20-45°	Dip 0-20-Irrespective of strike°	
Fair	Unfavourable	Fair	

*Some conditions are mutually exclusive. For example, if infilling is present, the roughness of the surface will be over-shadowed by the influence of the gouge. In such cases use A.4 directly.

Source: Bieniawski (1989)

Industrial Research (CSIR). The rating system was based on Bieniawski´s experience in shallow tunnels in sedimentary rocks. Originally, the RMR-system involved 49 unpublished case histories. Since then the classification has undergone several significant changes. In 1974 there was a reduction of parameters from 8 to 6 and in 1975 there was an adjustment of ratings and reduction of recommended support requirements. In 1976 a modification of class boundaries took place (as a result of 64 new case histories) to even multiples of 20 and in 1979 there was an adoption of the ISRM rock mass description. The newest version of RMR is from 1989, where Bieniawski published guidelines for selecting the rock reinforcement. In that version, Bieniawski suggested that the user could interpolate the RMR-values between different classes and not just use discrete values. Therefore, it is important to state which version is used when RMR-values are quoted. Since the Hoek-Brown, Yudhbir and Sheorey rock mass criteria suggest and prefer that the 1976 version of RMR should be used. When applying this classification system, one divides the rock mass into a number of structural regions and classifies each region separately. The RMR-system uses the following six parameters, whose ratings are added to obtain a total RMR-value.

i. Uniaxial compressive strength of intact rock material;
ii. Rock quality designation (RQD);
iii. Joint or discontinuity spacing;
iv. Joint condition;
v. Ground water condition; and
vi. Joint orientation.

The first five parameters (i-v) represent the basic parameters (RMRbasic) in the classification system. The sixth parameter is treated separately because the influence of discontinuity orientations depends upon engineering applications. Each of these parameters is given a rating that symbolizes the rock quality description.

Slope Mass Rating

Most of the empirical rating methods apply adjustment factors to their basic rock mass rating. These adjustment factors account for such things as defect orientation, excavation method, weathering, induced stresses and major planes of weakness. Bieniawski (1976 and 1989) applies the adjustments by subtracting them from the rock mass rating. Table 1 show that the defect orientation adjustment can dominate the RMR. If the defect orientations are deemed “very unfavourable” an adjustment of -60 is required to the basic rock mass rating. Even for defect orientations denoted as “fair” this adjustment is -25. There is no guideline as to what “very unfavourable” means. Bieniawski (1989) recommends the use of the Romana (1985) SMR corrections for slopes. Romana used the same basic rock mass rating as RMR_{89} but developed new adjustment factors for joint orientation and blasting to account for the lack of guidelines in the RMR methods. The equation for SMR is shown below. The joint orientation weighting includes a factor for the difference between joint dip and slope angle, F_3. This requires an iterative approach for design.

Table 7, 8 and Table 9 show the adjustment ratings.

$$SMR = RMR + F_1F_2F_3 + F_4$$

Romana (1985) developed his factors not only for rock mass failures but also for wedge and planar failure. A rock mass rating method should not be used for these two cases as they are defect controlled and can be assessed using such measures as stereographic projection. Even if the method was applicable, the ratings for planar failure are questionable. F_2 depends on defect dip and must account for the defect shear strength. However, the method seems to assume that friction angles are quite high. For example, bedding surface shears may attain strengths of ϕ' below 12° yet these would be given a 'very favourable' rating of 0.15.

Table 7 Adjustment rating for joints

Case		Very Favourable	Favourable	Fair	Unfavourable	Very unfavourable
P	$\lvert\alpha_j - \alpha_s\rvert$	>30°	30°-20°	20°-10°	10°-5°	<5°
T	$\lvert\alpha_j - \alpha_s - 180^\circ\rvert$					
P/T	$F_1 = (1 - \sin\lvert\alpha_j - \alpha_s\rvert)^2$	*0.15*	*0.4*	*0.7*	*0.85*	*1.00*
P	$\lvert\beta_j\rvert$	<20°	20°-30°	30°-35°	35°-45°	>45°
P	$F_2 = \tan^2\beta_j$	*0.15*	*0.4*	*0.7*	*0.85*	*1.00*
T	F_2	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
P	$\beta_j - \beta_s$	>10°	10°-0°	0°	0°-(-10°)	<-10°
T	$\beta_j - \beta_s$	<110°	110°-120°	>120°	-	-
P/T	F_3	*0*	*-6*	*-25*	*-50*	*-60*

P - Planar failure; α_s - Slope dip direction; α_j - Defect dip direction

T - Toppling failure; β_s - Slope dip; β_j - Defect dip

Source: Romana (1985)

Table 8 Adjustment rating for methods of excavation of slopes

Method	Natural Slope	Presplitting	Smooth Blasting	Blasting or Mechanical	Defficient Blasting
F_4	+15	+10	+8	0	-8

Source: Romana (1985)

Table 9 Tentative description of SMR classes

SMR	0-20	21-40	41-60	61-80	81-100
Class	V	IV	III	II	I
Description	Very Bad	Bad	Normal	Good	Very Good
Stability	Completely Unstable	Unstable	Partially Stable	Stable	Completely Stable
Failures	Big planar or soil like	Planar or big wedges	Some joints or many wedges	Some blocks	None
Support	Reexcavation	Important/ Corrective	Systematic	Occasional	None

Source: Romana (1985)

The CSMR method (Chen, 1995) is based on the SMR method. The CSMR applies a discontinuity condition factor, λ, that describes the conditions of the controlling discontinuity on which the ratings F1, F2 and F3 are based (Table 10). This factor ranges from 0.7 to 1.0. The CSMR method also assumes that the SMR method is applicable for a slope height of 80m but must be adjusted for other slope heights, H, using the slope height factor, x. The relationship for x, based on an extensive survey and rigorous analysis of slopes in China, is shown in Figure 3. With the addition of the two new factors, the equation for CSMR is defined as:

$$CSRM = \xi RMR + \lambda F_1 F_2 F_3 + F_4$$

$$\xi = 0.57 + 34.4H$$

where, *H* = Slope height in metres

Table 10 Discontinuity condition factor λ

λ	Defect Condition
1.0	Faults, long weak seams filled with clay
0.8 to 0.9	Bedding planes, large scale joints with gouges
0.7	Joints, tightly interlocked bedding planes

Source: Chen (1995)

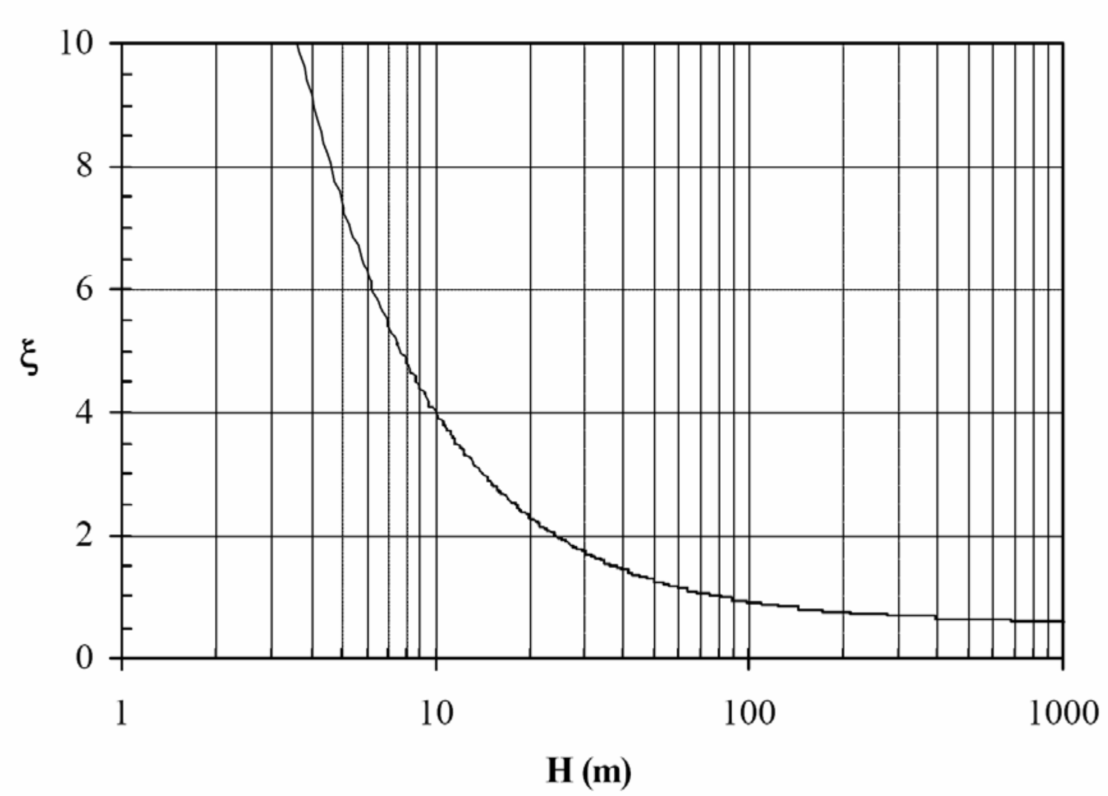


Figure 3 Slope height, H, vs slope height factor, x
Source: Chen (1995)

The CSMR has been based on the SMR and thus has similar problems. CSMR acknowledges the affect of slope height. It is the authors view that height should not be grouped with the rock mass rating (a defacto strength estimate) but should be addressed during the stability analysis where it will contribute to the stresses acting.

Cut slope

Japan Society of Engineering Geology (1992) stated that in order to design for the earthwork or tunnels, it is essential to probe ahead and to grasp geological conditions, soil and rock properties which make up the object of rock mass. But considering the complex and varied conditions of topographies and geologies in Japan, it is impossible to grasp all conditions at the stage of probing ahead. After the construction started pratically, problems which we have unexpected at the stage of probing ahead often rises. So original design, classified geological conditions strictly and designed each geological conditions minutely, often does not mean anything. For this reason, Japan Highway Public Corporation classifies familiar type of soil and geological conditions roughly, and tries to design or construct efficiently and rationally. Japan Society of Engineering Geology (1992) reported on the standard rock mass classification for the choice of cut slope gradient for earthwork design.

Table 11 Range of standard cut slope gradients for bedrock soil

Bedrock soil		Cut Height	Gradient
Hard rock			1:0.3 - 1:0.8
Soft rock			1:0.5 - 1:1.2
Sand	Those not dense, not solid and of bad grade distribution		1:1.5 -
Sandy soil	Those that are dense and solid	less than 5 m	1:0.8 - 1:1.0
		5 - 10 m	1:1.0 - 1:1.2
	Those not dense, not solid	less than 5 m	1:1.0 - 1:1.2
		5 - 10 m	1:1.2 - 1:1.5
Sandy soil mixed with gravel or rock mass	Those that are dense and solid or of good grade distribution	less than 10 m	1:0.8 - 1:1.0
		10 - 15 m	1:1.0 - 1:1.2
	Those not dense, not solid or of bad grade distribution	less than 10 m	1:1.0 - 1:1.2
		10 - 15 m	1:1.2 - 1:1.5
Cohesive soil		0 - 10 m	1:0.8 - 1:1.2
Cohesive soil mixed with rock mass or cobblestone		less than 5 m	1:1.0 - 1:1.2
		5 - 10 m	1:1.2 - 1:1.5

Note: 1) Silt is placed under cohesive soil. Individual consideration is given to soils not indicated in the table.
2) The gradient in the table is the gradient of a single slope not including the beam.
3) The indication of gradient 1:n=

Source: The Japan Highway Public Corporation (1992)

After construction starts, cut slope becomes weathered from surface as time goes by, and become unstable gradually. And generally speaking, natural ground is often complicated and ununiform. On this account, despite examining the cut slope stability for every individual geological condition in detail, the examination is often meaningless, regarding it as the whole road design. Generally, The Japan Highway Public Corporation (1992) adopted the value of cut slope gradient indicated in Table 11. It indicates the standard range of cut slope gradient produced by our experiences on the condition that the face of slope is protected from erosion to a certain degree.

However when engineering plane civil engineering design, it is necessary to consider the whole earthwork planning, and in filling section sometimes choosing gentle slope gradient to increase cumulative cut. In waste section, on the other hand, it is necessary to choose steep slope gradient protected stability by structure for decreasing cumulative cut to compare with standard slope gradient and many cutting. And in such places, large cut slope, slope in landslide area, or slopes with soil which may collapse, it is necessary to examine slope stability more minutely (The Japan Highway Public Corporation, 1992).

Logistic Regression

The Multiple Linear Regression Model

Multiple linear regression is in some ways a relatively straightforward extension of simple linear regression allowing for more than one independent variable. The objective of multiple regression is the same as that of simple regression; that is, we want to use the relationship between a response (dependent) variable and factor (independent) variables to predict or explain the behavior of the response variable. This chapter will illustrate the similarities and the differences between simple and multiple linear regression, as well as develop the methodology necessary to use the multiple regression model.

The multiple linear regression model is written as a straightforward extension of the simple linear model. The model is specified as

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m + \varepsilon,$$

where

y is the dependent variable

x_j, j = 1,2,..., *m,* represent *m* different independent variables

β_0 is the intercept (value when all the independent variables are 0)

β_j, j = 1, 2, ..., *m,* represent the corresponding *m* regression coefficients

ε is the random error, usually assumed to be normally distributed with mean zero and variance α^2

Although the model formulation appears to be a simple generalization of the model with one independent variable, the inclusion of several independent variables creates a new concept in the interpretation of the regression coefficients. For example, if multiple regression is to be used in estimating weight gain of children, the effect of each of the independent variables—dietary supplement, exercise, and behavior modification—depends on what is occurring with the other independent variables. In multiple regression we are interested in what happens when each variable is varied one at a time, while not changing values of any others. This is in contrast to performing several simple linear regressions, using each of these variables in turn, but where each regression ignores what may be occurring with the other variables. Therefore, in multiple regression, the coefficient attached with each independent variable should measure the average change in the response variable associated with changes in that independent variable, while all other independent variables remain fixed. This is the standard interpretation for a regression coefficient in a multiple regression model.

Multiple Logistic Regressions

The simple logistic regression model can easily be extended to two or more independent variables. Of course, the more variables, the harder it is to get multiple observations at all levels of all variables. Therefore, most logistic regressions with more than one independent variable are done using the maximum likelihood method. The extension from a single independent variable to m independent variables simply involves replacing $\beta_0 + \beta_1 x$ with $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m$ in the simple logistic regression equation given in Section 10.4. The corresponding logistic regression equation then becomes

$$\mu_{y/x} = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m)}$$

Making the same logit transformation as,

$$\mu_p = \log\left[\frac{\mu_{y/x}}{1 - \mu_{y/x}}\right],$$

we obtain the multiple linear regression model:

$$\mu_p = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m$$

General Information of Phuket province

The areas under study cover Phuket Island, about 900 km south of Bangkok on the west coast of peninsular Thailand. It is bound by latitudes 7^o 52' 12" and 7^o 57' 36" N and longitudes 9^o 15' 24" and 9^o 26' 48" E, encompassing an area of approximate 549 km^2. This includes three major districts, namely Amphoe Muang Phuket, Amphoe Thalang, and Amphoe Kathu. The mapped area covers the 1:50,000 topographic map of Changwat Phuket, sheet no 4624i, 4625ii.

The area studied covers approximately 549 km^2 in the Phuket Island. At least 60 percent of the area is granitic rocks of the Phuket Plutons. The ages of the granitices range from Cretaceous to Tertiary. The granites from composite plutons is elongated shape in the N-S direction. They have been divided, based upon field observation, into 5 types: from the older to the younger as coarse-grained porphyritic biotite granites (G-1), fine-to medium-grained biotite granites (G-2), medium-to coarse-grained biotite granite slightly porphyritic (G-3), fine-to-medium-grained biotite-muscovite granites locally porphyritic (G-4), and fine-grained biotite-muscovite-tourmaline granites (G-5) (Charusiri, 1980).

The permo-Carboniferous sedimentary rocks of the Phuket Group are wholly clastic and composed mainly of mudstone, laminated mudstone, diamictite, siltstone and sandstone. The stratified rocks are slightly metamorphosed due to tectonic effects and granitic intrusions. The general strike of the Phuket Group is from N-S to NE-SW with gentle dip. Structurally, both granitic and sedimentary rocks are considered principally to be faulted, and fractured by the tectonic episode developed from late Palezoic to Tertiary and locally by igneous activities.

Climate

The Phuket-Island climate can be classified as tropical rainforest climate with fairly uniform high temperatures and heavy rainfall throughout the year without distinct dry-cold season. The statistics produced by the Royal Thai Meteorological Department for Phuket during 1995 to 2004 reveal that the highest and lowest temperatures are about 36.2 ^{o}C and 16.9 ^{o}C, respectively. There are at least 6 months of heavy rainfall which are predominated by southwest monsoon rather than northeast monsoon. The yearly average rainfall is about 2,379 mm. The two highest rainfall peaks develop during the periods of transitional directions of monsoons. Monthly precipitation averages for Phuket is given below:

Table 12 Rainfall (m.m.) in Muang Phuket

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	T	0.0	0.0	5.0	121.1	295.7	212.0	453.4	494.3	388.6	399.6	67.3	2437.0
1999	64.2	90.5	111.0	265.4	152.1	229.8	224.3	337.9	381.6	426.3	242.1	25.1	2550.3
2000	59.1	104.4	112.7	183.9	234.0	240.9	65.3	367.7	290.5	416.9	167.9	127.7	2371.0
2001	69.2	36.2	189.9	75.9	164.1	267.9	222.1	225.8	495.3	224.6	112.6	118.8	2202.4
2002	9.1	0.0	59.2	86.8	202	223.5	201.6	239.3	361.9	223.3	178.1	114.4	1899.2
2003	13.3	0.0	147.2	72.3	92.6	230.7	356.7	393.0	352.3	658.6	112.3	36.0	2465.0
2004	21.3	2.7	10.1	51.8	195.1	338.8	350.7	266.8	173.9	387.8	127.1	66.7	1992.8
2005	1.2	3.8	8.2	84.2	311.7	158.3	72.4	138.3					773.1
1971-2000	21.7	30.3	59.2	135.4	282.6	244.0	283.5	293.5	381.4	305.0	173.8	59.4	2269.8
Rainfall (mm.) 1998-2005 and return period 30 year (1971-2000) (" T " = Trace)													

Source: The Meteorological Department (2006)

Table 13 Relative humidity (%) in Muang Phuket

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1998	68	67	67	68	73	80	82	83	83	85	84	79	77
1999	74	70	73	80	80	79	78	79	82	83	81	72	78
2000	73	71	75	81	79	81	77	79	80	82	79	80	78
2001	73	71	77	75	78	77	78	76	82	83	75	73	77
2002	67	64	68	73	76	78	75	76	81	81	79	77	75
2003	69	66	71	72	75	78	81	78	82	85	78	84	77
1971-2000	69	67	68	73	79	78	79	78	81	81	78	73	75
relative humidity (%) monthly 1998-2003 and return period 30 year (1971-2000)													

Source: The Meteorological Department (2006)

Table 14 Mean temperature (°C) in Muang Phuket

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1998	29.2	29.8	30.0	31.2	30.7	28.7	28.1	27.7	27.4	27.1	27.0	26.9	28.7
1999	27.7	28.3	28.9	28.1	28.1	27.8	28.0	27.8	27.3	27.1	27.0	26.9	27.8
2000	28.0	28.5	28.6	28.2	28.6	27.8	28.5	27.9	28.0	27.4	27.2	27.9	28.1
2001	28.1	28.6	28.3	29.7	28.9	29.1	28.4	29.3	27.4	27.5	27.8	28.5	28.5
2002	28.2	29.0	29.8	29.7	29.4	28.9	29.2	28.6	27.6	27.7	28.0	28.4	28.7
2003	28.5	29.4	29.6	29.7	29.3	28.6	27.7	28.4	27.6	26.8	28.3	27.8	28.48
2004	29.55	29.96	30.37	30.51	29.88	28.88	28.14	28.98	28.35	28.23	29.05	28.65	29.22
1961-1990	27.9	28.7	29.3	29.5	28.4	28.3	27.8	27.9	27.3	27.4	27.5	27.6	28.1
mean temperature (°C) monthly 1998-2004 and 30 year (1961-1990)													

Source: The Meteorological Department (2006)

Table 15 Mean max. temperature (°C) in Muang Phuket

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1998	34.7	35.3	35.7	36.4	35.2	32.9	32.4	32.2	31.5	30.9	31.1	31.0	33.3
1999	32.3	32.9	33.6	32.3	32.4	32.1	31.9	32.0	32.0	31.3	31.6	31.5	32.2
2000	32.8	-	-	32.1	32.3	31.3	32.2	31.4	32.1	31.3	30.8	31.7	31.8
2001	31.9	32.7	32.2	33.5	32.8	32.1	32.3	32.4	31.2	31.5	31.6	32.1	32.2
2002	32.4	33.7	33.8	33.6	32.8	32.2	32.6	32.0	31.6	32.1	32.0	32.1	32.6
2003	32.7	34.3	34.3	34.1	33.0	32.6	31.5	31.9	30.9	30.2	32.3	31.6	32.45
2004	33.58	33.95	34.25	34.53	33.01	31.88	31.26	31.90	31.91	31.72	32.41	32.07	32.70
1961-1990	31.8	32.9	33.5	33.4	32.0	31.6	31.2	31.2	30.7	30.9	31.0	31.2	31.8
mean max. temperature (°C) monthly 1998-2004 and 30 year (1961-1990)													

Source: The Meteorological Department (2006)

Table 16 Mean min. temperature (°C) in Muang Phuket

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1998	25.7	26.3	26.2	27.7	27.6	25.9	25.4	25.1	24.8	24.9	24.6	24.5	25.7
1999	24.7	25.1	25.9	25.2	25.4	25.1	25.5	25.0	24.5	24.6	24.6	24.3	25.0
2000	24.9	25.0	25.4	25.4	25.9	25.2	25.7	25.4	25.2	24.9	25.0	25.1	25.3
2001	25.1	25.1	25.4	26.4	26.5	26.0	25.5	26.1	24.9	24.9	25.4	25.0	25.5
2002	25.1	25.4	26.2	26.6	26.3	26.1	26.3	26.4	25.0	24.7	25.3	25.8	25.8
2003	25.5	26.0	26.3	26.3	26.7	25.6	25.0	25.4	24.8	24.5	25.3	25.0	25.53
2004	25.75	25.97	26.49	26.49	26.74	25.87	25.02	26.06	24.79	24.73	25.69	25.22	25.74
1961-1990	23.3	23.7	24.3	24.8	24.5	24.5	24.2	24.4	23.9	23.8	23.8	23.7	24.1
mean min. temperature (°C) monthly 1998-2004 and 30 year (1961-1990)													

Source: The Meteorological Department (2006)

Population

The population census was carried out in 2005 and an effort was made to obtain Thumbon for Phuket province.

Table 17 Population Density

	MALE	FEMALE	TOTAL	HOUSE
Phuket Province	140,703	151,542	292,245	128,110
Amphur Mueang Phuket	50,088	53,473	103,561	53,671
Ko Kaeo	4,273	4,404	8,677	3,967
Ratsada	14,675	15,365	30,040	14,993
Vichit	17,571	19,034	36,605	18,817
Chalong	7,429	8,031	15,460	8,793
Rawai	6,140	6,639	12,779	7,101
Amphur Kathu	2,323	2,503	4,826	2,819
Kamala	2,323	2,503	4,826	2,819
Amphur Thalang	30,110	30,654	60,764	23,705
Thepkrasatri	5,719	5,727	11,446	4,038
Srisunthon	6,227	6,495	12,722	5,734
Choeng Thale	4,664	4,928	9,592	4,507
Pa Khlok	5,621	5,590	11,211	4,076
Mai Khao	5,812	5,779	11,591	3,697
Sakhu	2,067	2,135	4,202	1,653
Thepkrasatri Municipality	2,841	2,968	5,809	2,426
Thepkrasatri	2,841	2,968	5,809	2,426
Choeng Thale Municipality	1,613	1,745	3,358	1,648
Choeng Thale	1,613	1,745	3,358	1,648
Kathu Municipality	8,274	9,334	17,608	9,359
Kathu	8,274	9,334	17,608	9,359
Karon Municipality	3,107	3,283	6,390	4,779
Karon	3,107	3,283	6,390	4,779
Patong Municipality	7,784	7,937	15,721	10,020
Patong	7,784	7,937	15,721	10,020
Phuket Municipality	34,563	39,645	74,208	19,683
Talat Yai	23,919	27,045	50,964	12,424
Talat Nua	10,644	12,600	23,244	7,259

Source: Department of Provincial Administration (2006)

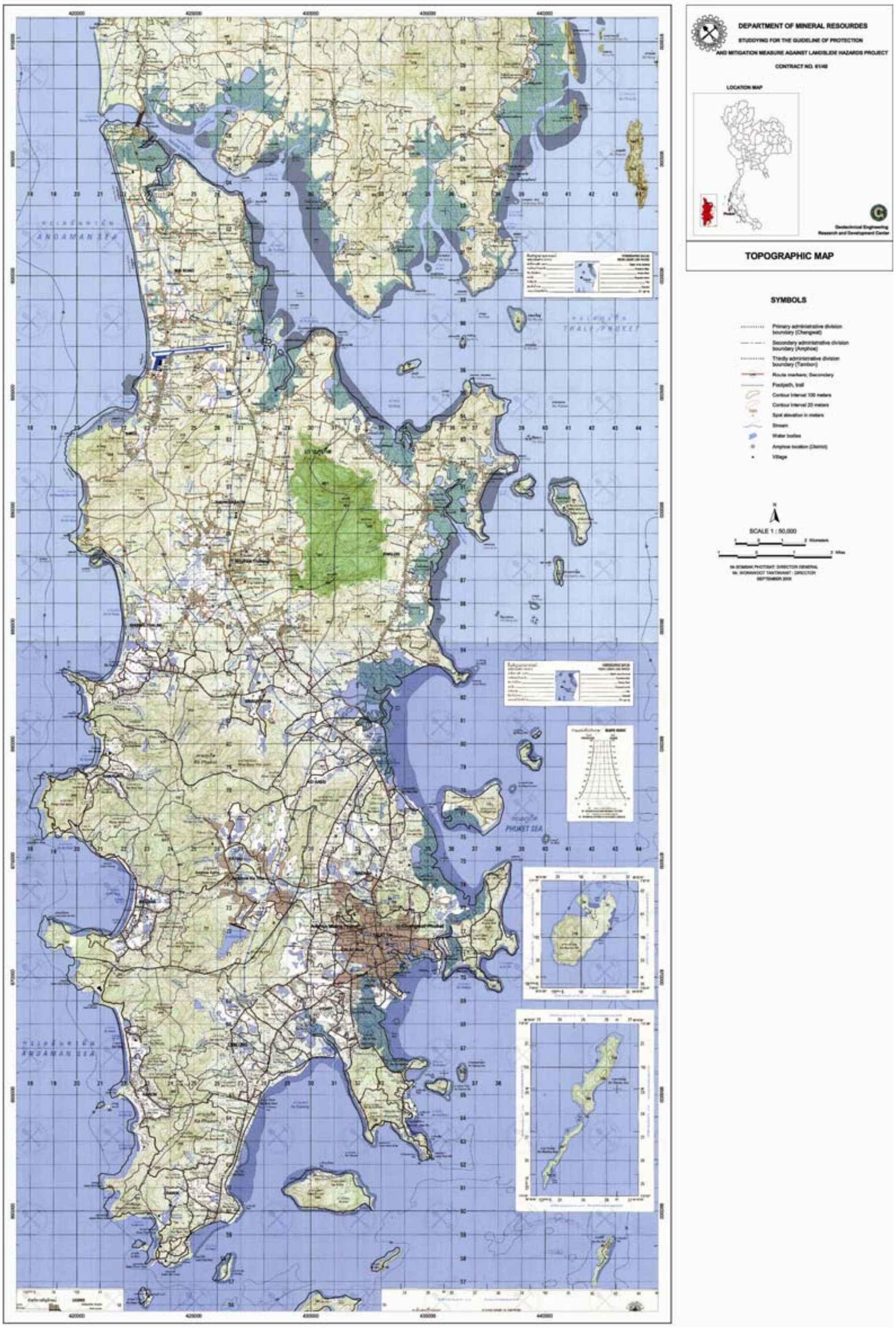


Figure 4 Topographic map of Phuket province
Source: Department of mineral resources (2006)

MATERIALS AND METHODOLOGY

Materials

1. Program spreadsheet (Microsoft Excel)
2. Book reference and thesis
3. Landslide location data
4. Soil strength parameter from parallel study
5. GIS program
6. GPS
7. Geologic investigation equipment (geology hammer, geology campus)

Methodology

This study emphasizes in producing landslide susceptibility map and landslide sensitive area for cut slope in Phuket. The study area is an island that has many development areas which satisfy for study area. This study deals with the application of relatively new tool in landslide hazard zonation: use of computerized system for handling of the geographical data, known as geographic information system (GIS). Eight factors were considered to be related to landslide including Geology (rock type, lineament), Landform (slope, elevation), Surface drainage zone, Land use, Soil characteristic, Engineering properties, Rainfall intensity and RMR or SMR. These factors are used for analyzing landslide hazard location.

The methodology adopted is illustrated on the flow diagram in figure 5. This study improved the accuracy of landslide susceptibility map by including RMR and SMR factors. The map of sensitive area for cut slope was produced by including SMR factors in the analysis which assume the cut slope on soft rock equal to 1:1.2 or 40^o (Japan Society of Engineering Geology, 1992).

The methodology included the following:

1. Data collection (7 factors)
2. Weight factor analysis for landslide hazard area
3. Processing of landslide susceptibility and hazard map (7 factors)
4. Field investigation
5. Weighting factor analysis including RMR value
6. Processing landslide susceptibility and hazard map by considering RMR value
7. Weighting factor analysis including SMR value
8. Processing natural landslide susceptibility map and hazard map by considering SMR value
9. Collect slope condition data form field investigation
10. Failure verification (RMR included)
11. Processing cut slope failure map and hazard map by considering RMR factor included
12. Failure verification (SMR included)

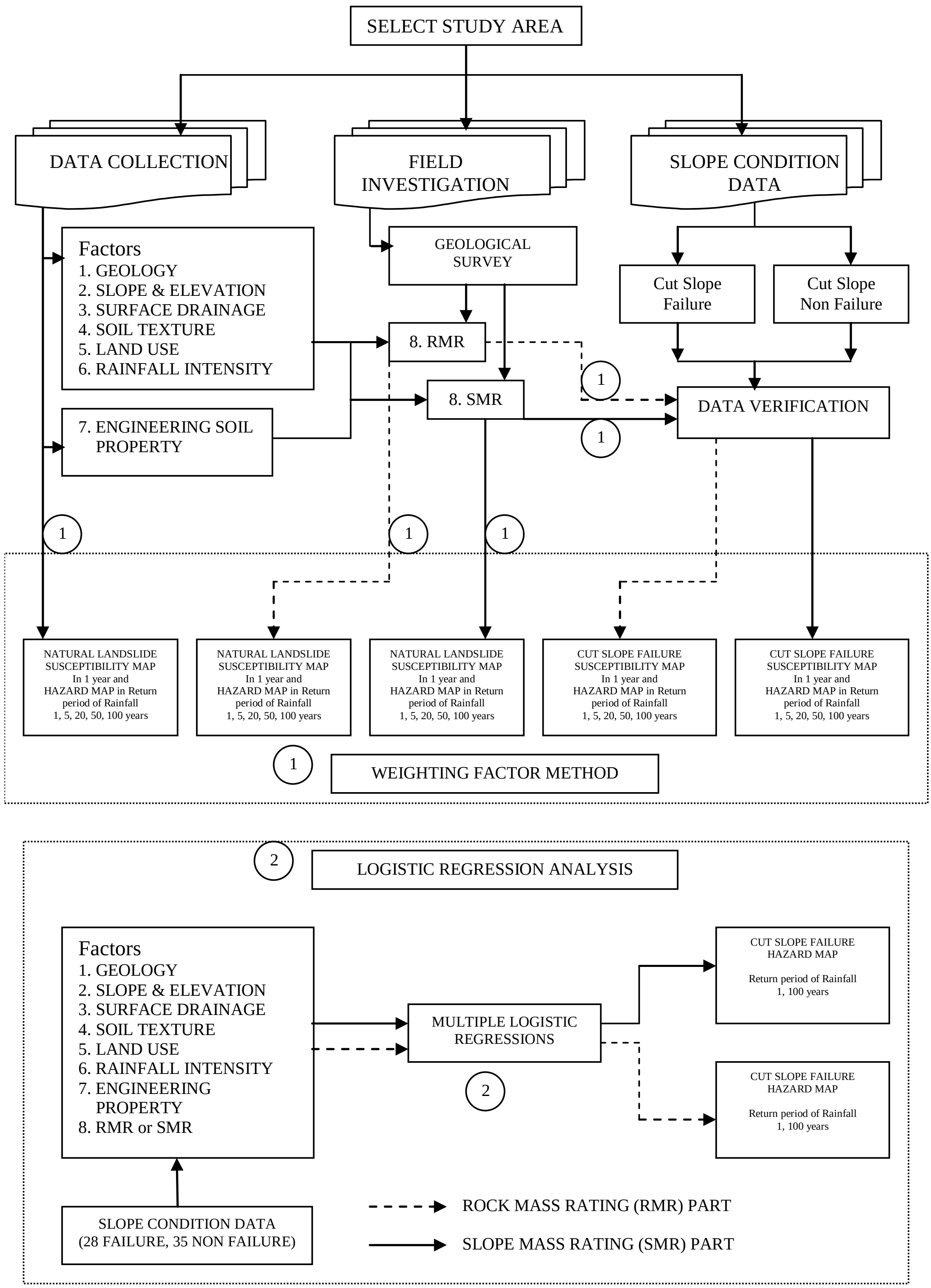


Figure 5 Flow diagrams showing all the methodologies

13. Processing cut slope failure map and hazard map by considering SMR factor included

14. Logistic multiple regression analysis (RMR factors included)

15. Processing cut slope probability of failure map by considering RMR factor included

16. Logistic multiple regression analysis by considering SMR factor included

17. Processing cut slope probability of failure map by considering SMR factor included

Data collection

The collection of fundamental geographic information system (GIS) data was used for analysis of landslide susceptibility. The data used included geology, slope and elevation, surface drainage, soil texture, land cover, rainfall, engineering properties. Table 18 shows GIS data discussed above.

Table 18 Data collection for the analysis of landslide sensitive area

No	Coverage	Organize	Scale Map
1	Province	Topographic map: Royal Thai Survey Department	1:50,000
2	Amphoes	Topographic map: Royal Thai Survey Department	1:50,000
3	Transportation	Topographic map: Royal Thai Survey Department	1:50,000
4	Contour	Topographic map: Royal Thai Survey Department	1:50,000
5	Land used	Land Development Department	1:50,000
6	Geologic Structures	Geology map: Mineral Resource Department	1:50,000
7	Geology	Geology map: Mineral Resource Department	1:50,000
8	Elevation	Topographic map: Royal Thai Survey Department	1:50,000
9	Slope	Topographic map: Royal Thai Survey Department, GERD	1:50,000
10	Streams and rivers	Topographic map: Royal Thai Survey Department	1:50,000
11	Watershed	Environmental Quality Promotion Department	1:50,000
12	Soil series group	Land Development Department	1:50,000
13	Rainfall	Meteorological Department Of Thailand, Royal Irrigation Department, GERD	1:50,000
14	Engineering properties	GERD	1:50,000

Gerd: Geotechnical Engineering Research and Development Center, Kasetsart University.

Evaluation Natural landslide susceptibility map and hazard map

After the data collection of fundamental geographic information system (GIS) maps were complete, which consist of 8 factors map as geology map (rock type and lineament), land form (slope and elevation), surface drainage, soil characteristic, land use, rainfall cumulative intensity 3 days, engineering properties and RMR or SMR factors. These were used to divide grid cell 25x25 meters and were overlaid by using the GIS analysis functions of geoprocessing and analysis menu within ArcView GIS software. The overlay with intersection and union option has been used for GIS analysis and recorded data from all of factor maps. After that, the attributes of intersection from 8 factors was used to calculate score by weighting factor analysis.

The trend of the landslide occurrence was observed from the plotted data. Each of the grid cell had been defined 5 levels of landslide susceptibility, which consisted of very low to nil susceptibility, low susceptibility, moderate susceptibility, high susceptibility and very high susceptibility to landslide.

Field Investigation

Field investigation was used to prepare a slope condition of the cut slope. It was used to compare with susceptibility of landslide map for the cut slope. The prepared landslide distribution and bedrock map as well as other maps e.g. contour, land use, land form map will be verified during the field visit. The existing pattern of cut slope and its magnitude was observed. Eighty seven cut slopes have been surveyed and after completing the field survey, data file was input in GIS map. The study involved field investigation on the geological engineering aspects of rock slopes in Phuket Island, Thailand. Field investigation had been conducted on failure and non failure slopes in development area to understand their recent massive failures.

The methods of investigation for RMR and SMR factors follow as much as practical the methods suggested by the International Society of Rock Mechanics (ISRM, 1981). The collected data include slope geometry, joint condition and orientation, rock conditions, and groundwater condition. The results were used to evaluate rock mass quality for landslide factor on landslide susceptibility map and sensitive area map for slope development.

Rock Mass Rating (RMR) and Slope Mass Rating (SMR) Estimation

Geotechnical data could be easily collected during exploration stages of a new or existing construction project as an integrated approach with investigation data collection. Rock outcrop mapping carried out along all natural outcrops or man-made excavations such as resort projects, river and road-cuts etc. located in close proximity to the surveying site. A typical geotechnical mapping sheet for the collection of pertinent data is shown in Fig 6.

Figure 6 Rock mass rating (RMR) descriptions for field survey sheet (ISRM, 1981)

												VALUE	RATING
Intact rock Strength	PLST	10	8	6.5	5.5	5	4.5	3	2	1	<1		
	UCS,Mpa	250	200	160	140	125	110	75	50	25	<25		
	Field Est.	Chipped by hammer		many blows by hammer to break				single blow		pocket knife			
	RATING	15	14	13	12	11	10	8	6	4	<3		
RQD	J Spacing	>200	40	20	14	10	8	7	6	5	4		
	RQD %	100	90	80	70	60	50	40	30	20	0		
	RATING	20	18	16	14	12	10	9	5	4	3		
Joint Spacing	Js, cm	>200	40	20	14	10	8	7	6	5	4		
	RATING	20	18	16	14	12	10	9	8	7	5		

								Set 1	Set 2	Set 3	VALUE	RATING
							Orientation J Spacing					
Joint Condition	Persistence	< 1m	1- 3m	3 - 10m	10 - 20m	> 20m						
	RATING	6	4	2	1	0						
	Aperture	None	< 0.1mm	0.1-1.0	1 - 5	5 - 10						
	RATING	6	5	4	1	0						
	Roughness	Vrough	Rough	SL Rough	Smooth	Slices						
	RATING	6	5	3	1	0						
	Infilling		Hard infilling		Soft Infilling							
		None	<5mm	>5mm	<5mm	>5mm						
	RATING	6	4	3	2	0						
	Weathering	FRESH	SW	MW	HW	CW						
	RATING	6	5	3	1	0						
							Sub-Total					

							VALUE	RATING
Groundwater	Inflow 1/min/10m	None Dry	< 10 Damp	10 - 25 Wet	25 - 125 Dripping	> 125 Flowing		
	RATING	15	10	7	4	0		

	DIP OF ADVERSE JOINT SET			VALUE	RATING
Adjustment for Joint Orientation	0 - 20	20 - 45	45 - 90		

RMR RATING	80 - 100	60 - 80	40 - 60	20 - 40	0 - 20	
DESCRIPTION	VERY GOOD	GOOD	FAIR	POOR	VERY POOR	
ROCK CLASS	1	2	3	4	5	
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span	
Cohesion of the rock mass	> 400 kpa	300-400 kPa	200-300 kPa	100-200 kPa	<100 kPa	
Friction angle of rock mass	> 45^o	35^o-45^o	25^o-35^o	15^o-25^o	<15^o	

A description of the pertinent geotechnical data to be included in a logging sheet is presented below. The minimum geotechnical information collected from the mapping of rock outcrops should comprise:

- Rock type description and alteration
- Weathering
- Discontinuity type, orientation, surface conditions, spacing and persistence
- Estimate of rock strength

Estimates of rock strength can be made based on the descriptions presented in Fig 6 and the use of either a pocket knife and/or geological hammer. An average rock strength should be selected per each identified rock type unless significant areas of rock of different strengths were presented within the natural outcrop of man-made excavation.

Photographs were taken of all natural outcrops and/or man-made excavations such as exploration audits or road cuttings in/upon which geotechnical data has been measured and recorded. Both far field and zoom photographs were taken to illustrated the variation of rock types, all joint sets, typical or important joint surfaces as well as joint spacing and persistence. Scales were always being included in each of the photographs.

During the field survey, the rock samples were colleted from each landslide and cut slope. These rock samples were identified for the rock type by geologist and were tested in the laboratory to observe the intact rock strength.

Assumption of estimating slope mass rating was the cut slope located in soft rock, slope direction parallel to slope of mountain and slope dip was 1:1.2 or 40^o (Japan Society of Engineering Geology,1992).

Slope Condition data

The slope condition data was defined from field investigation data in which definition of slope conditions were a Fail and a No Fail. The Fail was the failure of the cut slope after excavation and before inspection. The No Fail was the non failure of the cut slope after excavation and during inspection.

Data verification for RMR and SMR factor

The RMR and SMR factors were defined in GIS map depending on rock type and watershed. Before and after weighting factor analysis, RMR and SMR factors were verified. The data verification for RMR and SMR rating before weighting factor analysis, had objective to classify the rang of rating and after that to classify the rang of total landslide susceptibility score. The cutoff score procedure was employed to classify each grid cell as landslide, apparently landslide, apparently non-landslide and non-landslide area.

The cut of score point was defined as the boundary between a landslide, apparently landslide, apparently non-landslide and non-landslide area decision; for example a 89 cutoff score point means that the score of pixel being classified as landslide was equal to greater than 89, while the score less than 89 was classified as non-landslide.

Evaluation Sensitive Area for Cut slope

Evaluation of sensitive area and map production was divided into four steps. The first step produced landslide susceptibility map from 7 factors: geology, landform, surface drainage zone, land use and land cover, soil characteristics, rainfall intensity and engineering soil properties. And RMR factor or SMR factor was included in landslide susceptibility map. The second step produced landslide susceptibility map which depended on return period of rainfall. The third step produced sensitive area map for slope development. In assumption was 1:1.20 or 40^o cut slope on soft rock. The fourth step produced probability sensitive area for slope development map from logistic regression modal. Flow chart in Fig 7 illustrates the process of evaluation of sensitive area and map production.

STEP 1 PRODUCTION LANDSLIDE SUSCEPTIBILITY MAP BY WEIGHTING METHOD

STEP 2 PRODUCTION LANDSLIDE SUSCEPTIBILITY MAP BY WEIGHTING METHOD IN RAINFALL 1, 5, 20, 50 AND 100 YEARS RETURN PERIOD

STEP 3 EVALUATING LANDSLIDE SENSITIVE AREA FOR CUT SLOPE BY WEIGHTING METHOD IN RAINFALL 1, 5, 20, 50 AND 100 YEARS RETURN PERIOD

STEP 4 EVALUATING LANDSLIDE SENSITIVE AREA FOR CUT SLOPE BY LOGISTIC REGRESSION IN RAINFALL 1, 5, 20, 50 AND 100 YEARS RETURN PERIOD

Figure 7 Evaluation sensitive areas for cut slope process

Logistic regression

Logistic regression allowed one to from a multivariate regression relation between a dependent variable and several independent variables. The advantage of the logistic regression was that, through the addition of an appropriate link function to the usual linear regression modal, the variables may be either continuous or categorical, or any combination of both types. In present situation, the dependent variable was a binary variable representing the presence or absence of landslides. Where the dependent variable was binary, the logistic link function was appropriate. The logistic regression allows one to form a multivariate regression relation between a dependent variable and several independent variables (Atkinson and Massari, 1998).

The evaluation sensitive of cut slope was developed from field survey data obtained from cut slope in Phuket. Eight independent variables used a multiple regression analysis by Microsoft excel program. The slope condition data (Fail or No Fail) was used to regression analysis for dependent parameter, which assumed of qualitative of slope condition was 2.95 and -2.95 for Fail and No Fail respectively. The assumption Fail or no Fail was the occurrence probability for specific attributes.

RESULTS AND DISCUSSION

Data Collection (7 factors)

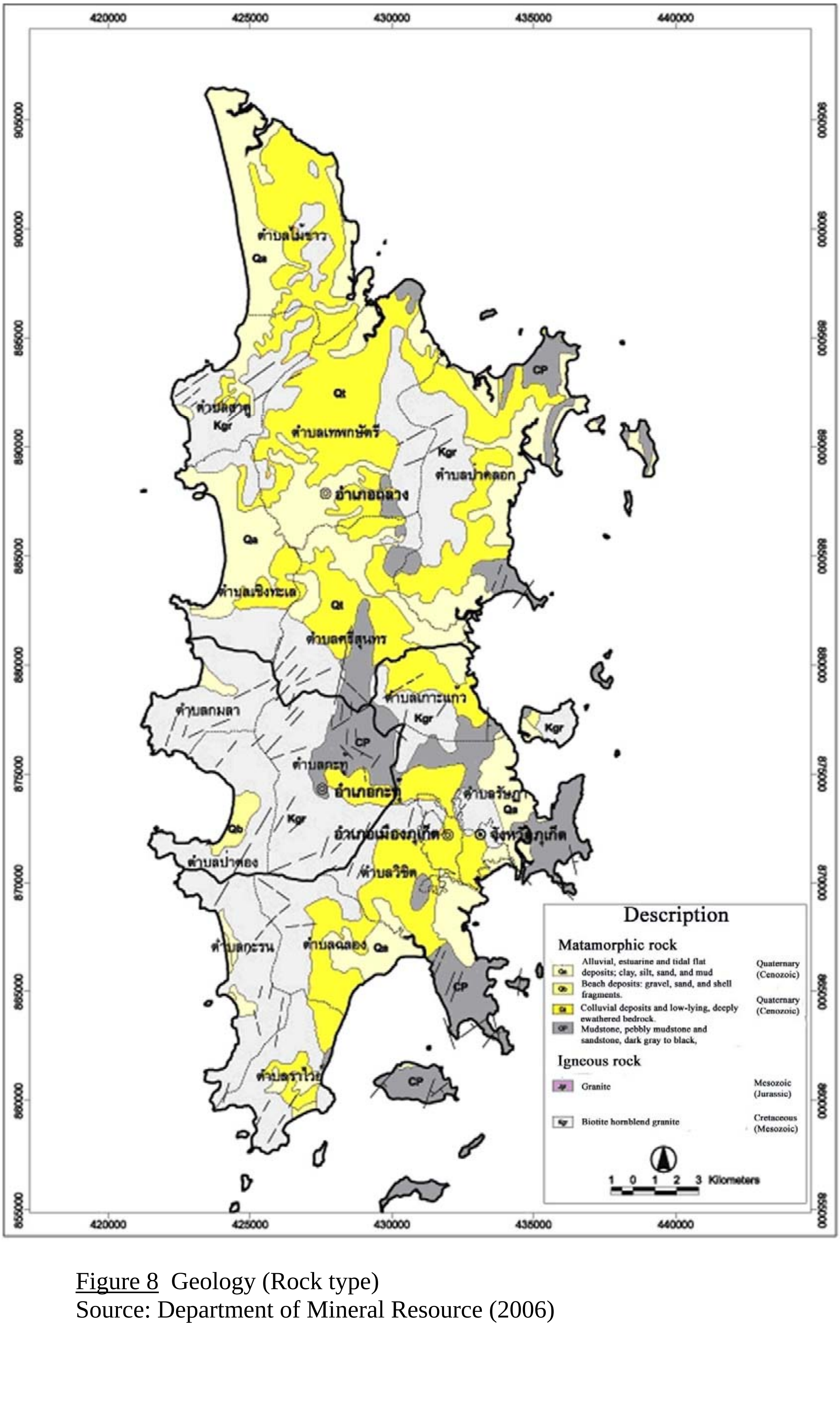
The data collection consists of 7 factors, which were collected from several sources in GIS data form such as geology map (rock type and lineament), land form data (slope and elevation), surface drainage data, soil characteristic data, land use map, rainfall intensity data and engineering soil properties. These are illustrated in Fig 8-Fig 16 and the summation of the each factor is area shown in Table 19.

Table 19 Plan area of 7 factors

Factors	pixel	Area (km^2)	%
Rock type			
Granite rock	322,484	201.55	36.71
Shale/Mudstone	116,916	73.07	13.31
Sandstone/Siltstone	0	0.00	0.00
Quartzite, Sandstone and Siltstone	0	0.00	0.00
Limestone/Dolomite	0	0.00	0.00
Colluvial	439,017	274.39	49.98
Sum	878,417	549.01	100.00
Lineament zone			
Sum	12,459	7.79	100.00
Slope			
0	310,365	193.98	35.33
0 - 15%	580,857	363.04	66.13
15 - 30%	111,240	69.53	12.66
30 - 50%	131,575	82.23	14.98
50 - 70%	46,596	29.12	5.30
> 70%	8,149	5.09	0.93
Sum	878,417	549.01	100.00
Elevation			
0	46,195	28.87	5.26
0 - 100	686,455	429.03	78.15
100 - 200	105,822	66.14	12.05
200 - 300	53,434	33.40	6.08
300 - 400	24,564	15.35	2.80
> 400	8,142	5.09	0.93
Sum	878,417	549.01	100.00

Table 19 Plan area of 7 factors (Continued)

Factors	pixel	Area (km^2)	%
Surface drainage			
Sum	33,477	20.92	100.00
Soil characteristics			
Gravel loam/Gravelly sand	1,894	1.18	0.22
Sand	20,439	12.77	2.33
Sandy loam	288,217	180.14	32.81
Clayey loam/loam	424,755	265.47	48.35
Clay, Mud	143,112	89.45	16.29
Sum	878,417	549.01	100.00
Land use			
Agriculture area	514,594	321.62	58.58
Urban and build-up area	192,923	120.58	21.96
Other deforestation	1,881	1.18	0.21
Forest area	169,019	105.64	19.24
Sum	878,417	549.01	100.00
Engineering soil properties			
Residual soil from Sandstone/Siltstone	0	0.00	0.00
Residual soil from Granite rock	322,484	201.55	36.71
Residual soil from Shale/Mudstone	116,916	73.07	13.31
Residual soil from Quartzite, Sandstone and Siltstone	0	0.00	0.00
Residual soil from Limestone/Dolomite	0	0.00	0.00
Colluvial	439,017	274.39	49.98
Sum	878,417	549.01	100.00
Rainfall cumulative intensity 3 days			
A. >203 mm.	0	0.00	0.00
B. 161-203 mm.	9,001	5.63	1.02
C. 119-161 mm.	822,385	513.99	93.62
D. 77-119 mm.	46,831	29.27	5.33
E. 35-76 mm.	0	0.00	0.00
Other	200	0.13	0.02
Sum	878,417	549.01	100.00



<u>Figure 8</u> Geology (Rock type)
Source: Department of Mineral Resource (2006)

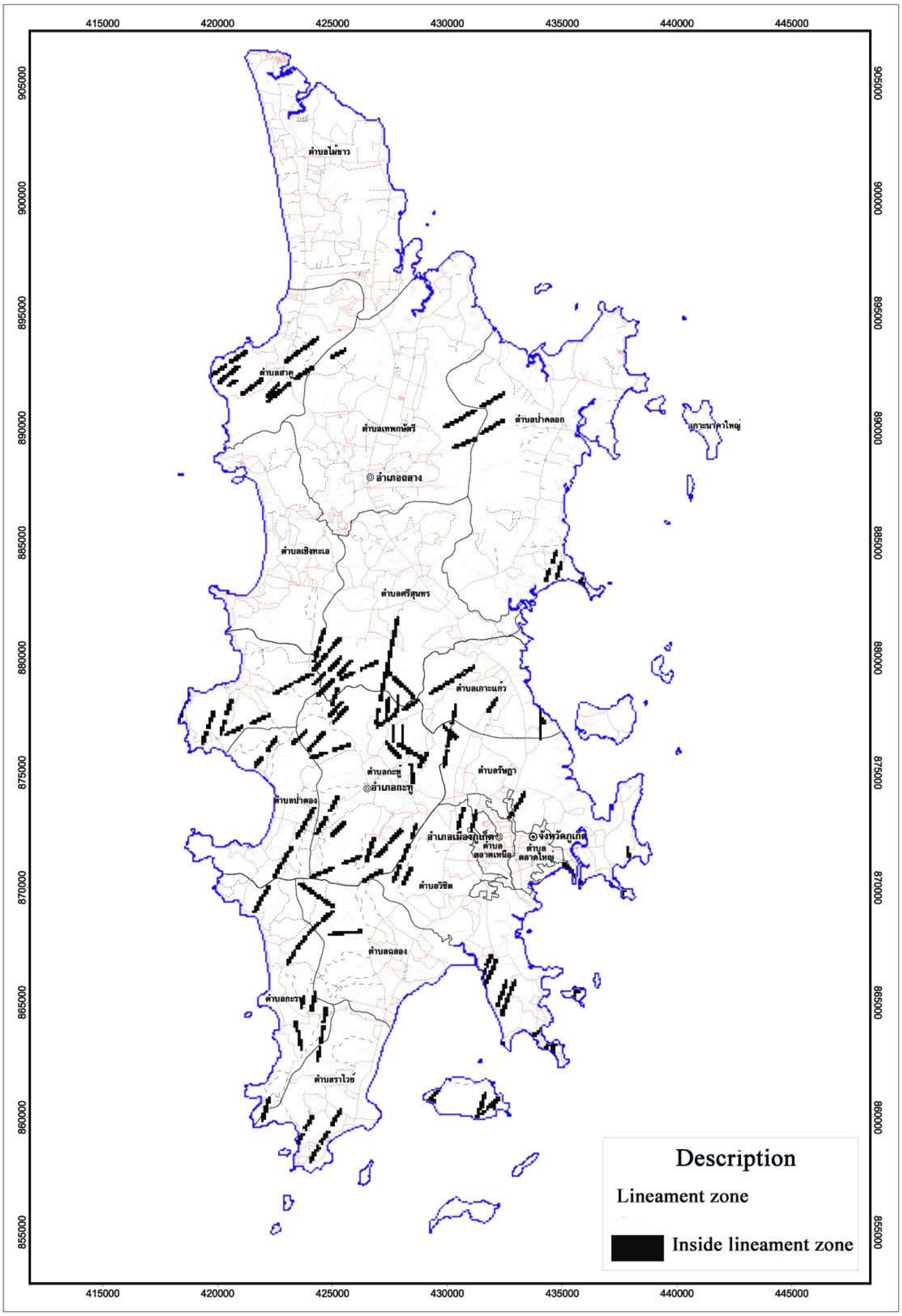


Figure 9 Geology (Lineament zone)
Source: Department of Mineral Resource (2006)

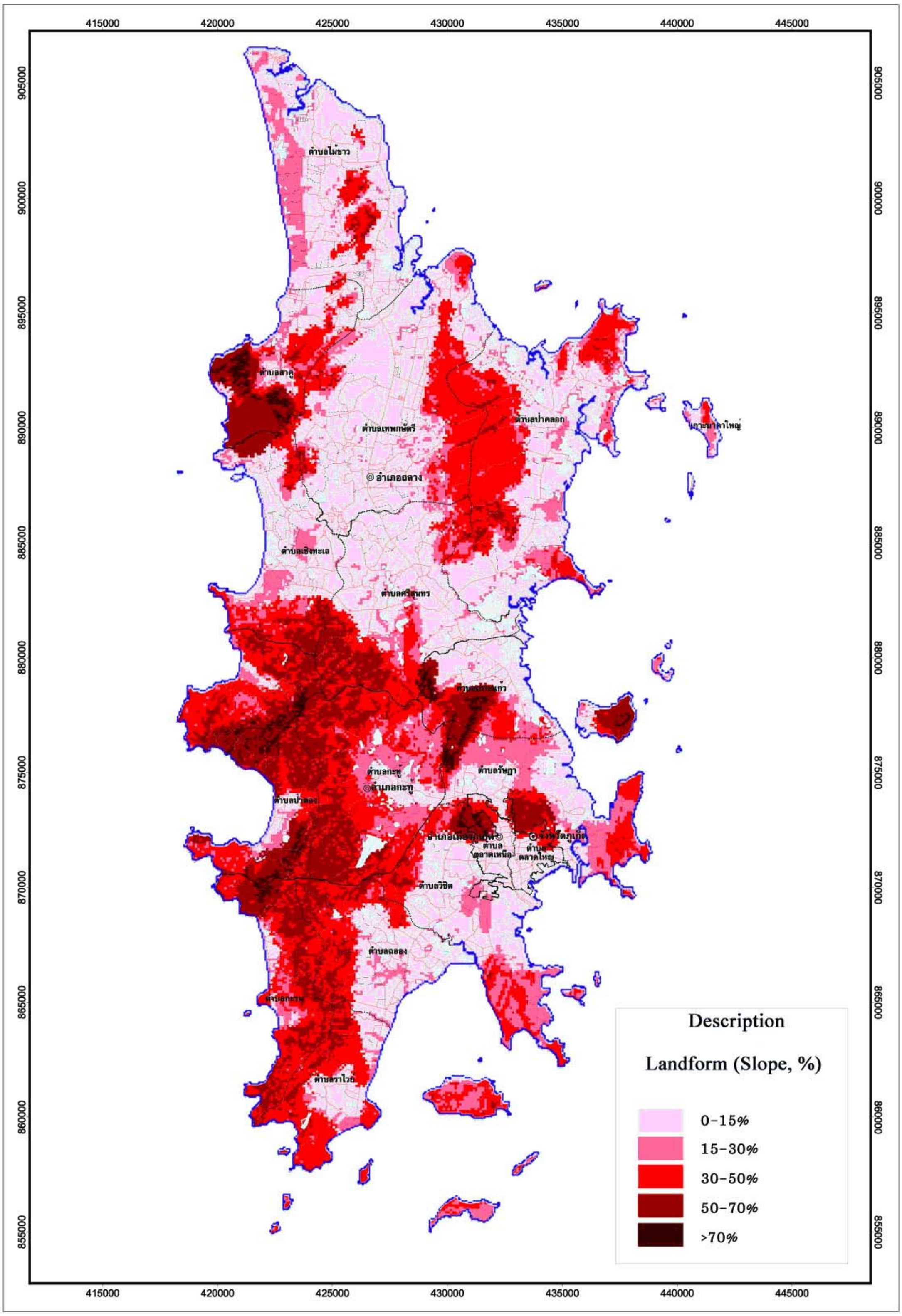


Figure 10 Landform (Slope)
Primary data: Royal Thai Survey Department (2006)

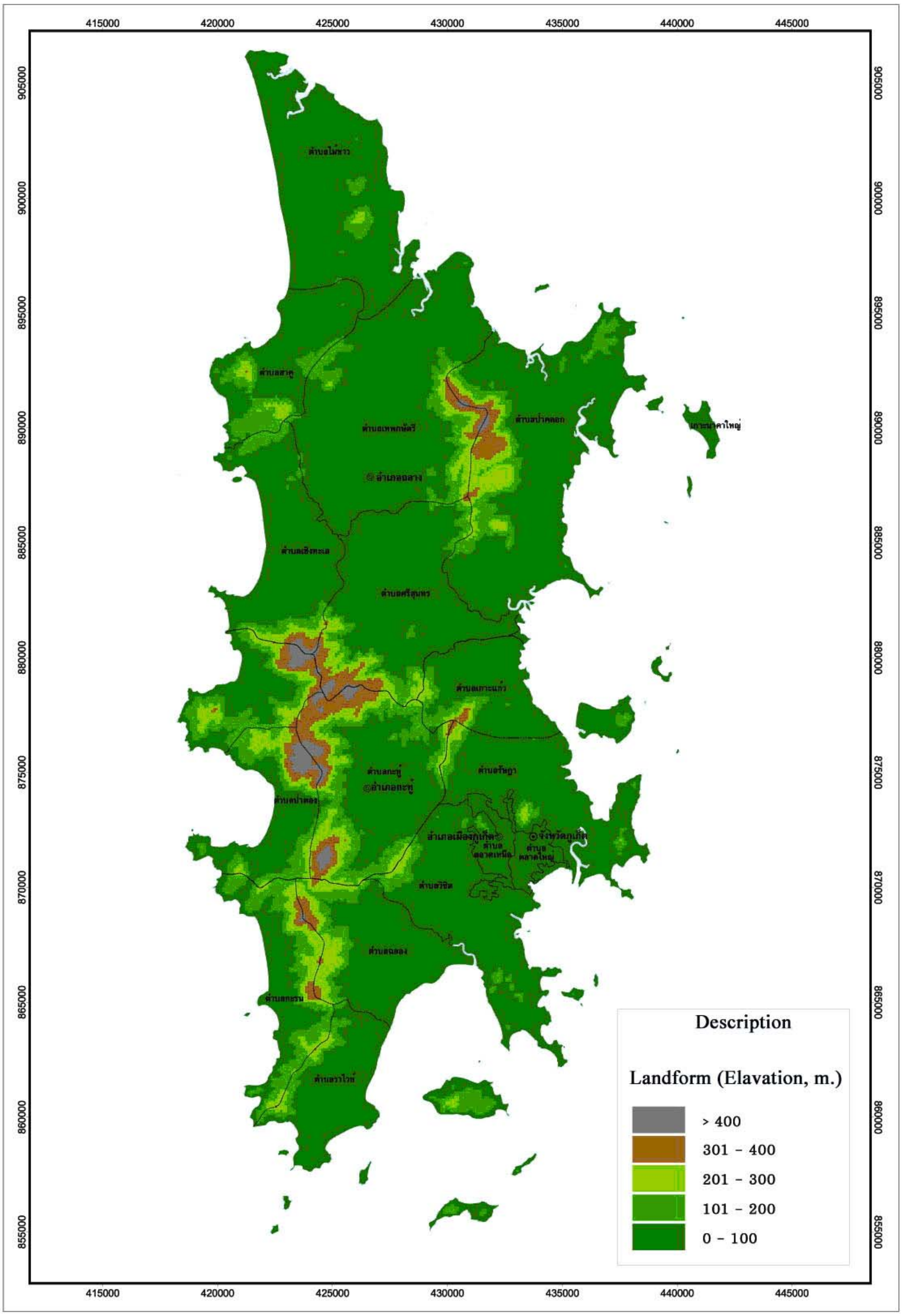


Figure 11 Landform (Elevation)
Primary data: Royal Thai Survey Department (2006)

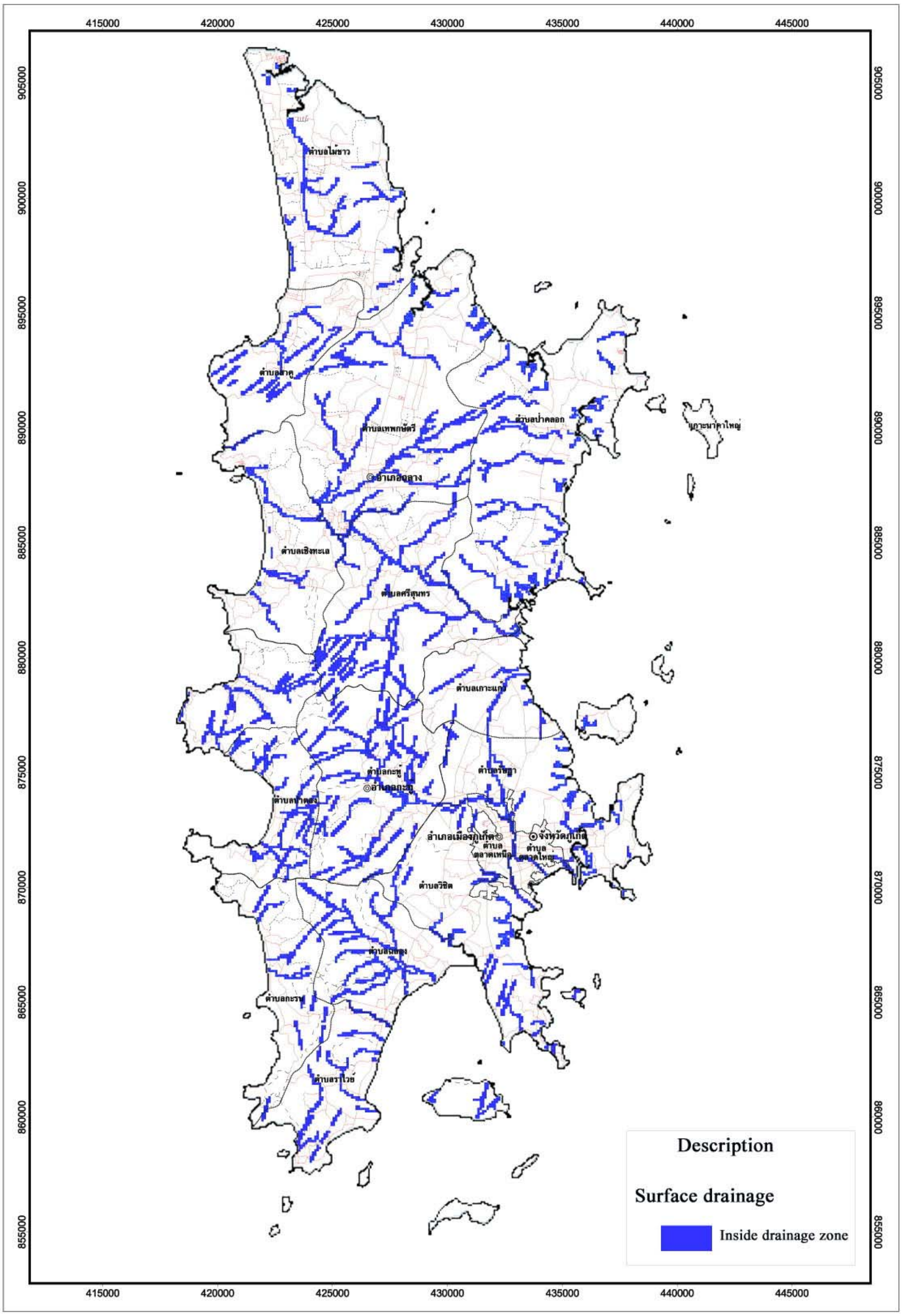


Figure 12 Surface drainage
Primary data: Royal Thai Survey Department (2006)

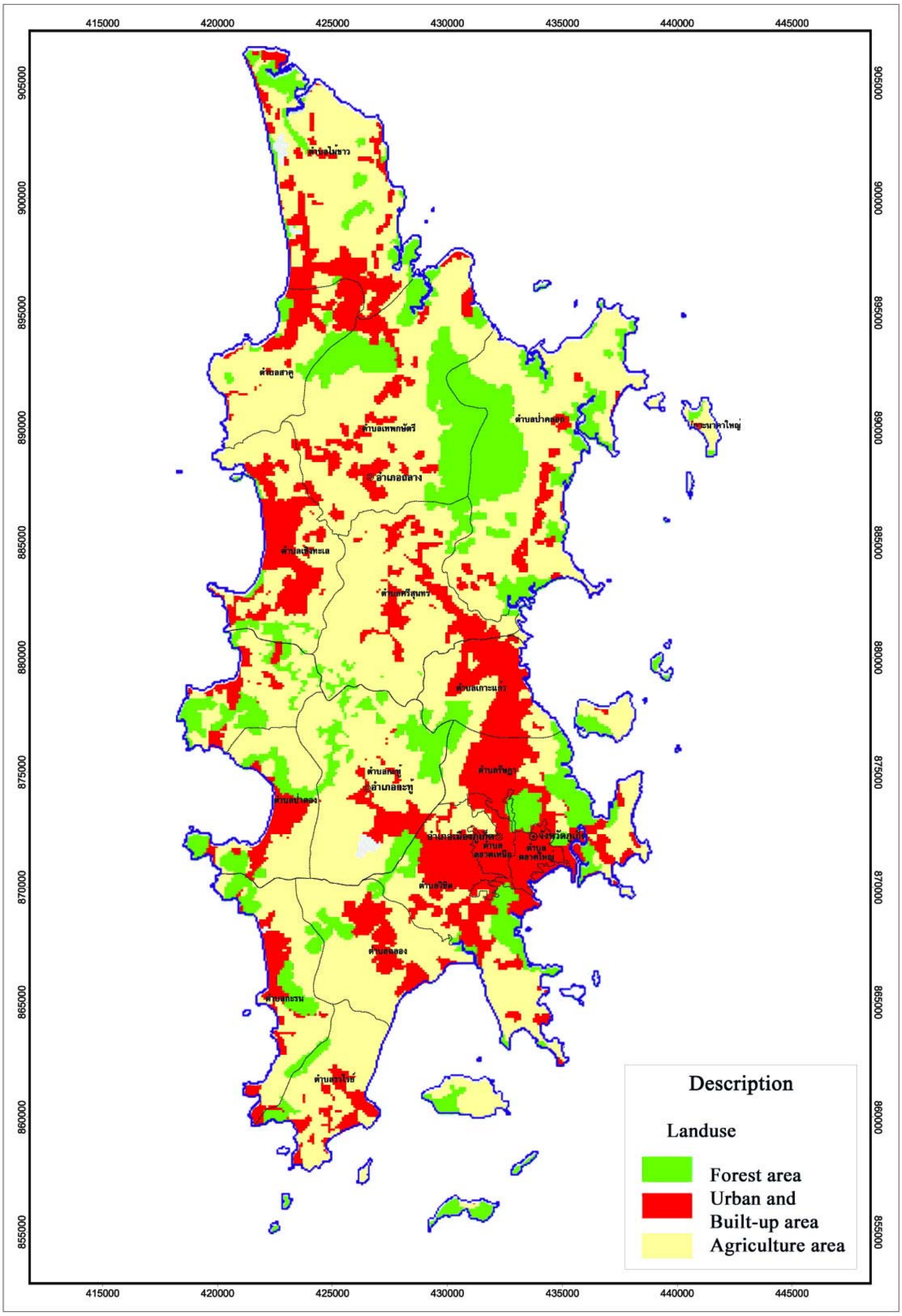


Figure 13 Land use and land cover
Primary data: Department of Land Development (2006)

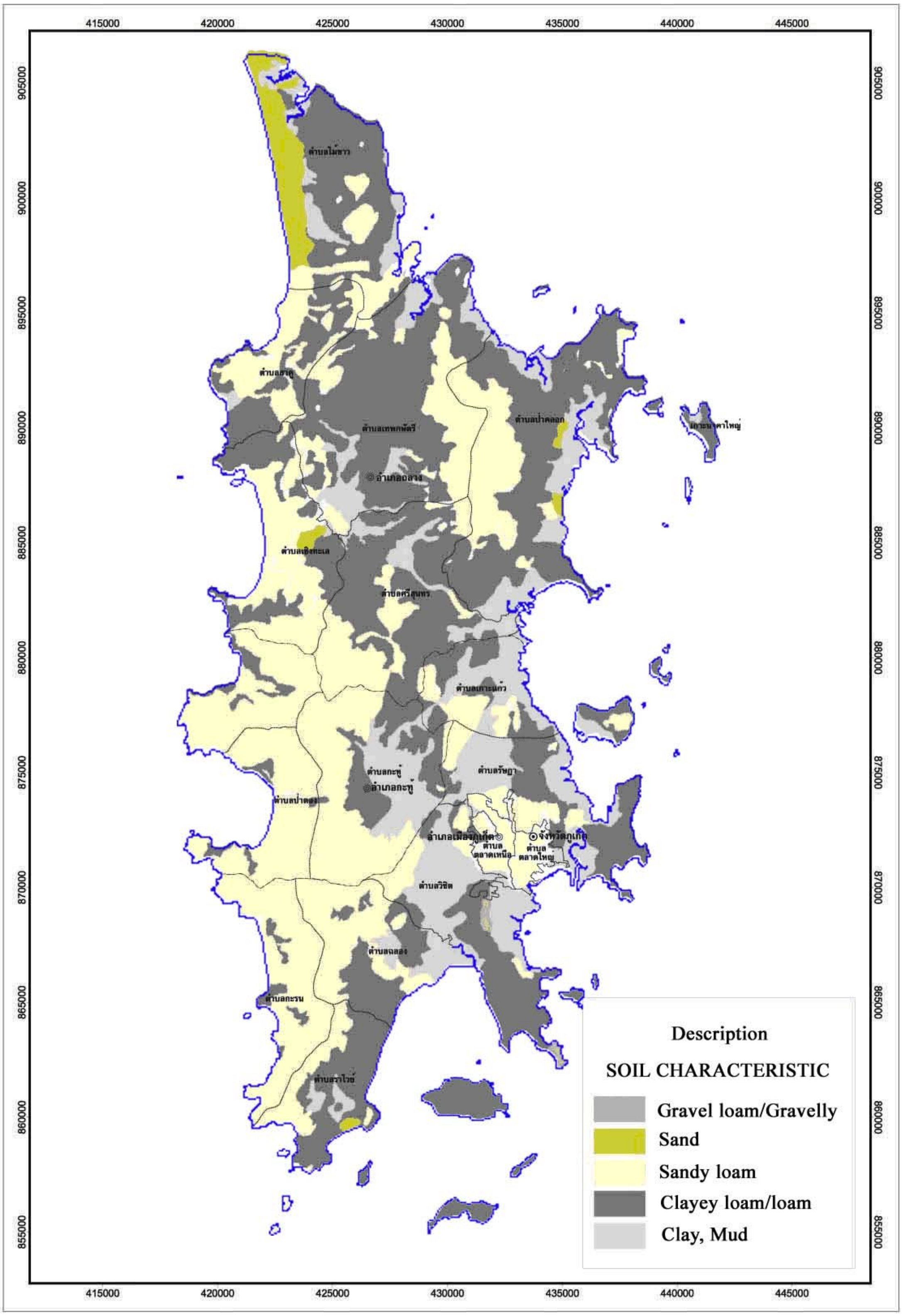


Figure 14 Soil characteristics
Primary data: Department of Land Development (2006)

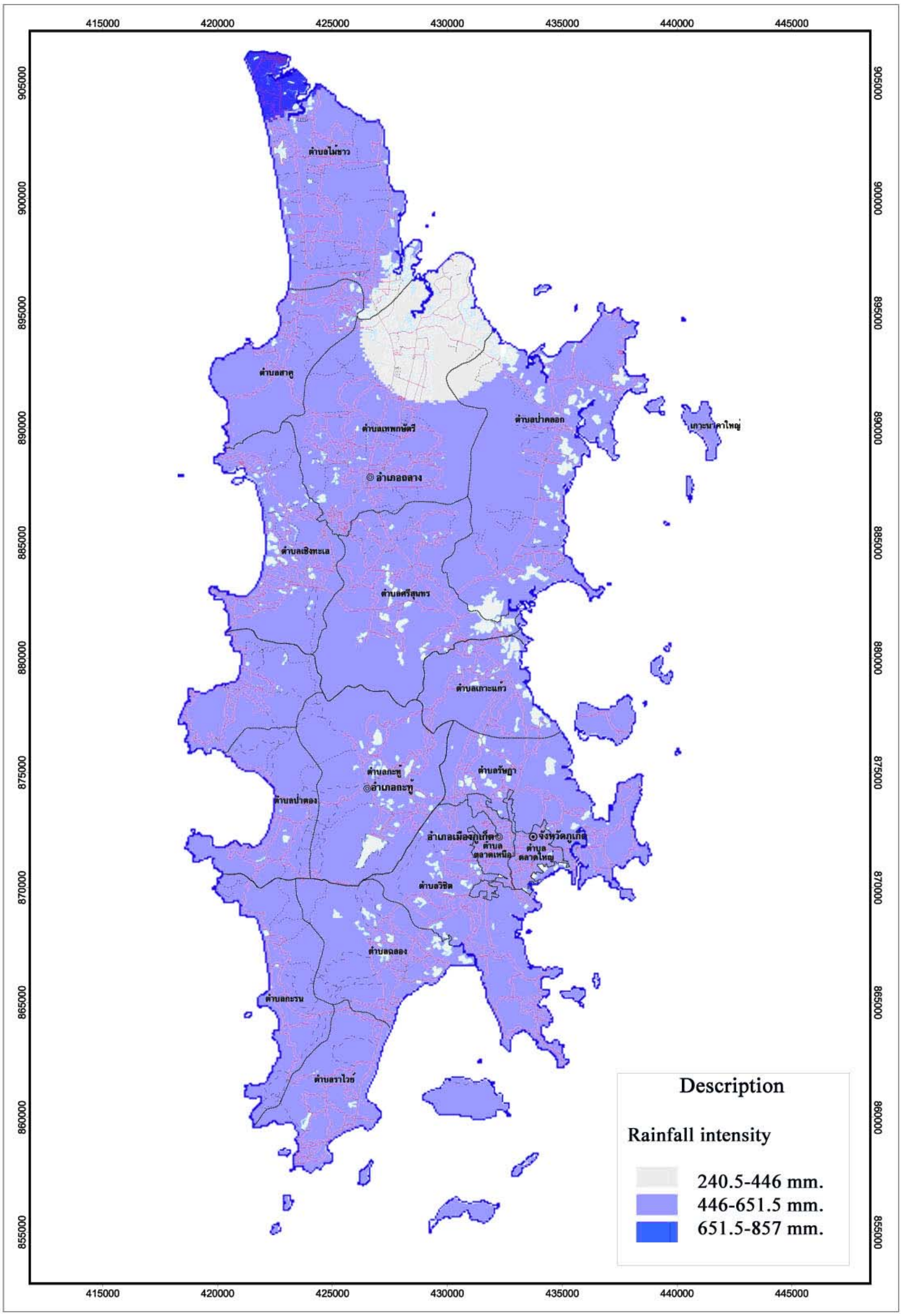


Figure 15 Rainfall intensity
Primary data: Meteorological Department of Thailand, Royal Irrigation Department (2006)

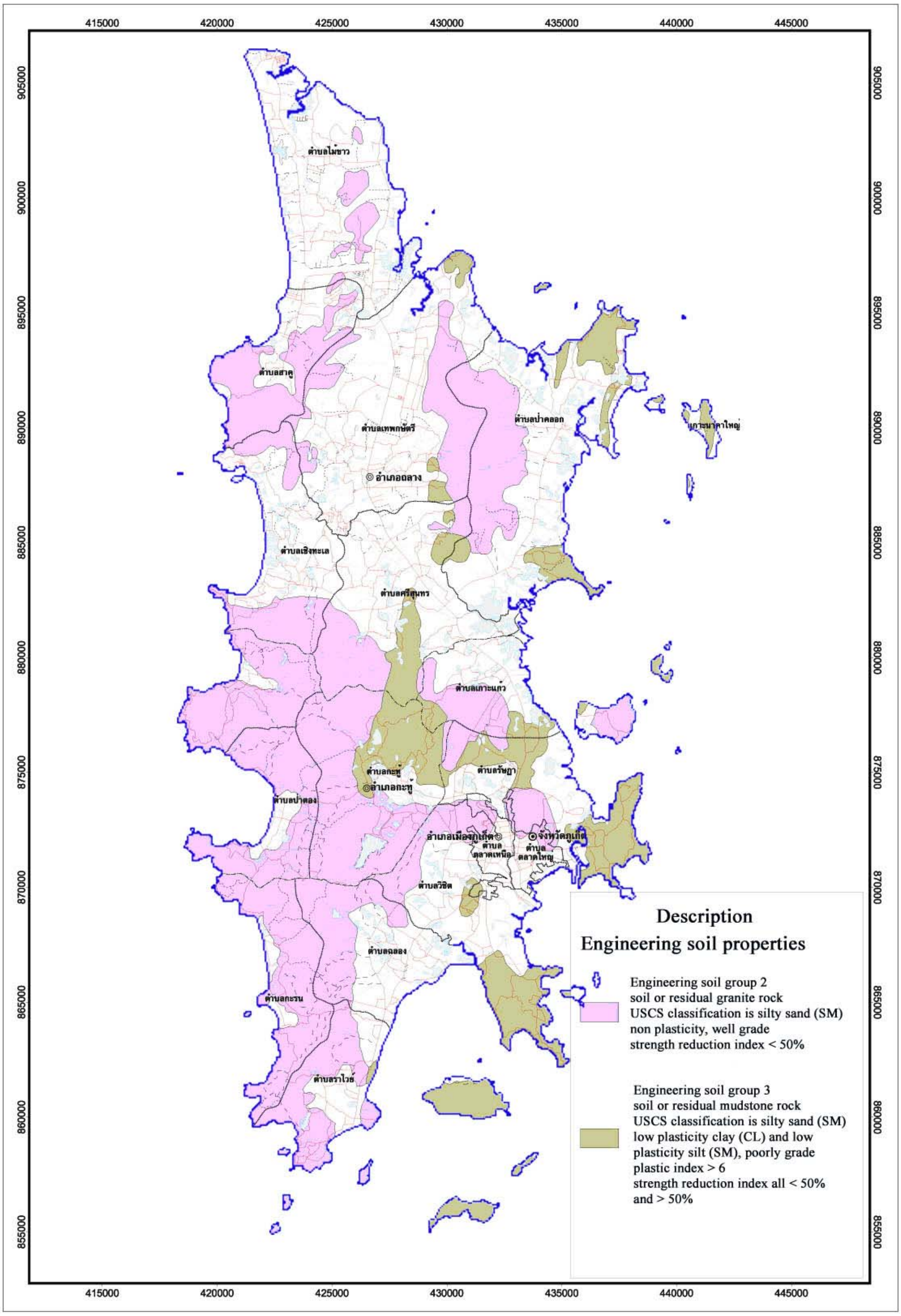


Figure 16 Engineering soil properties
Source: Geotechnical Engineering Research and Development Center (2006)

<u>Weighting Factor Analysis for Landslide Hazard Area</u>

This research is part of the project owned by Department of Mineral Resources and studied by Geotechnical Engineering Research and Development Center, Kasetsart University. Weighting factor method was selected to analyze hazard area. The appropriate weight was assigned to landslide influencing factors by expert opinion. Each of influencing factor was subdivided into subclasses of minor factors and given score number. Each minor factor was assigned score ranging from 1 to 5 according to their increasing in landslide potential. The weighing factor method is appropriate for analyzing the GIS data which gives the result in terms of area based. More accurate result but not appropriate for area-based analysis may be done by geotechnical engineering method.

Major factors used for landslide susceptibility analysis by weighing factor method were

1. Geology (Rock type and Lineament zone)
2. Landform (Slope and Elevation)
3. Surface drainage zone
4. Land use and land cover
5. Soil characteristics
6. Rainfall intensity
7. Engineering soil properties

The detailed descriptions of different rating values of each parameter and sub-parameters as well as the weight value are summarized below.

1. Geology (Rock type and lineament zone)

Rock type is one of the main factors for landslide hazard analysis. Each rock type has different mechanism for landslide. Table 21 shows rock group and is dominate rock in the region. Based on rock group in 6 provinces in southern part of Thailand, rock type can be classified by its landslide potential (Table20).

<u>Table 20</u> Landslide potential classification of rock type

Rock Type	Landslide Potential Class
Granite Rock	Very high potential
Shale/Mudstone	High potential
Sandstone/Siltstone	Medium potential
Quartzite, Sandstone and Siltstone	Low potential
Limestone/Dolomite	Very low potential

Table 21 Potential landslide level of rock series in 6 provinces **(**By rock type**)**

Potential landslide level	Satun	Phangnga	Krabi	Trang	Ranong	Phuket	Rock type
Very high	Kgr,Tr Jgr, Trgr	Kgr,Tgr, Jgr	Kgr	Trgr	Jgr,Trgr, Kgr	Kgr	Granite Rock
High	Cb,Ck, SD(C)	EP,CP	CP,Tr	CP,SD (C)	CP	CP	Shale/ Mudstone
Medium	E, SD	JK,DC	Mz,JK,T rJ, T	(S)DC ,JK,T, TrJ	SD		Sandstone/S iltstone
Low	C			C	C		Quartzite, Sandstone and Siltstone
Very low	O,P	P	P	Tr,O,P	P		Limestone/ Dolomite

Note: Tr trang - Dolomite mixed Shale and Gravel stone
Tr Krabi –Shale mixed Clay stone and Siltstone

Source: Department of mineral resource (2006)

Lineament zone means fault, fracture and joint. Earth movements involve plastic folding and brittle fracture of rocks, as well as uplift and subsidence. These are tectonic features, caused by large scale movements of crustal plates. Under the high confining pressures at kilometers of depth, and over the long time scales of tectonic processes, most rock may show the plastic deformation, and fractures occur when and where the plastic limits are exceeded. Groundwater is attracted to a fault zone due to the greater conductivity of the fractured and loosened rock to be found in the fault zone. Faults can act as conduits for flow of water, which explains why rocks adjacent to them are often found to be hydro thermally altered. Replacement of original minerals by clays, zeolites, and silica or calcite, as well as precipitation of these minerals in void spaces, grossly changes the character of the rocks near the fault zones, as a result of which stability problems would ensue (Lee. 1995). Influencing of lineament zone is buffered 20 meters from center of lineament line (Thassanapak, 2001).

Table 22 Landslide potential classification of lineament zone

Lineament Zone	Landslide Potential Class
Area inside lineament zone	Very high potential
Area outside lineament zone	Very low potential

2. Landform (Slope and elevation)

Slope is an important factor for landslide susceptibility. Therefore landform or geomorphic is various hill slope characteristics including the relief, steepness of slope, shape of the land surface, slope orientation and aspects, etc. However, only slope gradient and elevation are taken into consideration under the present study due to many limitations.

Table 23 Landslide potential classification of slope

Slope	Landslide Potential Class
Slope > 70%	Very high potential
Slope 50 – 70 %	High potential
Slope 30 – 50 %	Medium potential
Slope 15 – 30 %	Low potential
Slope 0 – 15 %	Very low potential

Elevation is landslide susceptibility factor. Pantanahiran (1994) reported that most of the landslide areas are located between elevation 400-600 meters on Phipun and Kririwong Nakronsrithammarat. Hathaitip (2004) divided elevation in Phuket for landslide hazard analysis as follows:

Table 24 Landslide potential classification of elevation

Elevation	Landslide Potential Class
Elevation > 401 meters	Very high potential
Elevation 301 - 400 meters	High potential
Elevation 201 - 300 meters	Medium potential
Elevation 101 - 200 meters	Low potential
Elevation 0 - 100 meters	Very low potential

3. Surface drainage zone

Surface drainage zone was considered by buffering 10 meters from center of river (Thassanapak, 2001). Groundwater or stream affects the stability of slopes by generating pore pressures, both positive and negative, which alter stress conditions, changing the bulk density of the material forming the slope, developing both internal and external erosions, changing the mineral constituents of the materials forming the slopes (Lee, 1995).

Table 25 Landslide potential classification of surface drainage zone

Surface Drainage Zone	Landslide Potential Class
Area inside Surface drainage zone	High potential
Area outside Surface drainage zone	Very low potential

4. Land used and land cover

Effect of vegetation on slope stability held reduction energy from rainfall. Root of large tree held slope stable. Other deforestation, urban area and agriculture area was cause of slope failure.

Table 26 Landslide potential classification of land used

Land Used	Landslide Potential Class
Agriculture area	High potential
Urban and built-up area	Medium potential
Other deforestation	Low potential
Forest area	Very low potential

5. Soil characteristic

Texture of soil refers to its surface appearance. Soil texture is influenced by the size of the individual particles present in it, divided into gravel, sand, silt, and clay. This study uses soil agricultures group to correlate with drainage (Department of Land Development, 2001).

Table 27 Landslide potential classification of soil characteristic

Soil Characteristic	Landslide Potential Class
Gravel loam/Gravelly sand	Very high potential
Sand	High potential
Sandy loam	Medium potential
Clayey loam/loam	Low potential
Clay, Mud	Very low potential

Table 28 Soil group (Department of Land Development, 2001)

Group	Soil characteristics	drainage	Landform (%Slope)
1	Clayey and mud	Poor	Flat (<1%)
2	Clayey and mud	Poor	Flat (<1%)
3	Clayey and mud	Poor	Flat (<1%)
4	Clayey and mud	Poor	Flat (<1%)

Table [illegible] Soil group (Department of Land Development, 2001) (Continued)

Group	Soil characteristics	drainage	Landform (%Slope)
5	Clayey and mud	Very poor	Flat (<1%)
6	Clayey and mud	Very poor	Flat (<2%)
8	Clayey and mud	Very poor	Flat (<1%)
9	Clayey and mud	Very poor	Coastal (<1%)
10	Clayey and mud	Very poor	Coastal (<1%)
11	Clayey and mud	Very poor	Coastal or Flat (<1%)
12	Clayey and mud	Very poor	Coastal to Flat (<1%)
13	Clayey and mud	Very poor	Coastal (<1%)
14	Clayey and mud	Very poor	Coastal (<1%)
15	Clayey loam and loam	Poor	Flat (<2%)
16	Sandy loam	Good	Flat (<2%)
17	Sandy loam	Poor	Flat (<2%)
18	Sandy loam	Very poor	Flat (<2%)
19	Sandy loam	Poor	Flat (<2%)
20	Sandy loam	Very poor	Flat (<2%)
21	Sandy loam	Fair to poor	River bank or Flat (<1%)
22	Sandy loam	Poor	Flat (<2%)
23	Sand	Very poor	Beach (<2%)
24	Sand	Fair to poor	Flat (<2%)
25	Gravel and gravelly loam	Poor	Flat (<2%)
26	Clayey loam and loam	Good	Plateau to Hill (2-35%)
27	Clayey loam and loam	Good	Plateau to Hill (2-20%)
28	Clayey and mud	Good	Plateau to Flat (<2%)
29	Clayey and mud	Good	Plateau to Hill (2-35%)
30	Clayey and mud	Good	Hill or Mountain (20-50%)
31	Clayey and mud	Fair	Plateau to Hill (2-20%)
32	Clayey loam and loam	Good	Plateau to Hillside (1-12%)

Table 28 Soil group (Department of Land Development, 2001) (Continued)

Group	Soil characteristics	drainage	Landform (%Slope)
33	Sandy loam	Fair	Plateau to Hillside (1-12%)
34	Clayey loam and loam	Fair	Plateau to Steep Slope (2-20%)
35	Sandy loam	Fair	Plateau to Steep Slope (2-20%)
36	Clayey loam and loam	Good	Plateau to Steep Slope (2-20%)
37	Sandy loam	Fair	Plateau to Flat Slope (2-5%)
38	Sandy loam	Good	Plateau to Flat Slope (<2%)
39	Sandy loam	Good	Plateau to Steep Slope (2-20%)
40	Sandy loam	Good	Plateau to Steep Slope (2-20%)
41	Sand	Fair	Plateau to Flat Slope (1-12%)
42	Sand	Fair	Flat to Highland (1-5%)
43	Sand	Very Good	Beach or sand rise (1-5%) Some Hillside
44	Sand	Very Good	Highland to Hillside (2-20%)
45	Gravel and gravelly loam	Good	Highland to Hillside (2-20%)
46	Gravel and gravelly loam	Good	Highland to Steep Slope (2-12%)
47	Clayey loam and loam	Good	Highland to Hillside (5-34%)
48	Sandy loam	Good	Highland to Hillside (12-35%)
49	Sand	Fair	Highland to Flat Slope (2-12%)
50	Gravel and gravelly loam	Good	High land to Hill side (12-35%)
51	Gravel and gravelly loam	Good	Highland to Hillside (12-35%)
52	Clayey loam and loam	Good	Highland to Hillside (2-20%)

Table 29 Soil group (Department of Land Development, 2001) (Continued)

Group	Soil characteristics	drainage	Landform (%Slope)
53	Clayey loam and loam	Good	Plateau to Hillside (2-20%)
54	Clayey and mud	Fair	High land to Steep Slope (5-19%)
55	Clayey and mud	Fair	High land to Flat Slope (1-12%)
56	Clayey loam and loam	Good	Plateau to Hillside (5-34%)
57	Clayey and mud	Very poor	Flat (<1%)
58	Clayey and mud	Very poor	Flat (<1%)
59	Clayey and mud	Very poor	Flat in valley (<2%)
60	Sandy loam	Good	Highland to Flat Slope (1-12%)
61	Slope complex		Highland to Steep Slope (5-19%)
62	Slope complex		Steep Slope (>35%)

6. Rainfall intensity

The magnitude, intensity, and duration of storm all play role in determination whether a hill slope will fail. Excessive rainfall weakens earth materials by displacing air and increasing the pore water pressure along shear surface. This study used two kinds of rainfall intensity which are 3 days cumulative of 1 year return period rainfall and 3 days cumulative of 1, 5, 20, 50, 100 years return period rainfall.

Table 29 Landslide potential classification of rainfall intensity (3 days cumulative rainfall for 1 year return period)

Rainfall Intensity	Landslide Potential Class
Rainfall intensity > 203 mm.	Very high potential
Rainfall intensity 161 - 203 mm.	High potential
Rainfall intensity 119 - 161 mm.	Medium potential
Rainfall intensity 77 - 119 mm.	Low potential
Rainfall intensity 35 – 77 mm.	Very low potential

Table 30 Landslide potential classification of rainfall intensity (3 days cumulative rainfall for 1, 5, 20, 50, 100 years return period)

Rainfall Intensity	Landslide Potential Class
Rainfall intensity > 857 mm.	Very high potential
Rainfall intensity 651.5 - 857 mm.	High potential
Rainfall intensity 446 – 651.5 mm.	Medium potential
Rainfall intensity 240.5 - 446 mm.	Low potential
Rainfall intensity 35 – 240.5 mm.	Very low potential

7. Engineering soil properties

Landside susceptibility factor from engineering soil properties was studied by using index of unstable soil. Appendix table 3 - 4 show a laboratory test of soil and weathered rock consisting of Undisturbed, Disturbed and Pocket Penetrometer Test. These were parallel study results which were used for divided landslide potential levels. The soil engineering properties were classified in term of parent rocks or residual soil. The engineering soil properties were different from rock type parameter. Residual soil from sandstone/siltstone has strength reduction when considered at natural water content with saturated condition more than residual soil from granite rock (Appendix table 4). But it was different from soil characteristics because the engineering soil properties were soil engineering and soil characteristics and soil textures in which primary data were collected from agricultural soil.

Table 31 Landslide potential classification of engineering soil properties

Engineering Soil Properties	Landslide Potential Class
Residual soil form Sandstone/Siltstone	Very high potential
Residual soil form Granite Rock	High potential
Residual soil form Shale/Mudstone	Medium potential
Residual soil form Quartzite, Sandstone and Siltstone	Low potential
Residual soil form Limestone/Dolomite	Very low potential

The 7 related factors were used for landslide hazard analysis by weighing factor method. The assigned weight system to parameters influencing the landslide in Phuket are summarized and presented in Table 32. Table 33 shows the landslide potential and the range of a total score for all return periods of rainfall.

Table 32 The numerical weight assignment to the parameters influencing the landslide potential in Phuket

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

Table 33 The landslide potential and the range of total score for all return periods of rainfall

Landslide Susceptibility Classes	Range of Score
Very high susceptibility to landslide	101-120
High susceptibility to landslide	82-101
Moderate susceptibility to landslide	63-82
Low susceptibility to landslide	44-63
Very low to nil susceptibility to landslide	25-44

Processing of landslide susceptibility and hazard map (7 factors)

In determining the numerical rating of altogether 7 parameters/sub-parameters responding to the landslide in Phuket, an area of 25x25 square meters grid cell has been employed for the analysis by GIS program. After that, the weight-rating values of each parameter/sub-parameters or each derivative map will be determined in each square grid cell. Finally, the scores of weight-rating in each 25x25 square meters grid cell will be obtained from the summation of weight-rating values of each derivative map. These means that the overall areas of Phuket are subdivided into a small 25x25 square grid cell. The landslide susceptibility factors are shown in Fig 8- Fig 16. Landslides susceptibility analysis was produced from difference factor for comparison of each map in Fig 17.

The results of processing of landslide susceptibility map considered by weighting factor analysis are shown in Fig 18. Plan area was classified by landslide susceptibility class shown in Table 34 and Fig 19.

Fig 20 – Fig 24 shows the results of processing of landslide hazard map considered by weighting factor analysis in terms of probability of return period of rainfall. Scores were classified by half of range between 25 to 120 which was 73 score. Fig 25 shows landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considering 7 related factors. Predicted landslide hazard area for 5 return periods of rainfall considering 7 related factors is shown in Table 35 and Fig 26. The plan area of landslide hazard was 4.14%, 7.68%, 14.15%, 16.29% and 18.59% for 1, 5, 20, 50 and 100 years return period of rainfall respectively in which the plan area of landslide hazard for 1 year return period overlap with plan area of landslide hazard for 5, 20, 50 and 100 year return period.

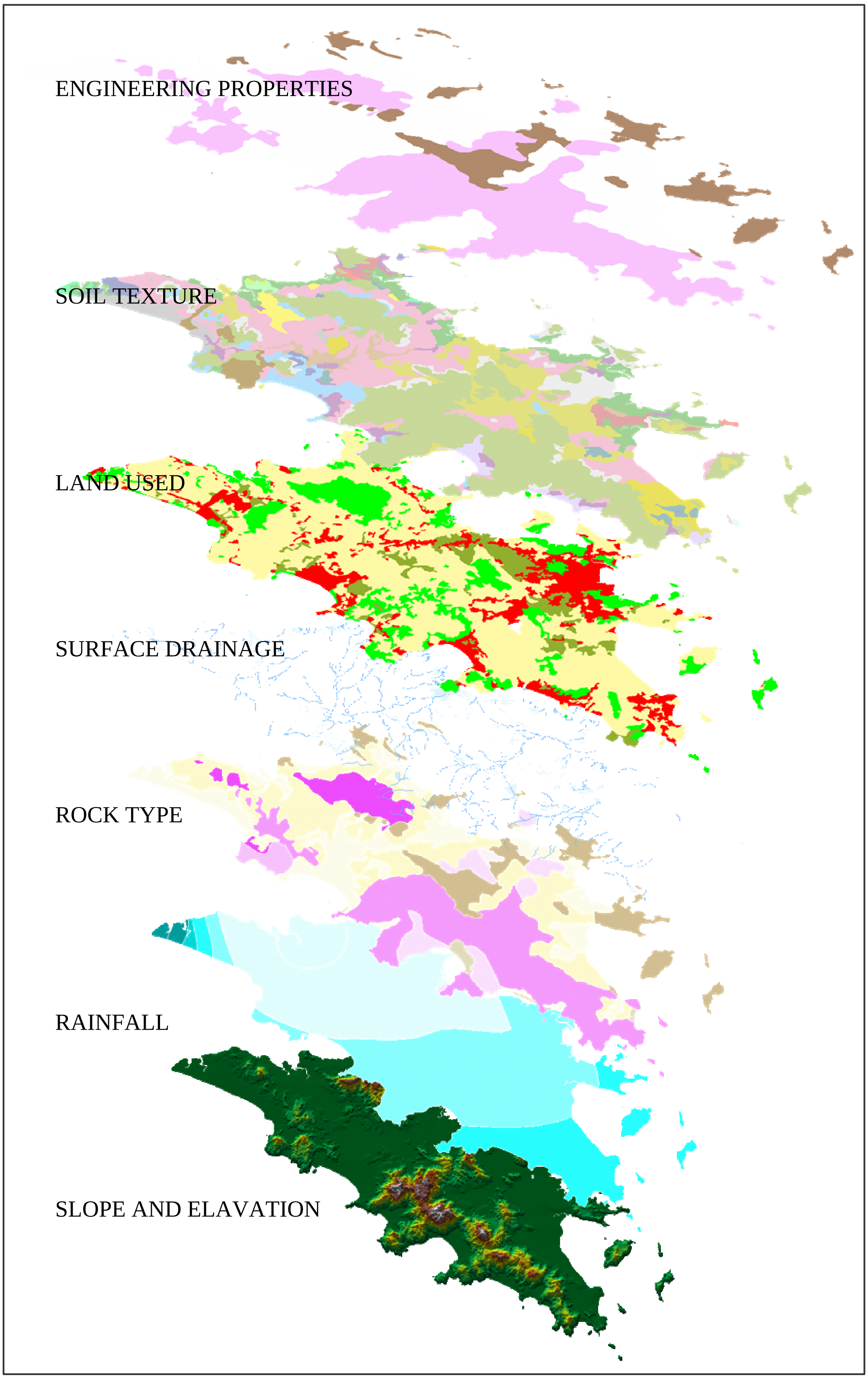


Figure 17 GIS layers of considered factors
Source: Department of mineral resource (2006)

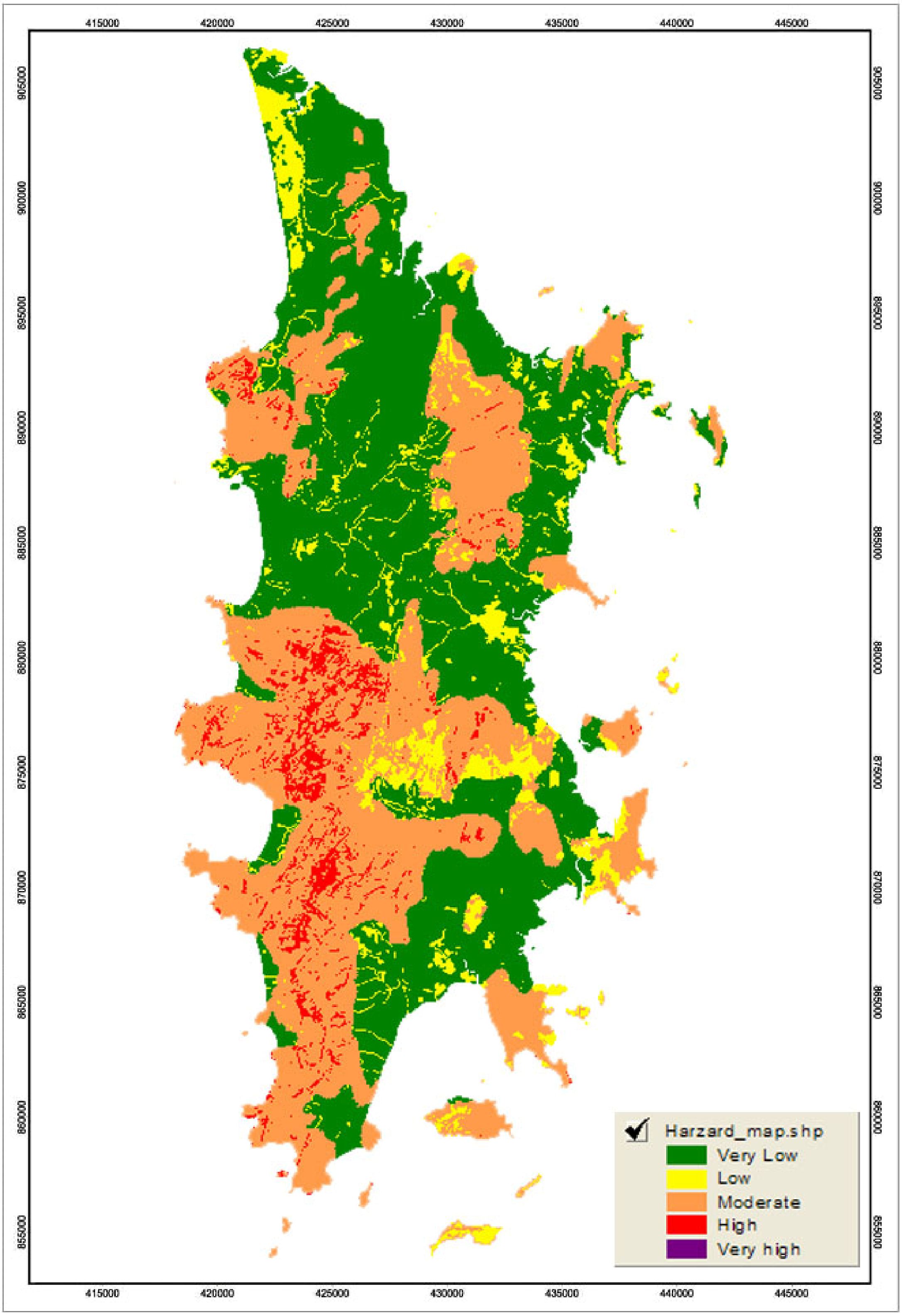


Figure 18 Landslide susceptibility map by weighting factor method considered 7 related factors

Table 34 Predicted landslide susceptibility area considering 7 related factors

Score	Landslide Potentials Classes	pixel	Area (km^2)	%
101-120	Very high potential	1	0.00	0.00
82-101	High potential	49,234	30.77	5.60
63-82	Moderate potential	353,056	220.66	40.19
44-63	Low potential	101,342	63.34	11.54
25-44	Very low to nil potential	374,784	234.24	42.67
	Sum	878,417	549	100.00

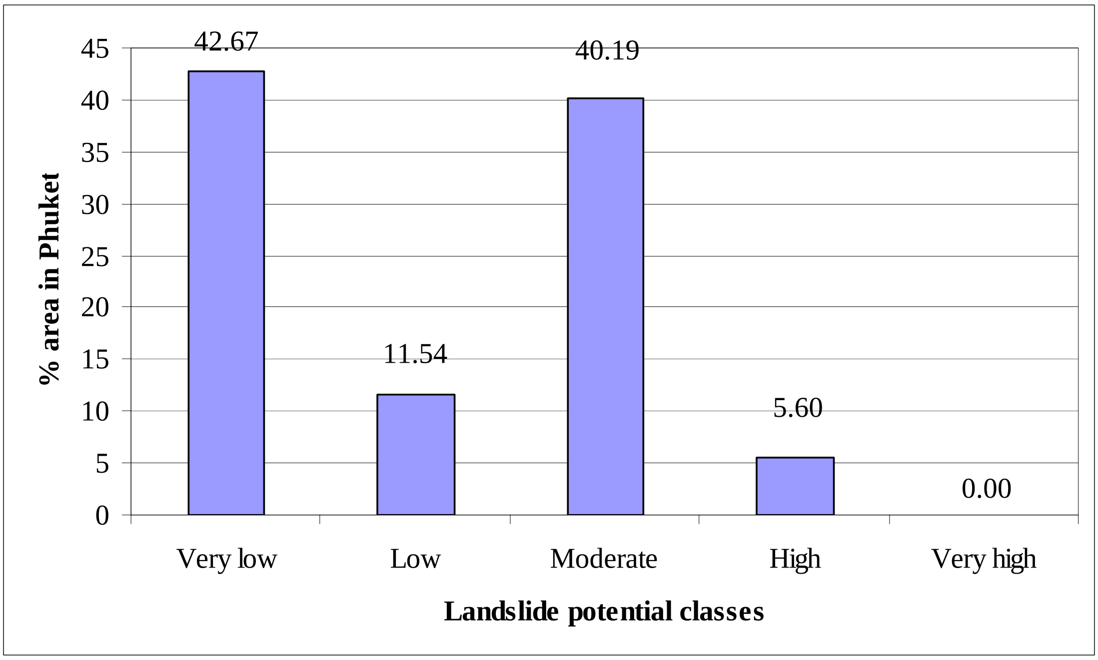


Figure 19 Predicted landslide susceptibility area considering 7 related factors

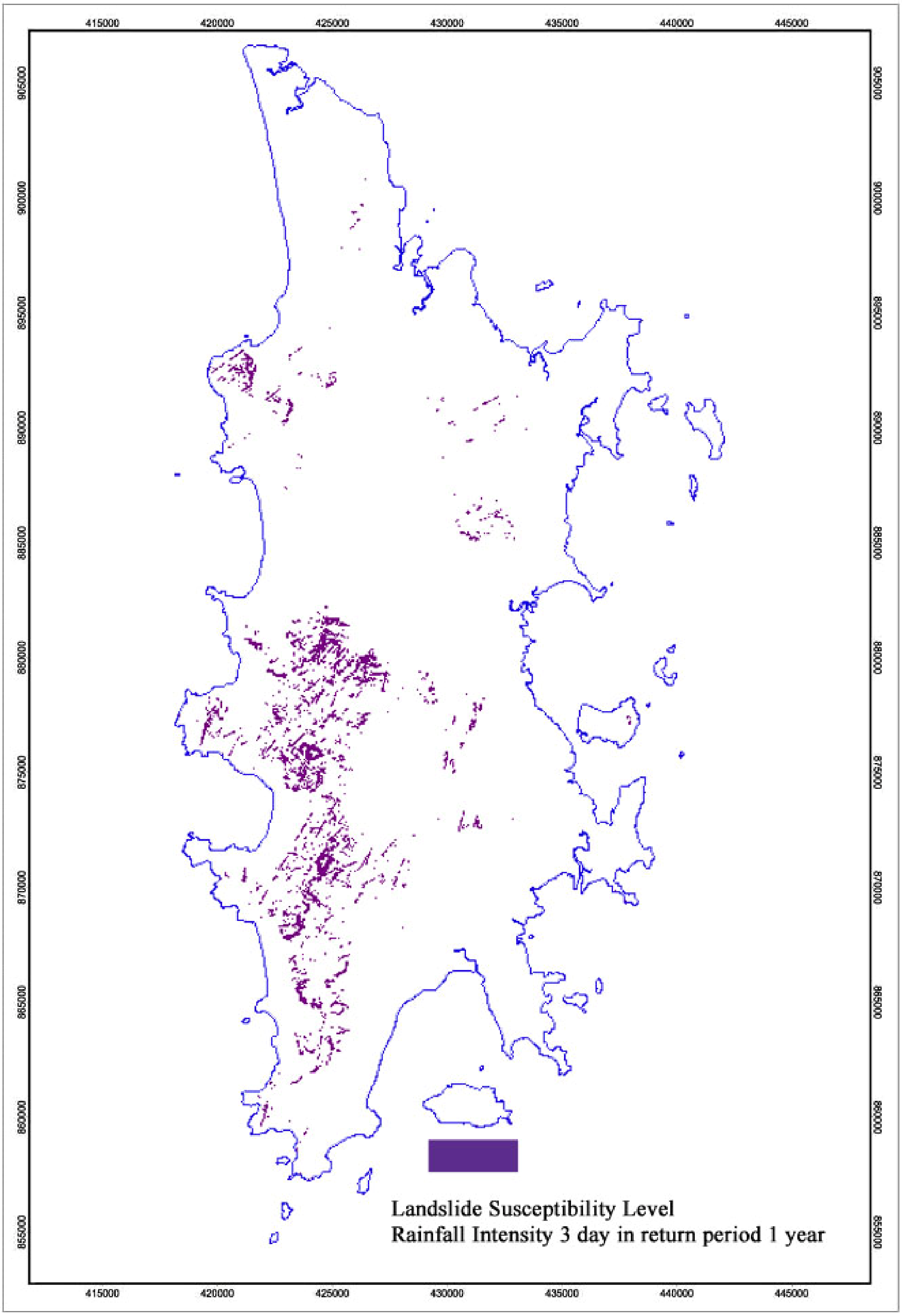


Figure 20 Landslide hazard map considering 1 year return period of rainfall

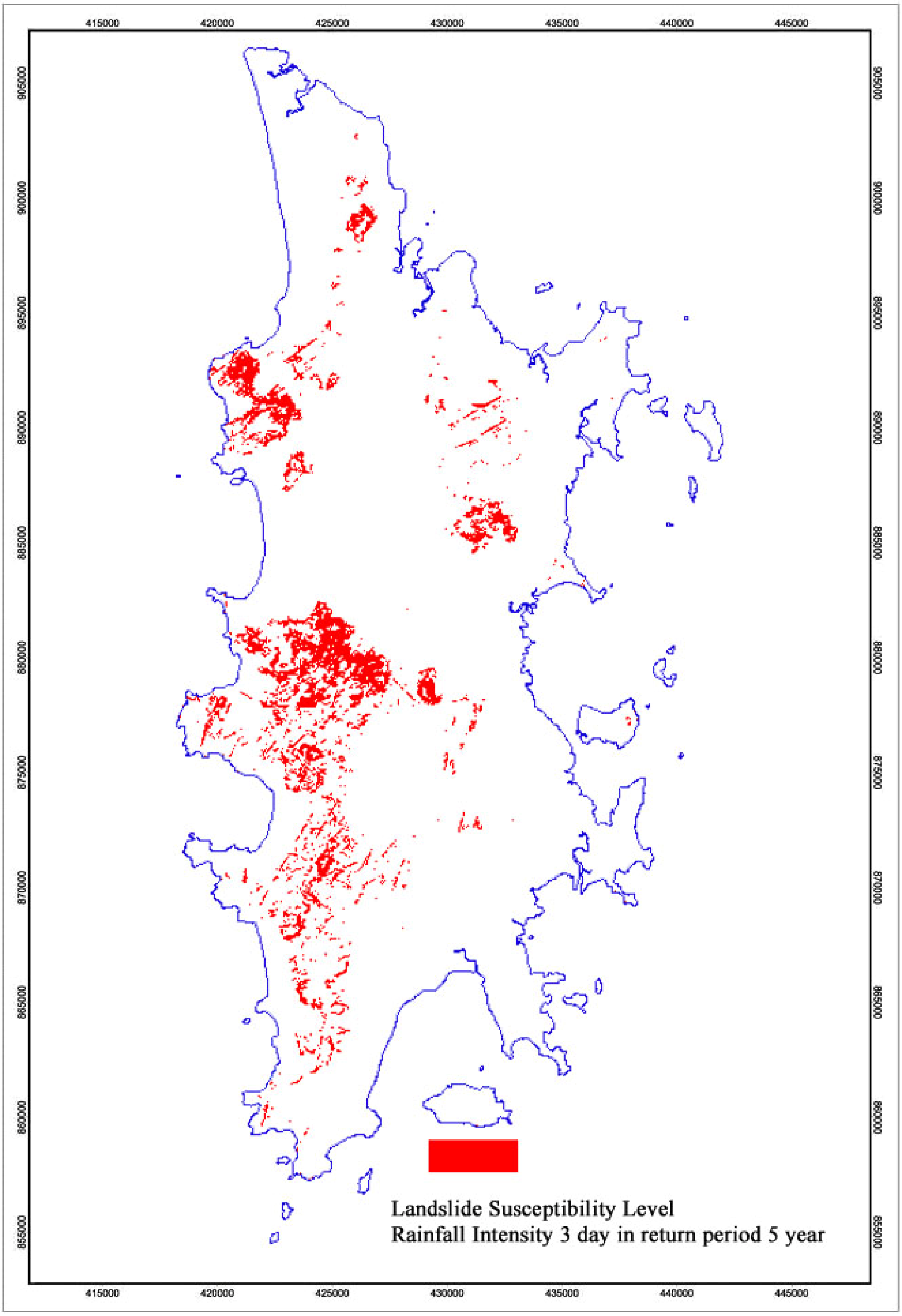


Figure 21 Landslide hazard map considering 5 years return period of rainfall

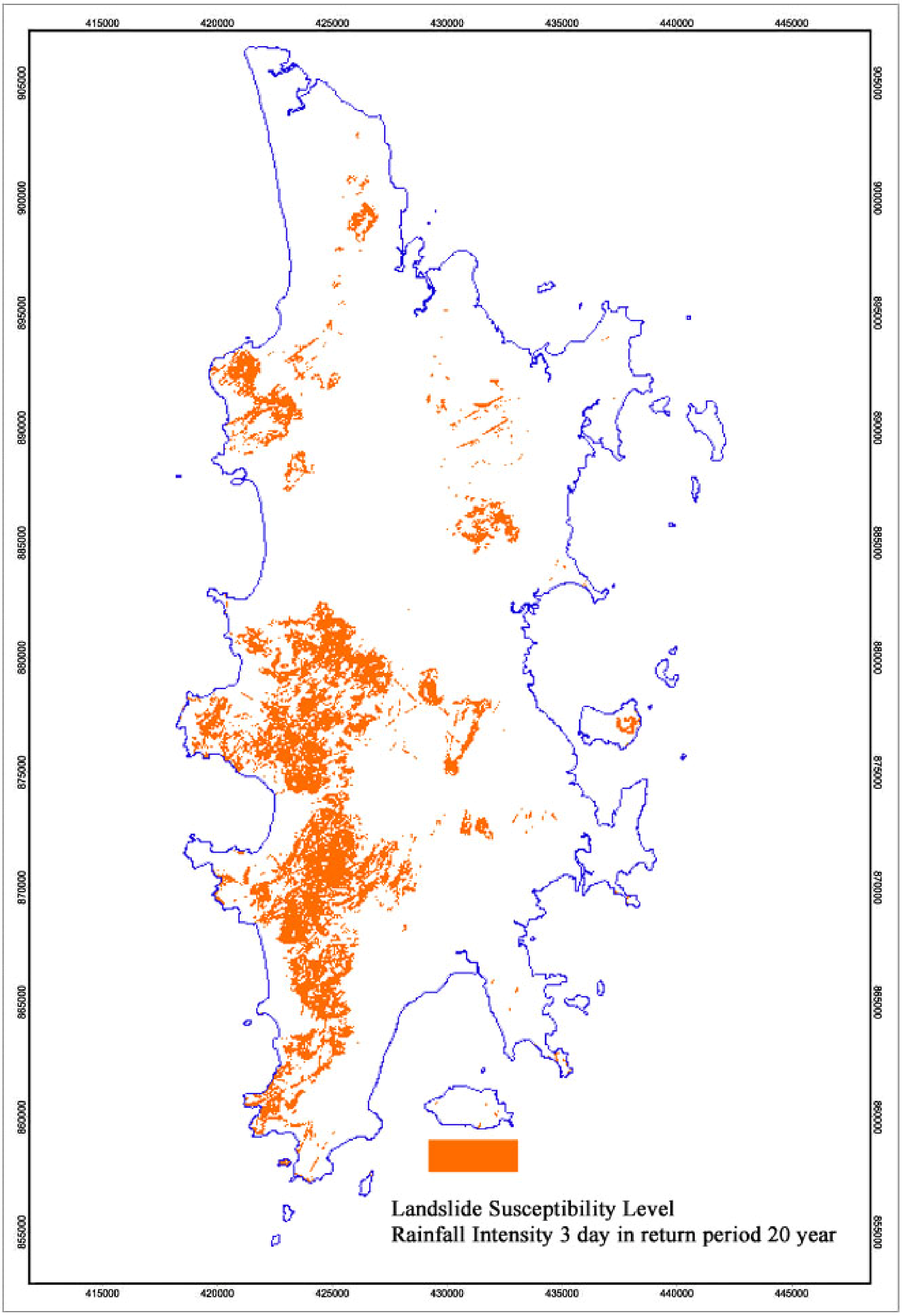


Figure 22 Landslide hazard map considering 20 years return period of rainfall

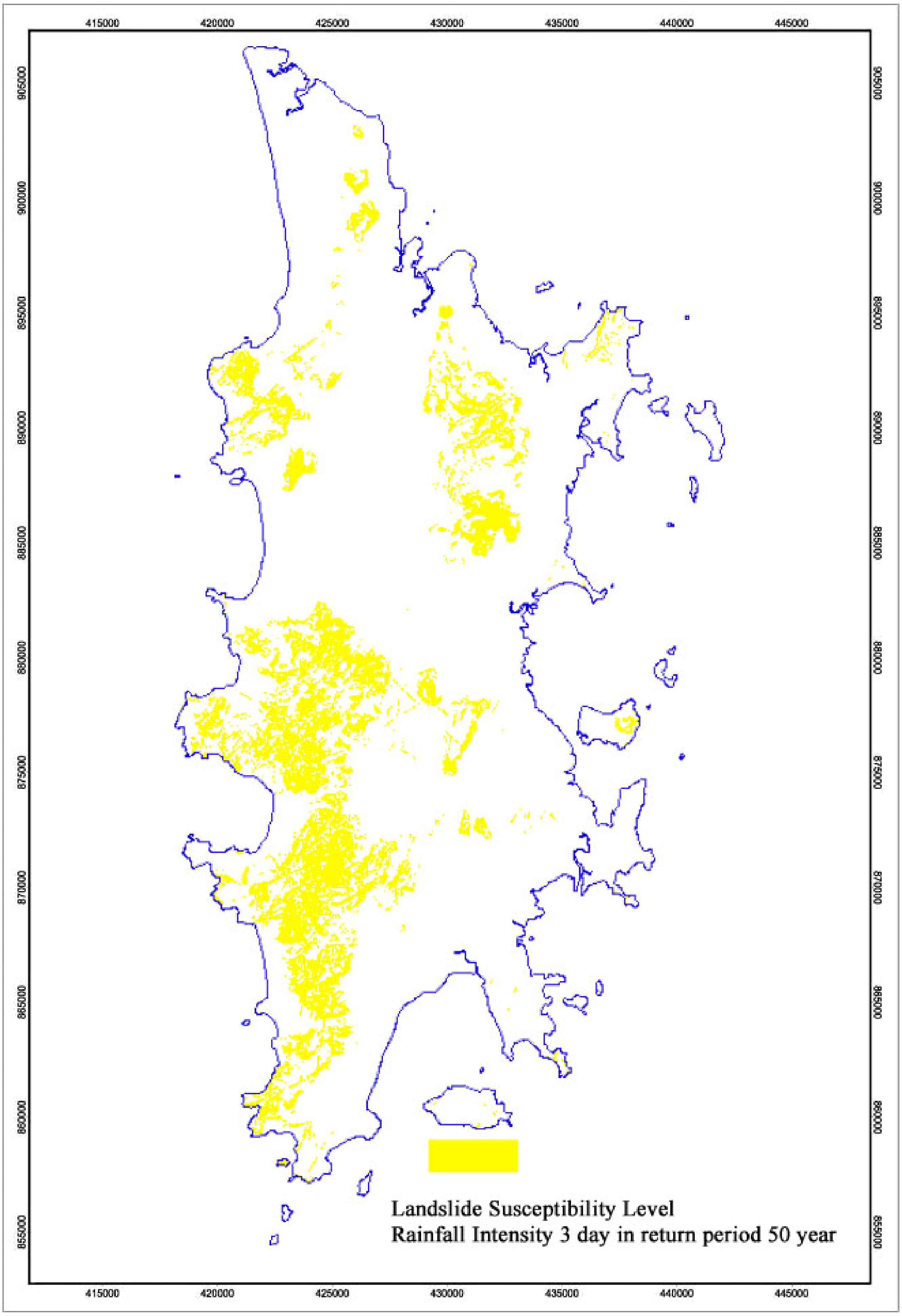


Figure 23 Landslide hazard map considering 50 years return period of rainfall

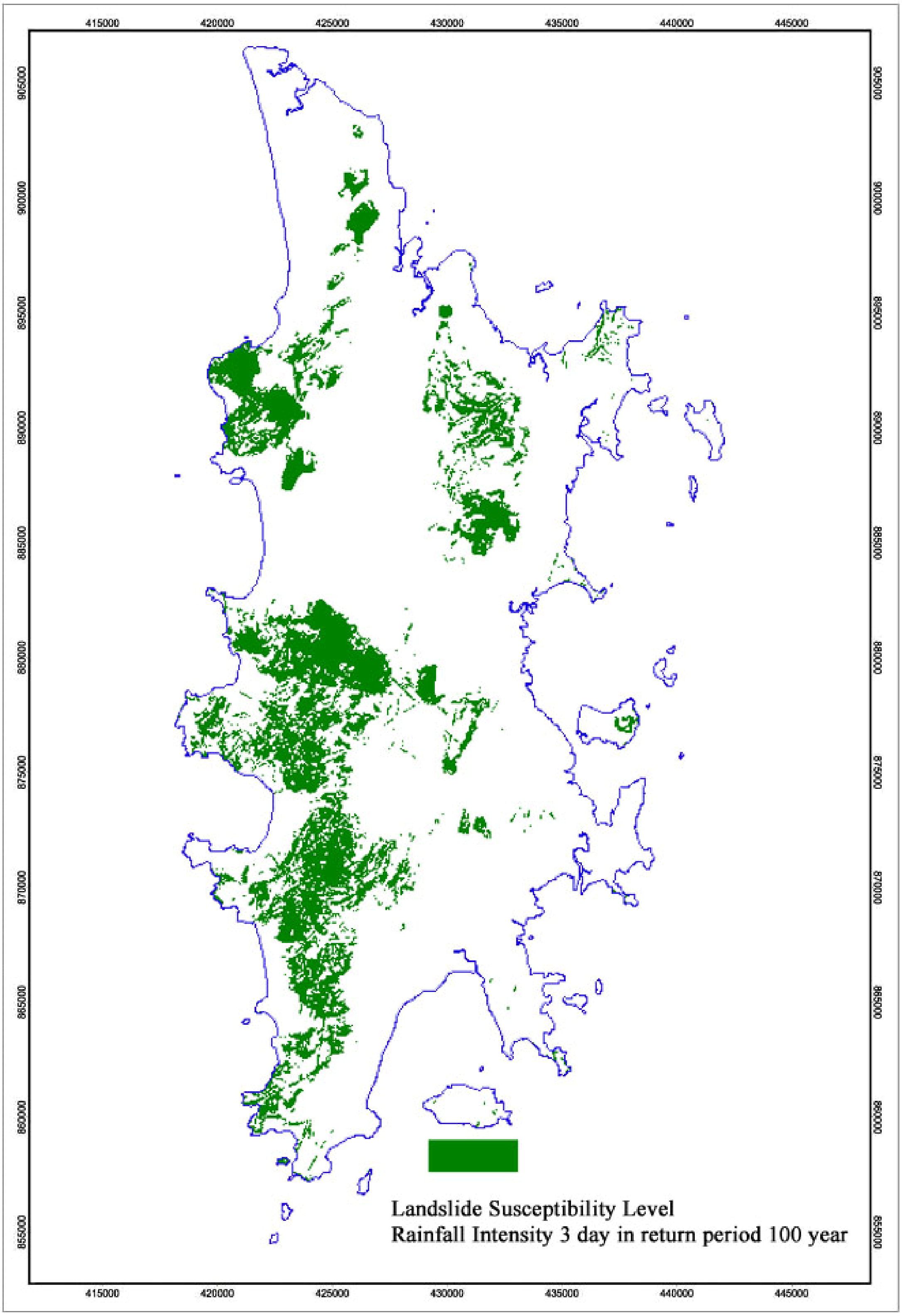


Figure 24 Landslide hazard map considering 100 years return period of rainfall

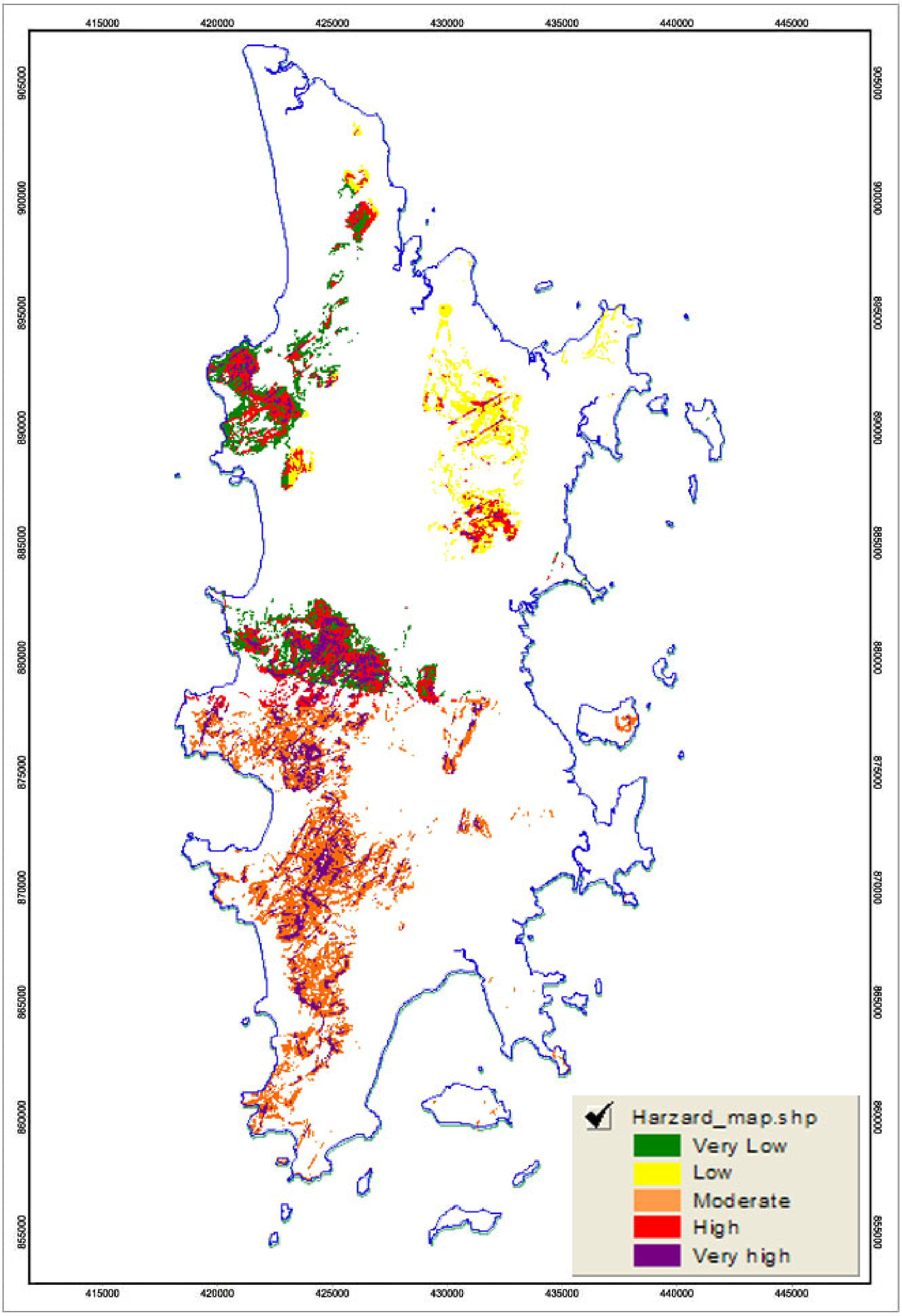


Figure 25 Landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors

Table 35 Predicted landslide hazard area for 5 return periods of rainfall considering 7 related factors

Return period of rainfall year	Landslide classify	pixel	Area (km^2)	%
1	Fail	36,329	22.71	4.14
	No fail	842,088	526.31	95.86
5	Fail	67,480	42.18	7.68
	No fail	810,937	506.84	92.32
20	Fail	124,302	77.69	14.15
	No fail	754,115	471.32	85.85
50	Fail	143,130	89.46	16.29
	No fail	735,287	459.55	83.71
100	Fail	163,268	102.04	18.59
	No fail	715,149	446.97	81.41

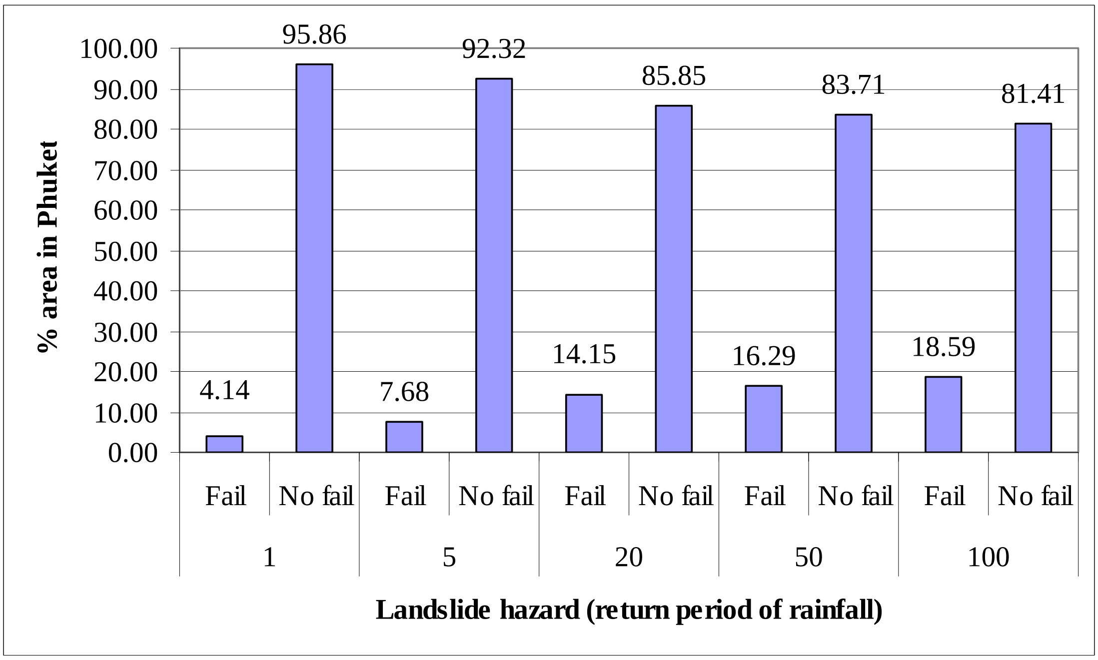


Figure 26 Predicted landslide hazard area for 5 return periods of rainfall considering 7 related factors

Table 36 Comparison of landslide potential area and landslide hazard area considering 7 related factors

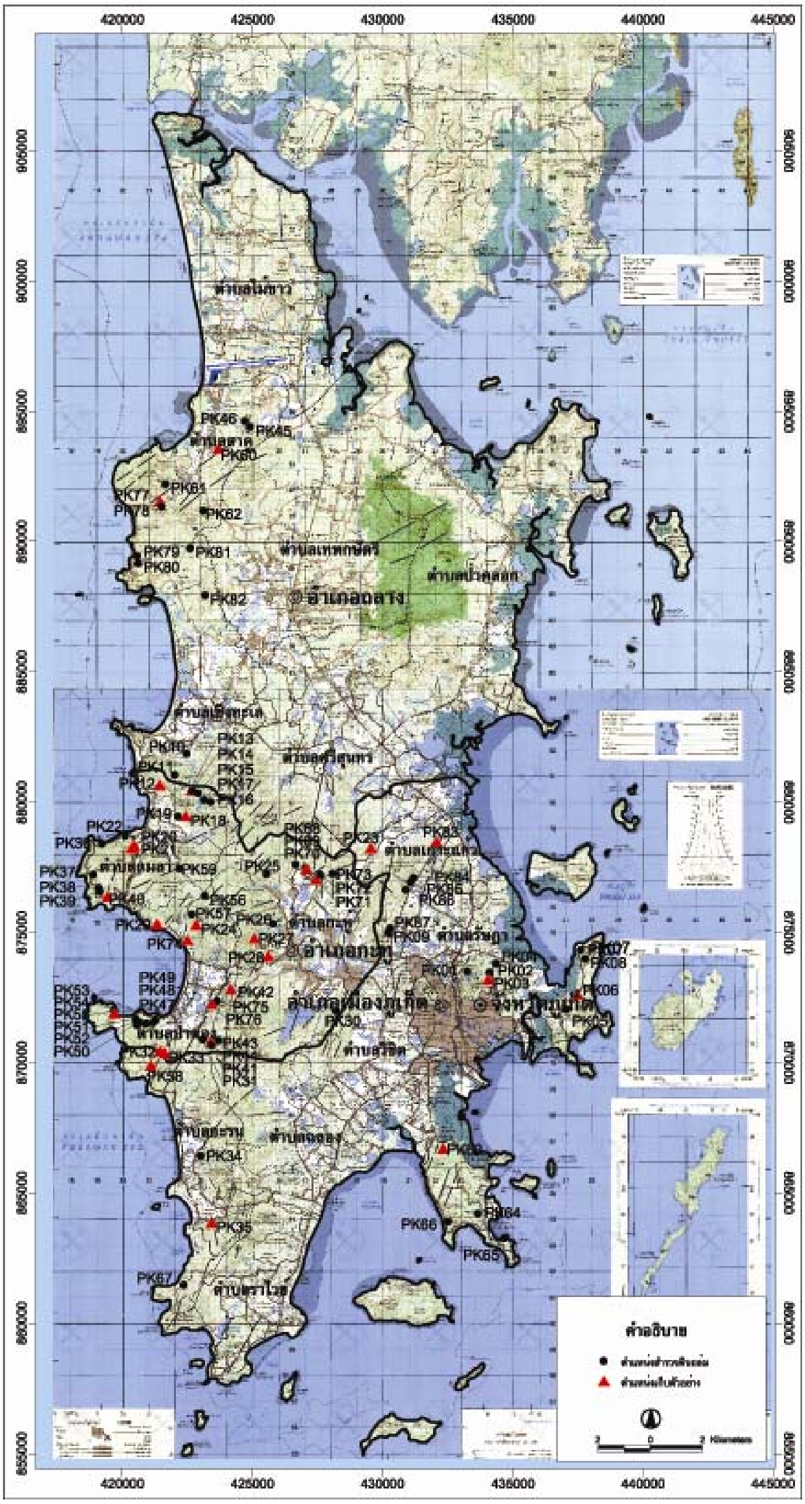
Landslide Potentials Classes	Landslide susceptibility map (%)	Landslide hazard map (%)
Very high	0.00	4.14
High	5.60	7.68
Moderate	40.19	14.15
Low	11.54	16.29
Very low	42.67	18.59
Sum	100.00	

The comparison of predicted landslide susceptibility and landslide hazard area considered 7 related factors shows in Table 36 which was evaluated by same weighting factor method but the results were different. When considered annual probability in case of landslide susceptibility has no area in very high landslide potentials classes but landslide hazard has area in very high landslide potentials classes, the landslide potentials classes of landslide susceptibility mean in annual probability but landslide hazard mean 1.0, 0.2, 0.05, 0.02 and 0.01 annual probability for 1, 5, 20, 50 and 100 years return period of rainfall respectively.

Field Investigation

The physiographic setting of Phuket Island is underlying mostly the granitic mountain range approximately 40 percent of the total area, especially the western side of the island. The highest elevation of the hillslope are 541 m MSL at Khao Khun Wa and 515 m MSL at Khao Mai Tao Sip Song on the western part of the area and slope steepness more than 30 degrees (Thassanapak, 2001). Inventory map was produce by field investigation. Fig 27 shows field survey location in Phuket. Field survey consisted of 87 points, which are located in watershed map (Table 37 and Appendix table 1).

Most of field investigation was cut slope for development which had a little bit natural landslide. There are numerous failure slope developments in weathered granite which have caused damage to adjacent building (Fig 28). There are numerous road cuts across these granite hill slopes (Fig 29 and Fig 30). Hillside cuts required for highway construction often destabilize slope gradient of the hill slope. Most of these failures tend to be earth flow or earth slump (Fig 31). The slope failure revealed that the earth materials were the weathered granitic rock (Fig 32). An attempt to remedy and control these failures is seen along Highway no. 4233, especially the route between Kamala beach and Patong beach and along the distance from Patong beach to Karon beach (Fig 33). And cut slope for residential or commercial building is very close; some cases show failure (Fig 35), some cases still did not (Fig 34) depending on degree of weathering rock.



Note: PKxx is field survey location

Figure 27 Location of field investigation
Source: Department of mineral resource (2006)

Figure 28 Station PK32 cut slope for borrow area in Patong Kathu, N 870435 E 421425. The rock is granite (G2). Rock slump failure mode.

Figure 29 Station PK85 cut slope for highway construction number 0402 in Ratsada Muang, N 876928 E 430877. The rock is granite (G4). The slope is still stable.

Figure 30 Station PK38 cut slope for road along Ao Na Khale in Kamala Kathu (Khao Pak Bang), N 876700 E 419075. The rock is granite (G2). The slope failed by soil.

Figure 31 Station PK39 cut slope for road along Ao Na Khale in Kamala Kathu (Khao Pak Bang), N 876570 E 419110. The rock is granite (G2). The slope failed by soil.

Figure 32 Station PK40 cut slope for road along Ao Na Khale in Kamala Kathu (Khao Pak Bang), N 876360 E 419400. The rock is granite (G4). The slope failed by soil.

Figure 33 Station PK20 cut slope for highway construction number 4233 between Kamala-Patong beach, N878200 E420400. The rock is granite (G2). Conventional rotation failure.

Figure 34 Station PK09 cut slope for highway construction number 0402 in Ratsada Muang, N 875000 E 430200. The rock is granite (G4). The slope is still stable.

Figure 35 Station PK35 cut slope for housing construction between road number 4233 and 4028 in Karon Muang, N 863850 E 423400. The rock is granite (G2). The slope failed by soil.

Watershed Analysis

Result from field investigation evaluated by 24 watersheds. This study surveyed only 14 watersheds in Table 37 and Fig 36-37. Field surveys emphasized to collected fail or no fail of cut slope but in table natural landslide were included.

Table 37 Field investigation in 14 watersheds

No.	Watershed	Area (km^2)	No. Observation	FAIL	NO FAIL
1	AO KUNG BASIN	21.57			
2	AO PO BASIN	31.58			
3	CHALONG BASIN	43.44	1	-	1
4	CHAT CHAI BASIN	28.81			
5	KAMALA BASIN	18.05	17	15	2
6	KARON BASIN	9.27	1	-	1
7	KATA BASIN	4.68	1	1	-
8	KATA NOI BASIN	2.20	1	1	-
9	KHAO KHAT BASIN	3.03			
10	KHOCHAO BASIN	1.31			
11	LAEM KHAEK BASIN	1.97	3	2	1
12	LAEM NGA BASIN	11.73	6	4	2
13	LEAM MAI NGANG BASIN	1.58			
14	LEAM YANG BASIN	4.42			
15	MUANG BASIN	90.13	21	2	19
16	MUM NAI BASIN	1.06			
17	MUM NOK BASIN	5.73			
18	NA KHALE BASIN	3.89	1	1	-
19	PATONG BASIN	18.85	20	11	9
20	RAWAI BASIN	6.94			
21	SAPAM BASIN	64.68	2	-	2
22	THA MAPHRAO BASIN	40.74	1	-	1
23	THALANG BASIN	85.41	6	1	5
24	THUNG NUNG BASIN	17.40	6	1	5
25	SMALL ISLANDS	23.24			
	SUMMATION	541.71	87	39	48

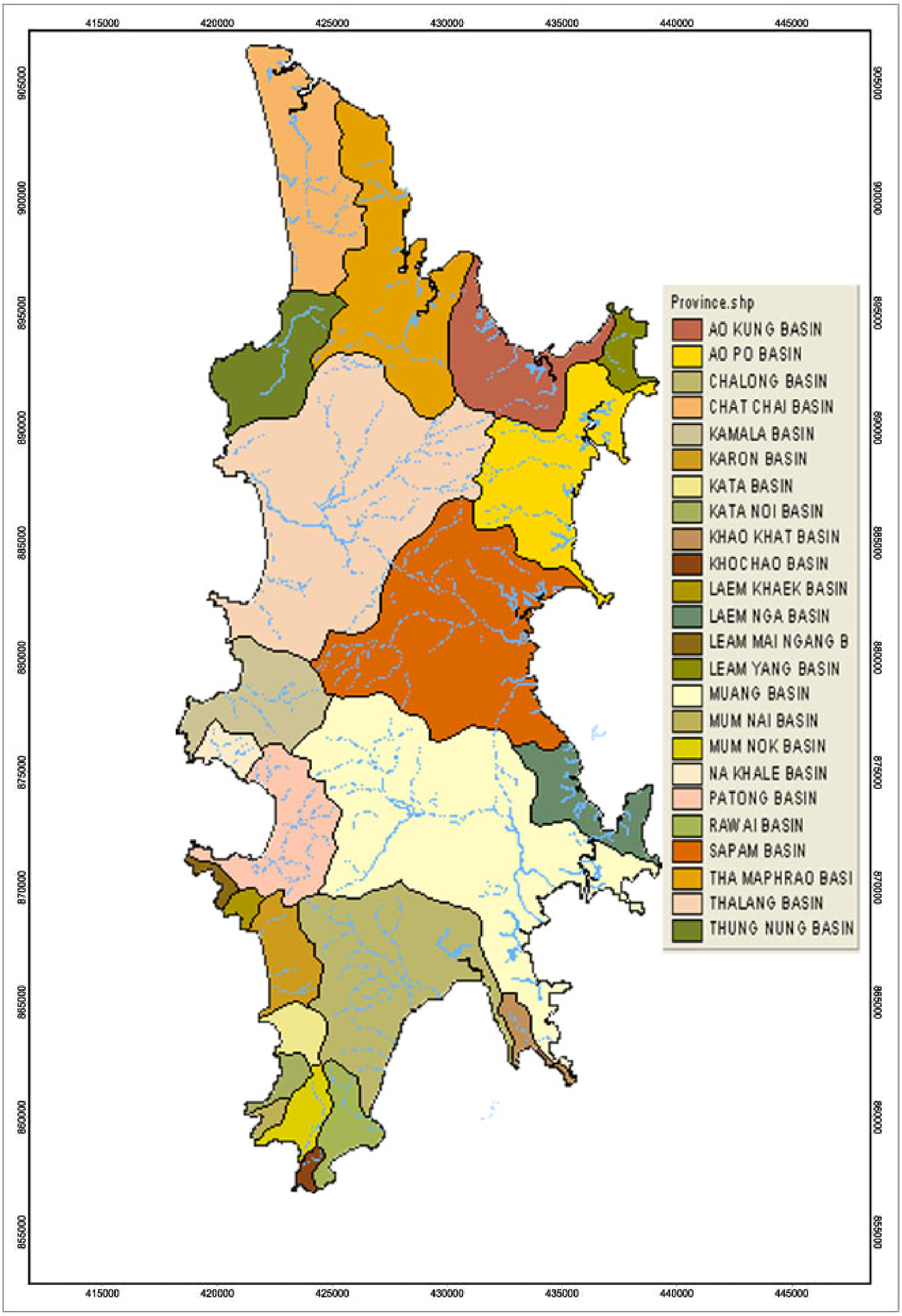


Figure 36 Watershed and surface water resources in Phuket
Source: Department of Environmental Quality Promotion (2004)

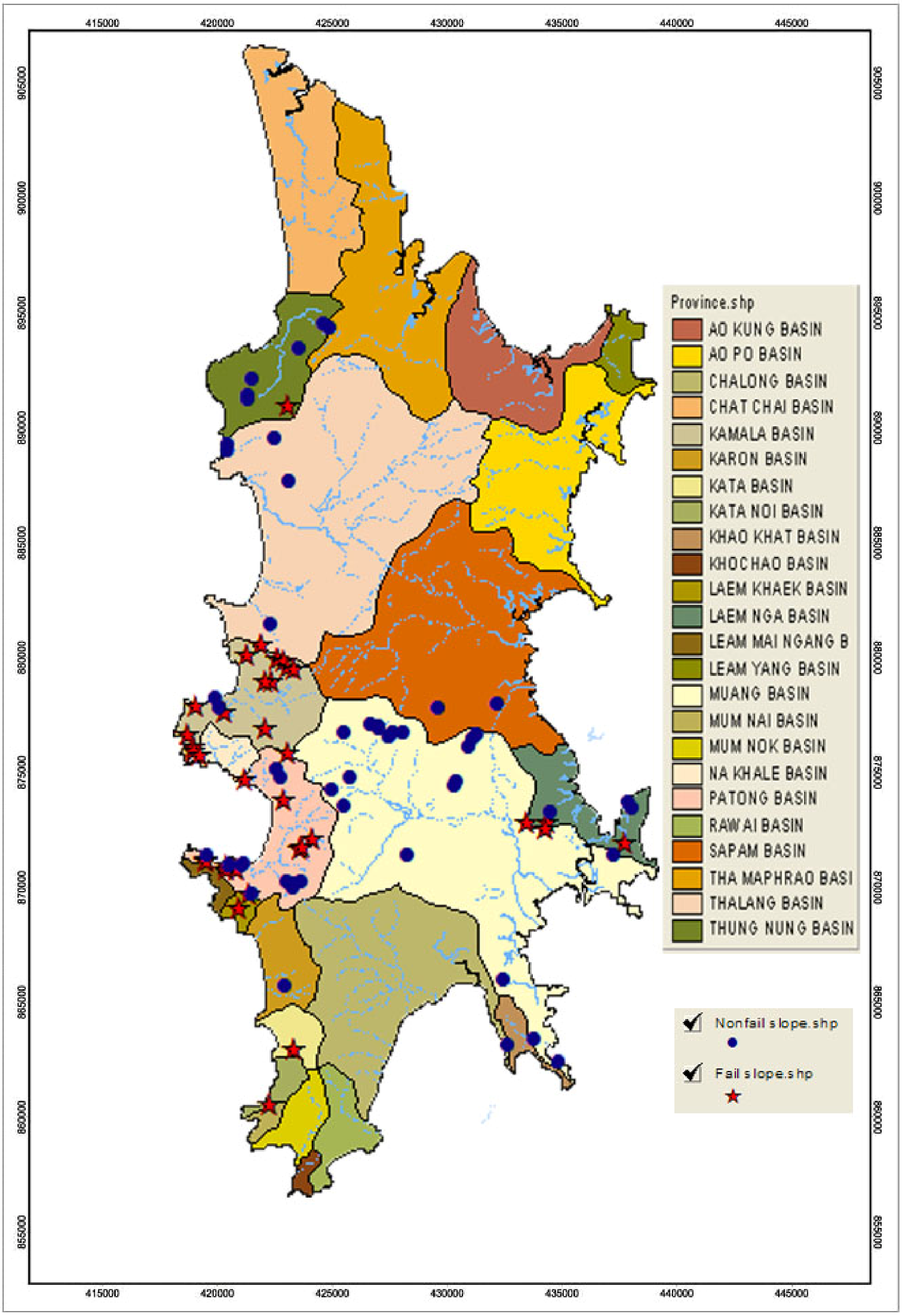


Figure 37 Field survey locations, cut slope condition

Weight Factor Analysis Including RMR Value

Table 38 and Appendix table 1 show RMR rating estimation from field investigation data. Table 39 shows average rock mass rating classified by rock type.

Table 38 Field investigation data for RMR rating

NO.	Parameter	In Field+Lab				
		kalim	DTAC	sire'	patong 50 yrs	gabion 2
1	point-load	2.46 MPa	2.94 Mpa	-	7.92 Mpa	1.19 Mpa
2	RQD	73.47%	69%	0%	87%	20%
3	spacing of discontinuities	200-300 mm	300-600 mm	100 mm	200-600 mm	200-300 mm
4	condition of discontinuities					
	4.1 discontinuities length	> 20 m	> 20 m	> 20 m	> 20 m	> 20 m
	4.2 separation	1-2 mm	1-2 mm	< 1 mm	0.1-1 mm	1-3 mm
	4.3 roughness	Slightly rough	Slightly rough	Smoooth	Rough	Slightly rough
	4.4 infilling	Soft < 5 mm	Soft < 5 mm	Soft < 5 mm	None	Soft < 5 mm
	4.5 weathering	highly weathered	Moderately weathered	highly weathered	highly weathered	highly weathered
5	general condition	Damp	Damp	Damp	Damp	Damp
B	slope	Fair	Fair	Unfavourable	Fair	Very Unfavourable

Table 39 Average rock mass rating classified by rock type

Rock type	BASIN	Number	Avg. RMR
CP	CHALONG BASIN	1	55.00
	LAEM NGA BASIN	4	47.50
	MUANG BASIN	9	51.00
G2	KAMALA BASIN	14	35.50
	KARON BASIN	1	60.00
	KATA BASIN	1	47.00
	KATA NOI BASIN	1	32.00
	MUANG BASIN	4	60.75
	PATONG BASIN	13	46.07
	THA MAPHRAO BASIN	1	60.00
	THALANG BASIN	2	54.00
	THUNG NUNG BASIN	2	56.00
G3	THUNG NUNG BASIN	3	47.00
	THALANG BASIN	3	57.00
G4	LAEM KHAEK BASIN	3	34.67
	MUANG BASIN	5	59.80
	NA KHALE BASIN	1	45.00
	PATONG BASIN	6	42.33
	SAPAM BASIN	2	64.50

Fig 38 shows relationship between failure of cut slope and RMR value. Fig 39 shows relationship between non-failure of cut slope and RMR value.

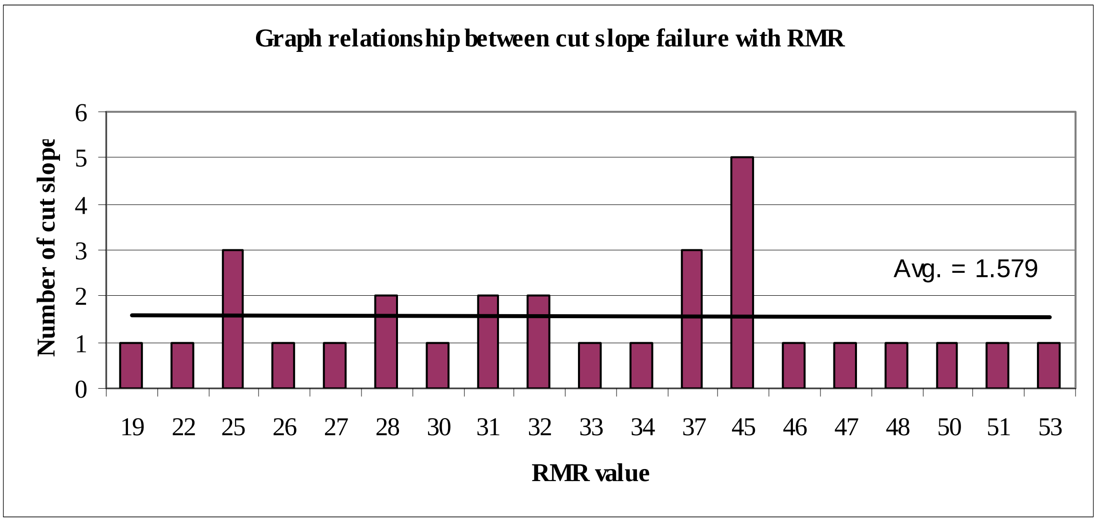


Figure 38 Graph relationships between cut slope failures and RMR rating

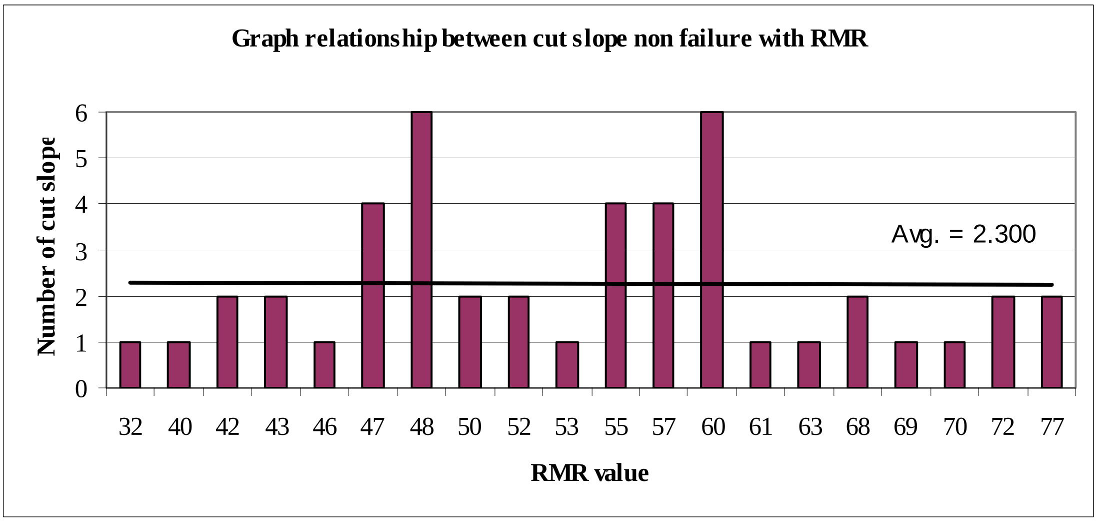


Figure 39 Graph relationships between cut slope non failures and RMR rating

Fig 40 shows normal distribution curve RMR value classified by slope condition. Fig 41 shows cumulative frequency of RMR value classified by slope condition. Fig 42 shows landslide potential classified by RMR value. These could assign the numerical weight for the RMR factor influencing the landslide in Phuket (Table 40).

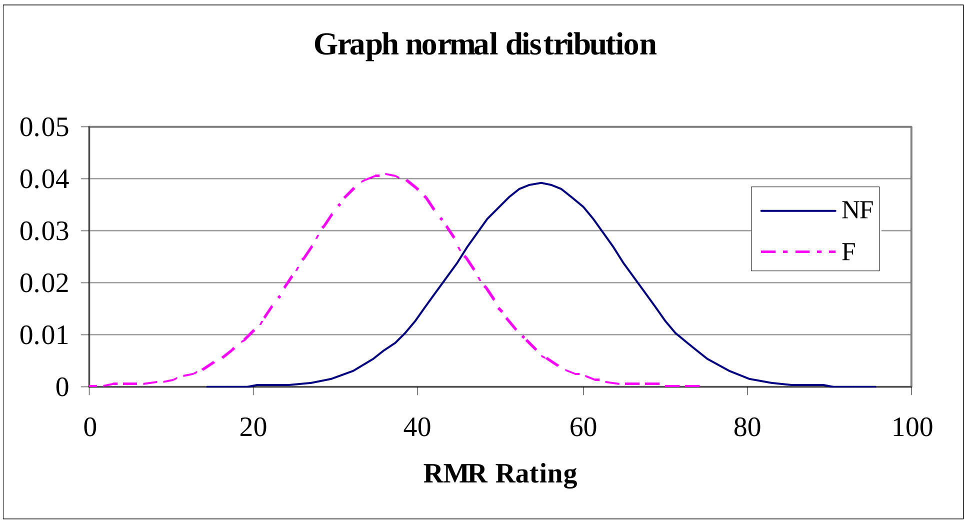


Figure 40 Normal distribution curve RMR value classified by slope condition

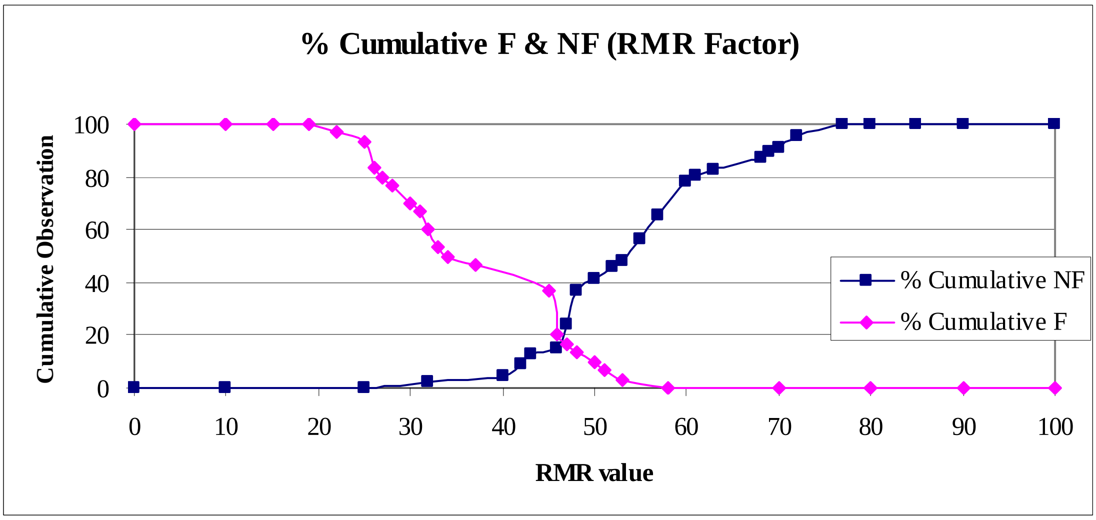


Figure 41 Cumulative frequency of RMR value classified by slope condition

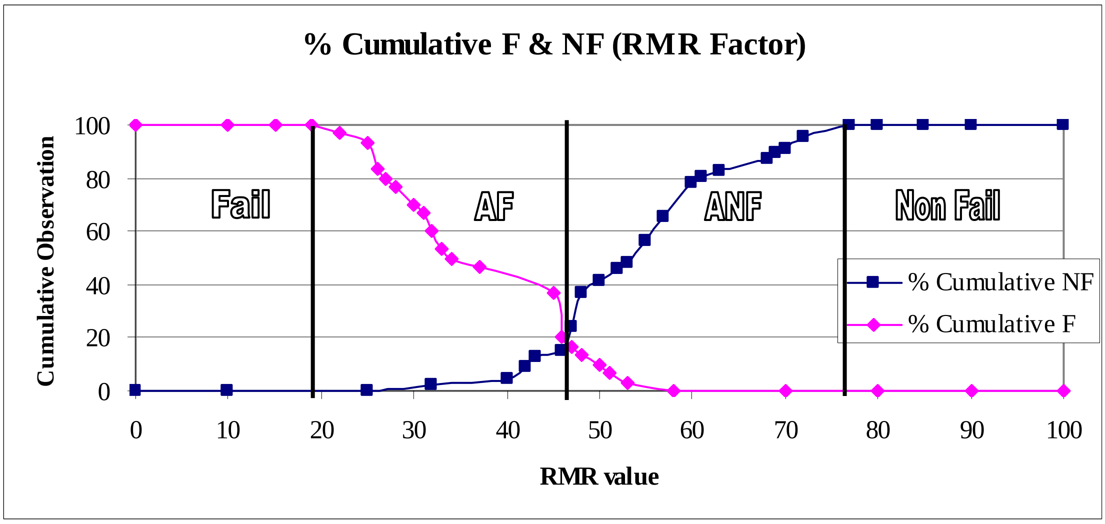


Figure 42 Landslide potential classified by RMR value

Table 40 The numerical weight assignment to the RMR factor influencing the landslide in Phuket.

Parameter	Weight Value		Rating Value		
	Parameter	Sub-parameter	Description	Landslide potential	Rating
RMR	5		A. 0 - 19 B. 19 - 46 C. 46 - 77 D. 77 - 100	F AF ANF NF	4 3 2 1

Processing Landslide Susceptibility and Hazard Map by Considering RMR Value

In this section, the processing of landslide susceptibility map determined the numerical rating of 7 related factors and RMR factor following weighting factor method (Table 40). The weight-rating values of each parameter determined in each 25x25 square meters grid cell, in which the summation of weight-rating values were classified range of score by landslide susceptibility classes (Table 33). The result are shown in Fig 43. Table 41 and Fig 44 show area of landslide classes considered by 7 related factors and RMR factor included.

This study performed comparison of landslide susceptibility map between RMR factor determination and non RMR factor determination in 1 year return period of rainfall intensity. The engineering soil properties factor and RMR factor were determined for landslide susceptibility factor because they are new factor in weighing factor method. Comparison of landslide susceptibility map between RMR factor determination and non RMR factor determination in 1 year return period of rainfall intensity is shown in Fig 45. The landslide susceptibility map for non RMR factor determination has higher landslide susceptibility in flat area than the landslide susceptibility map for engineering soil properties factor and RMR factor determination. Fig 46 shows comparison of landslide classes between considered by 7 related factors and considered by including 7 related factors and RMR factor which show the result of landslide high potential class in case RMR factor included had more area than no RMR factor included. So, the RMR factor was important factor to determine landslide susceptibility map.

Fig 47 (a) to (e) shows the results of processing of landslide hazard map considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by half of range between 25 to 120 which was 73 score. Fig 48 shows landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors and RMR factor included. Predicted landslide hazard area for 5 return periods of rainfall considered 7 related factors and RMR factor as shown in Table 41 and Fig 44. The plan area of landslide hazard was 2.20%, 4.79%, 10.01%, 11.10% and 13.30% for 1, 5, 20, 50 and 100 years return period of rainfall respectively in which the plan area of landslide hazard for 1 year return period overlap with plan area of landslide hazard for 5, 20, 50 and 100 year return period.

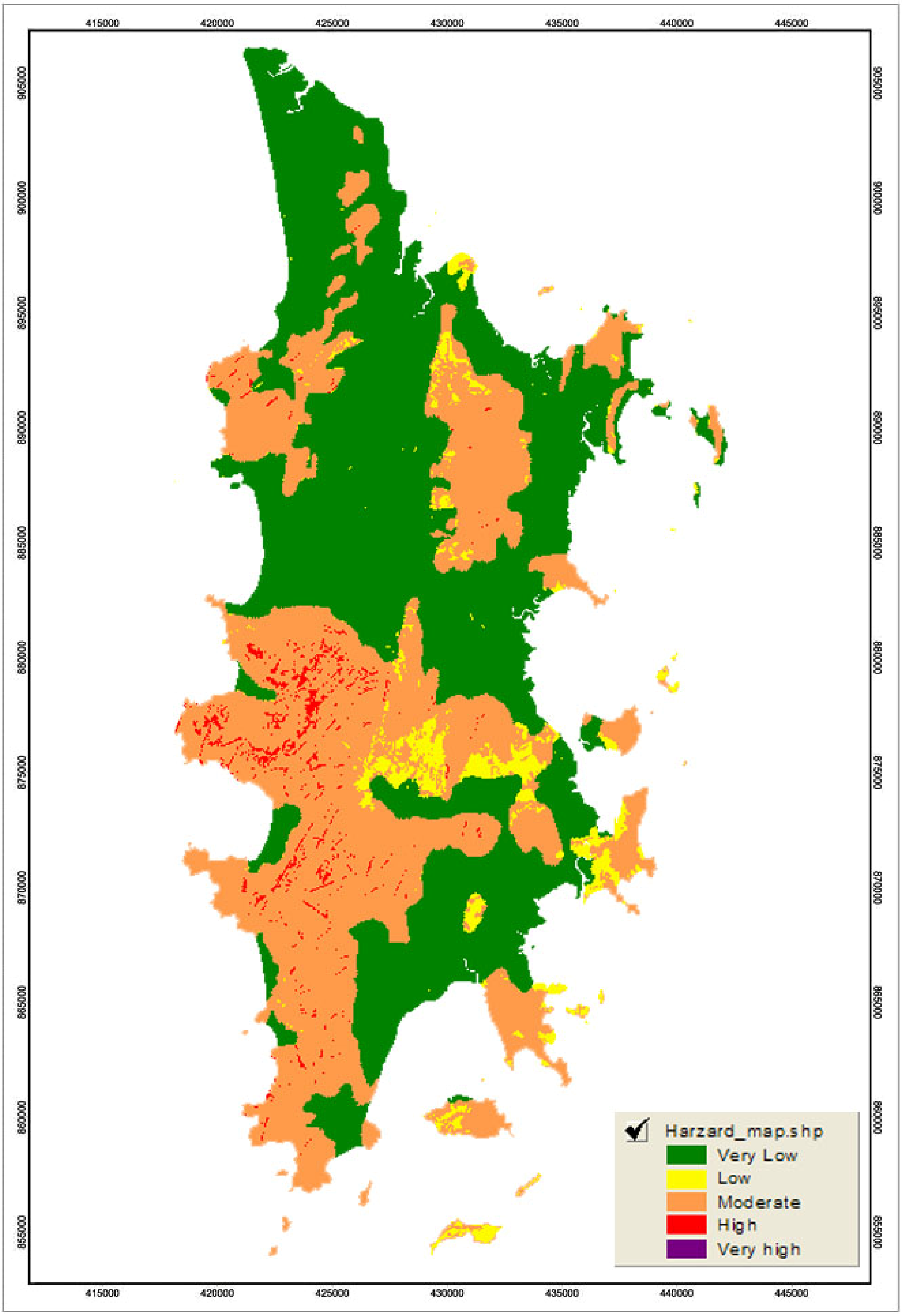


Figure 43 Landslide susceptibility map by considering 7 related factors and RMR factor

Table 41 Area of landslide classes considered by including 7 related factors and RMR factor

Score	Landslide Susceptibility Classes	pixel	Area (km^2)	%
101-120	Very high potential	0	0.00	0.00
82-101	High potential	19,330	12.08	2.20
63-82	Moderate potential	374,654	234.16	42.65
44-63	Low potential	46,554	29.10	5.30
25-44	Very low potential	437,879	273.67	49.85
	Sum	878,417	549	100.00

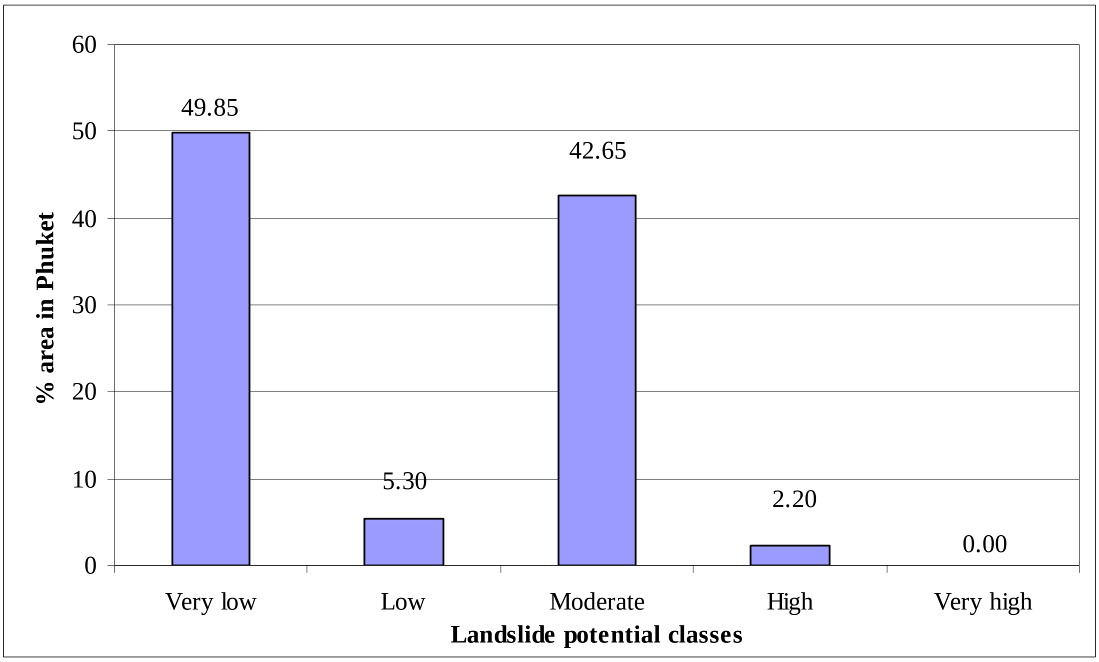
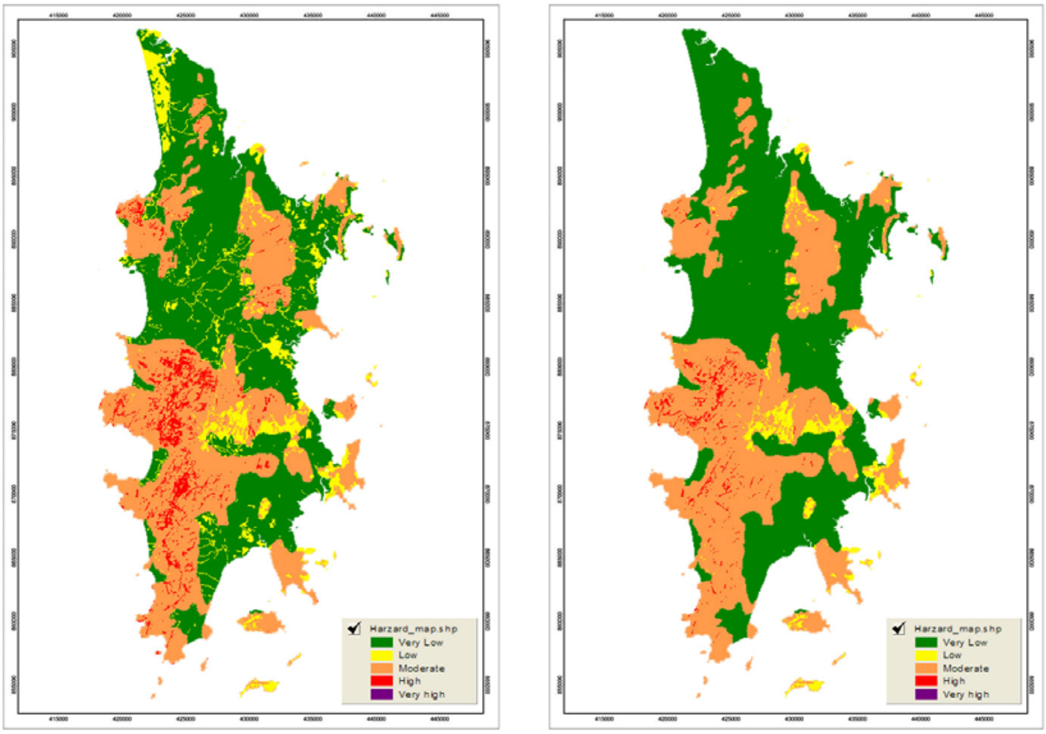


Figure 44 Area of landslide classes considered by including 7 related factors and RMR factor



(a) 7 factors (b) 7 factors and RMR factor

Figure 45 Comparison between the landslide susceptibility map by considering 7 related factors and considered by including 7 related factors and RMR factor

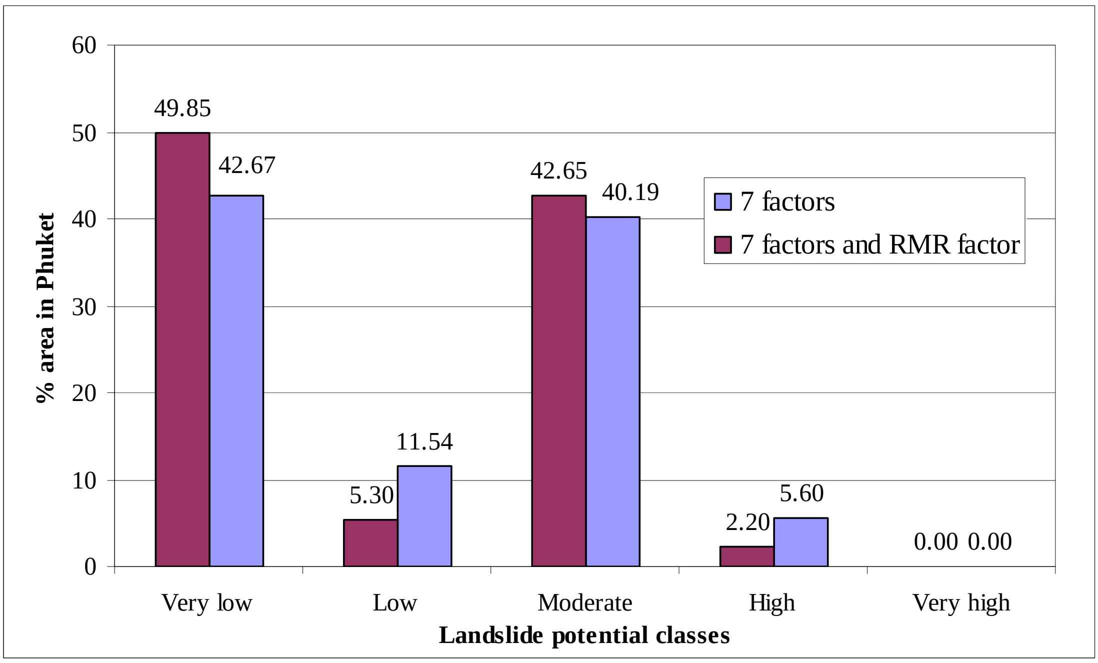
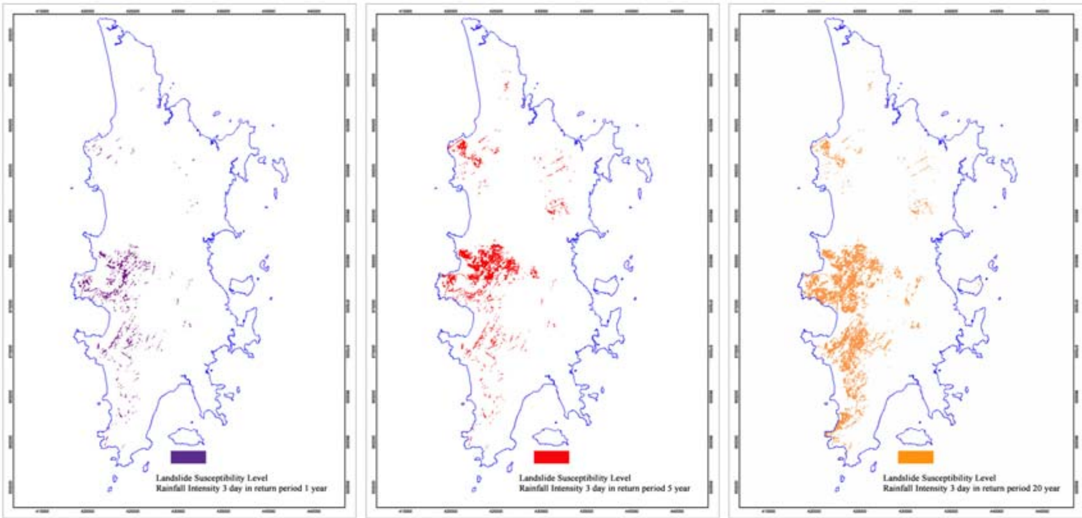
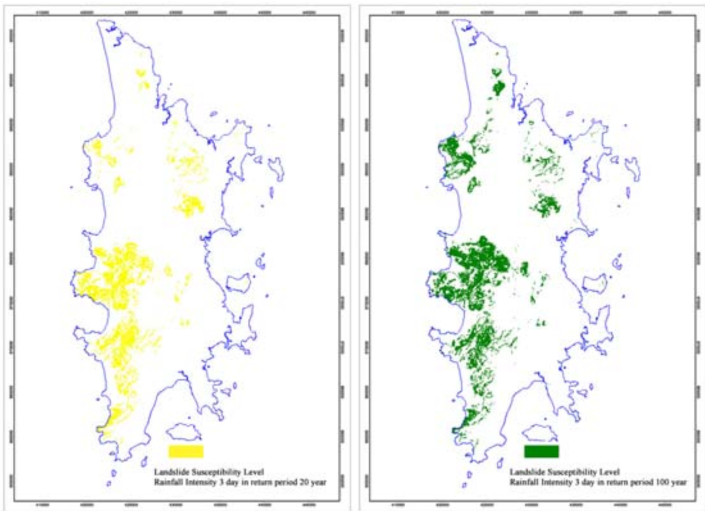


Figure 46 Comparison of landslide classes between considered by 7 related factors and considered by including 7 related factors and RMR factor



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 47 The landslide hazard map in Phuket shown by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (RMR factor Included)

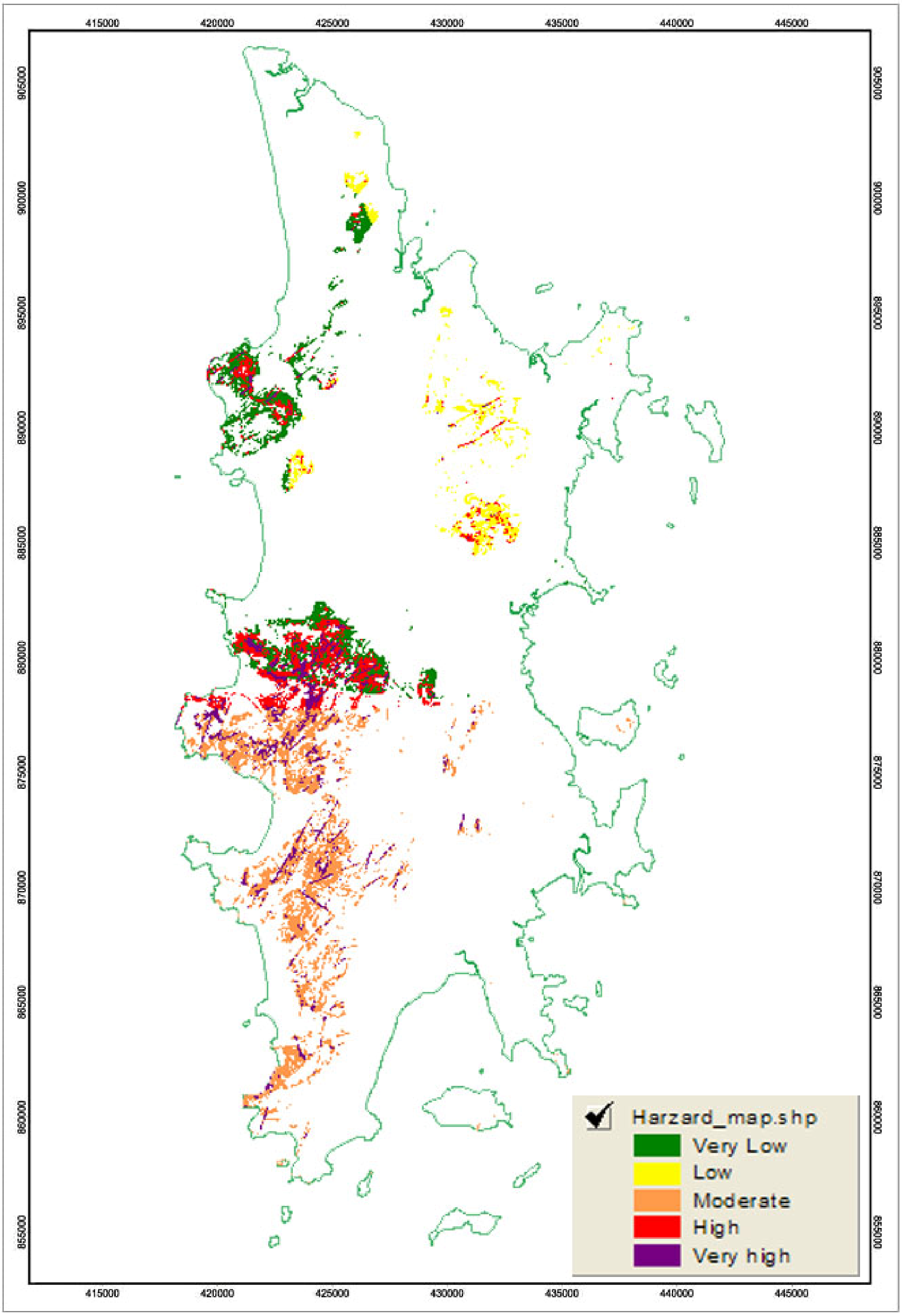


Figure 48 The landslide hazard map in Phuket by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (RMR factor Included)

Table 42 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and RMR factor

Return period of rainfall	Landslide classify	pixel	Area (km^2)	%
001	Fail	19,330	12.08	2.20
	No fail	859,087	536.93	97.80
005	Fail	42,094	26.31	4.79
	No fail	836,323	522.70	95.21
020	Fail	87,949	54.97	10.01
	No fail	790,468	494.04	89.99
050	Fail	97,544	60.97	11.10
	No fail	780,873	488.05	88.90
100	Fail	116,870	73.04	13.30
	No fail	761,547	475.97	86.70

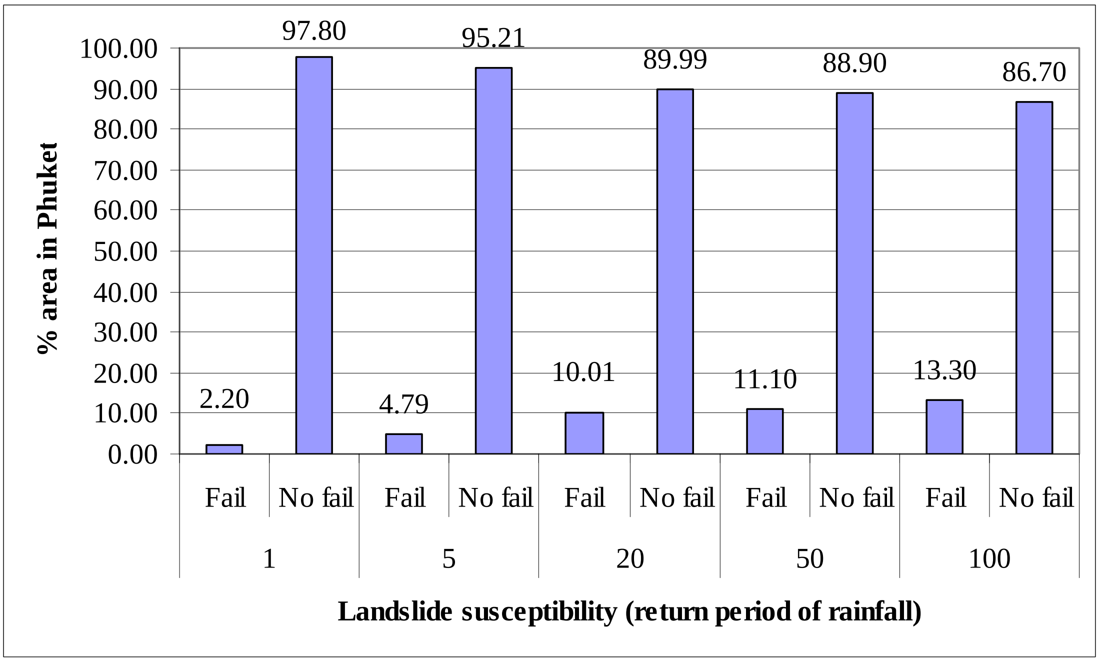
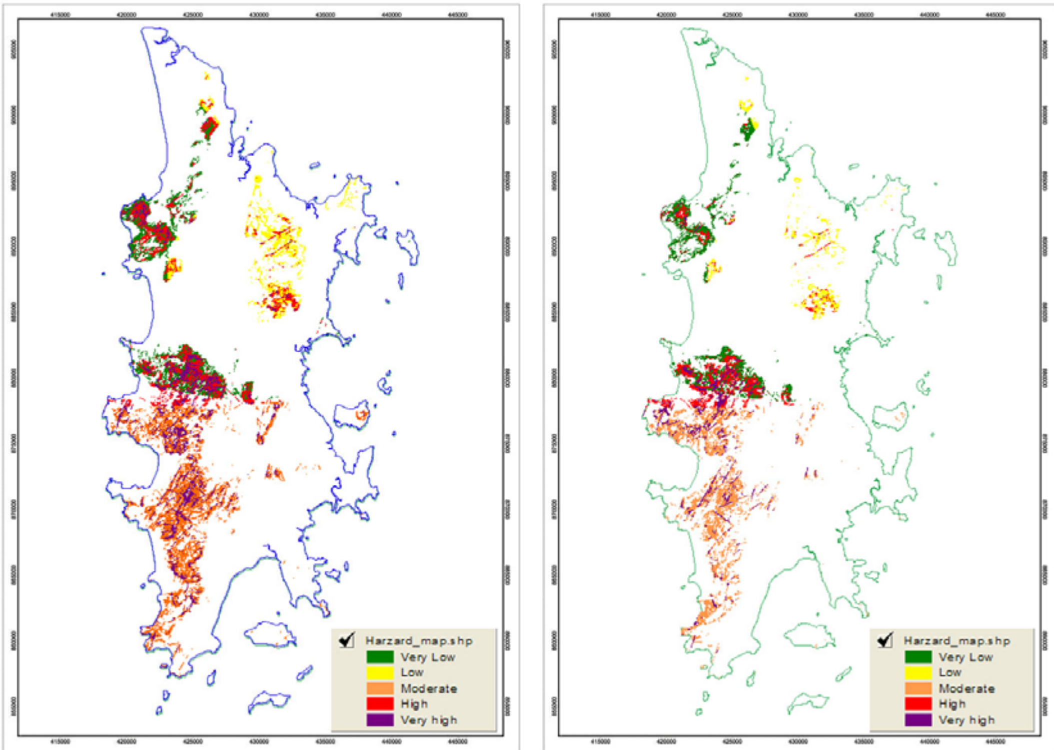


Figure 49 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and RMR factor



(a) 7 factors (b) 7 factors and RMR factor

Figure 50 Comparison between the landslide hazard map by considering 7 related factors and considered by including 7 related factors and RMR factor

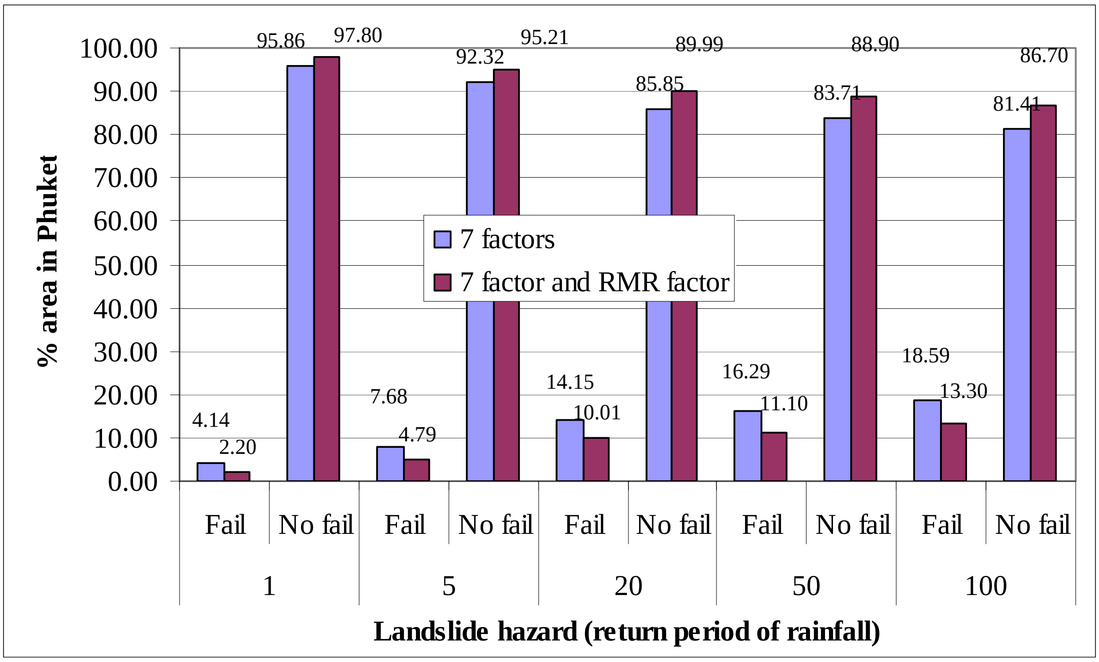


Figure 51 Comparison of landslide hazard between considered by 7 related factors and considered by including 7 related factors and RMR factor

Weighting Factor Analysis Including SMR Value

Appendix table 2 shows SMR rating estimation from field investigation data. Table 43 shows example of SMR estimation from field investigation. Table 44 shows average slope mass rating classified by rock type and watershed.

Table 43 Example of SMR estimation PK06

	Direction	Dip	F1	F2	F3	F4	RMR	SMR
Slope	278	40						
Bedding	324	40	0.15	0.85	-25	0	27	23.81
J1	183	88	0.15	1	0	0	27	27.00
J2	73	69	0.15	1	0	0	27	27.00
J3	26	45	0.15	1	-6	0	27	26.10
J4	130	64	0.15	1	0	0	27	27.00
J5	215	18	0.15	0.15	-60	0	27	25.65

Table 44 Average slope mass rating classified by rock type

Rock type	BASIN	Number	Avg. SMR
CP	CHALONG BASIN	1	25.25
	LAEM NGA BASIN	4	40.06
	MUANG BASIN	9	50.75
G2	KAMALA BASIN	14	33.88
	KARON BASIN	1	60.00
	KATA BASIN	1	47.00
	KATA NOI BASIN	1	32.00
	MUANG BASIN	4	60.52
	PATONG BASIN	13	45.55
	THA MAPHRAO BASIN	1	59.10
	THALANG BASIN	2	54.00
	THUNG NUNG BASIN	2	56.00
G3	THUNG NUNG BASIN	3	47.00
	THALANG BASIN	3	57.00
G4	LAEM KHAEK BASIN	3	32.54
	MUANG BASIN	5	57.16
	NA KHALE BASIN	1	26.94
	PATONG BASIN	6	41.43
	SAPAM BASIN	2	60.90

Fig 52 shows relationship between failure of cut slope and SMR value. Fig 53 shows relationship between non-failure of cut slope and SMR value.

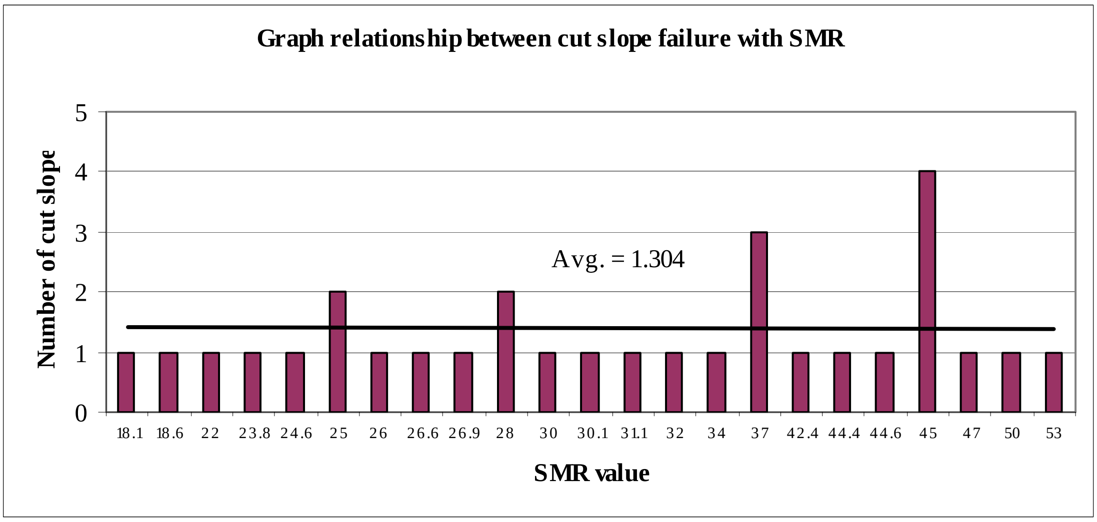


Figure 52 Graph relationships between cut slope failures and SMR rating

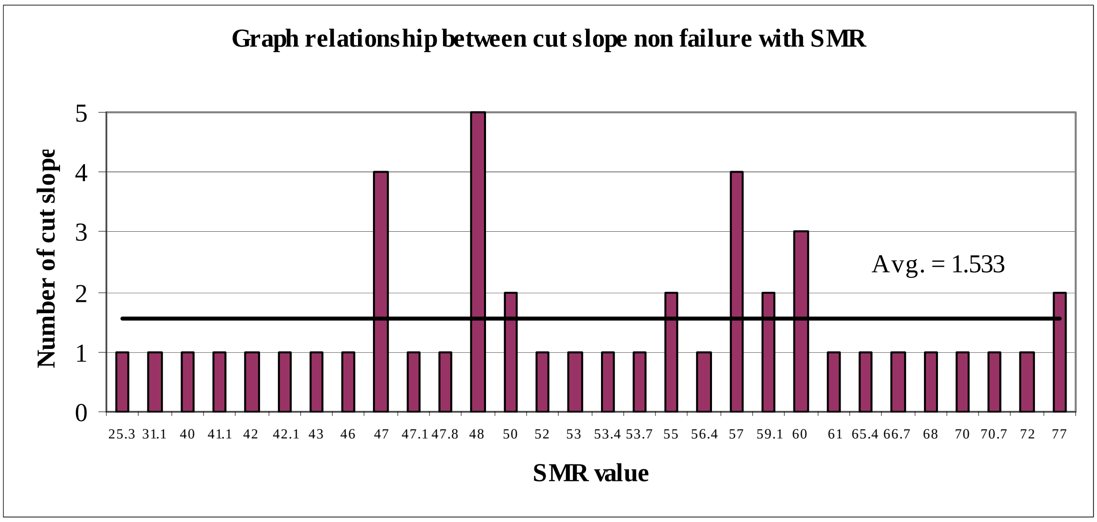


Figure 53 Graph relationships between cut slope non failures and SMR rating

Fig 54 shows normal distribution curve SMR value classified by slope condition. Fig 55 shows cumulative frequency of SMR value classified by slope condition. Fig 56 shows landslide potential classified by SMR value. These could assign the numerical weight for the SMR factor influencing the landslide in Phuket (Table 45).

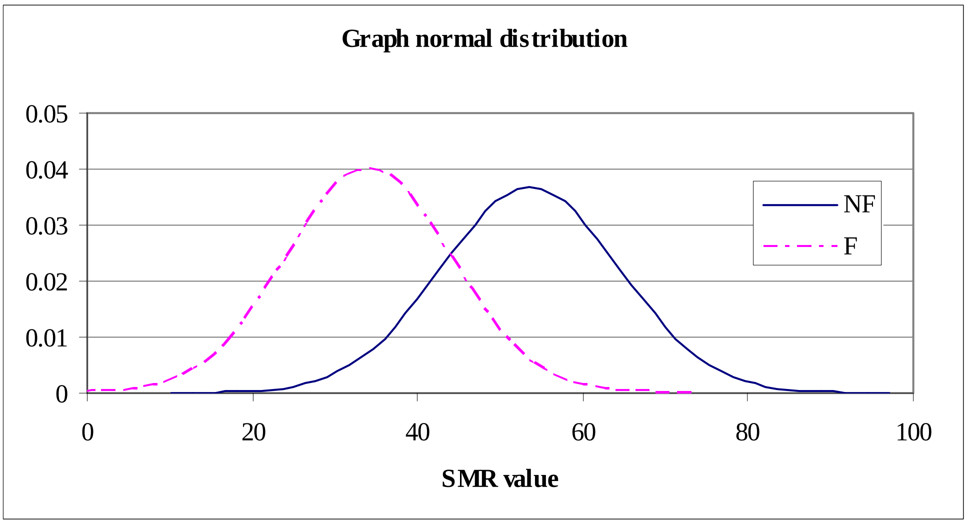


Figure 54 Normal distribution curve SMR value classified by slope condition.

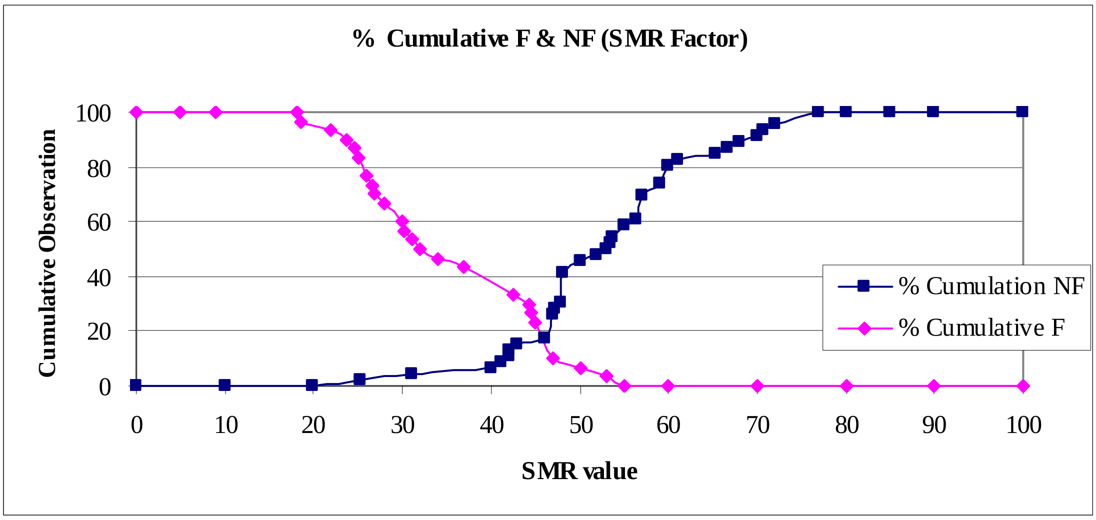


Figure 55 Cumulative frequency of SMR value classified by slope condition

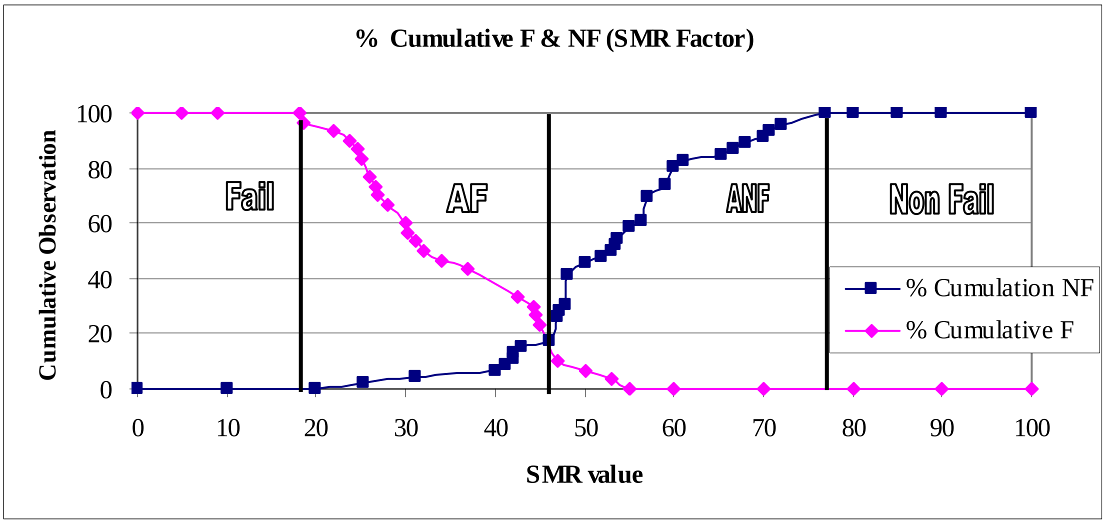


Figure 56 Landslide potential classified by SMR value

Table 45 The numerical weight assignment to the SMR factor influencing the landslide in Phuket

Parameter	Weight Value		Rating Value		
	Parameter	Sub-parameter	Description	Landslide potential	Rating
SMR	5		A. 0 - 19 B. 19 - 46 C. 46 - 77 D. 77 - 100	F AF ANF NF	4 3 2 1

Processing Landslide Susceptibility and Hazard Map by Considering SMR Value

In this section, the processing of landslide susceptibility map determined the numerical rating of 7 related factors and SMR factor following weighting factor method (Table 45). The weight-rating values of each parameter determined in each 25x25 square meter grid cell, in which the summation of weight-rating values were classified range of score by landslide susceptibility classes (Table 33). The result are shown in Fig 57. Table 46 and Fig 58 show area of landslide classes considered by 7 related factors and SMR factor included.

This study performed comparison of landslide susceptibility map between SMR factor determination and non SMR factor determination in 1 year return period of rainfall intensity. The engineering soil properties factor and SMR factor were determined for landslide susceptibility factor because they are new factor in weighing factor method. Comparison of landslide susceptibility map between SMR factor determination and non SMR factor determination in 1 year return period of rainfall intensity is shown in Fig 59. The landslide susceptibility map for non SMR factor determination has higher landslide susceptibility in flat area than the landslide susceptibility map for engineering soil properties factor and SMR factor determination. Fig 60 shows comparison of landslide classes between considered by 7 related factors and considered by including 7 related factors and SMR factor which show the result of landslide high potential class in case SMR factor included had more area than no SMR factor included. So, the SMR factor was important factor to determine landslide susceptibility map.

Fig 61 (a) to (e) shows the results of processing of landslide hazard map considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by half of range between 25 to 120 which was 73 score. Fig 62 shows landslide hazard map in Phuket using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors and RMR factor included. Predicted landslide hazard area for 5 return period of rainfall considered 7 related factors and RMR factor are shown in Table 38 and Fig 63. The plan area of landslide hazard was 5.93%, 9.01%, 14.67%, 18.12% and 13.50% for 1, 5, 20, 50 and 100 years return period of rainfall respectively in which the plan area of landslide hazard for 1 year return period overlap with plan area of landslide hazard for 5, 20, 50 and 100 year return period.

Fig 64 and Fig 65 show comparison between the landslide hazard map which considered only 7 related factors, 7 related factors and RMR factor included and 7 related factors and SMR factor included. The results were slightly different.

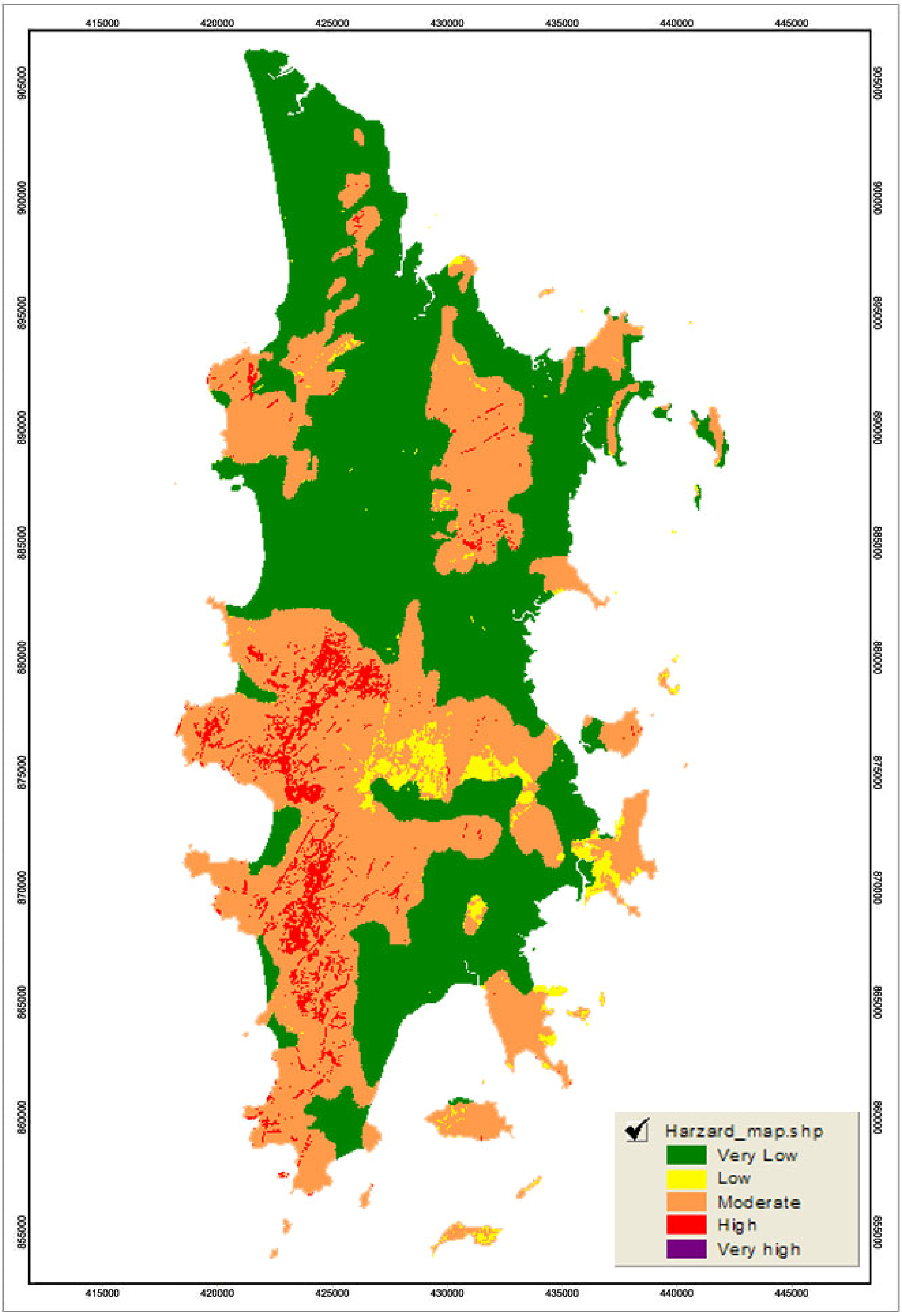


Figure 57 Landslide susceptibility map by considering 7 related factors and SMR factor

Table 46 Area of landslide classes considered by including 7 related factors and SMR factor

Score	Landslide Susceptibility Classes	pixel	Area (km^2)	%
101-120	Very high potential	0	0.00	0.00
82-101	High potential	51,965	32.48	5.92
63-82	Moderate potential	355,369	222.11	40.46
44-63	Low potential	33,330	20.83	3.79
25-44	Very low potential	437,753	273.60	49.83
	Sum	878,417	549	100.00

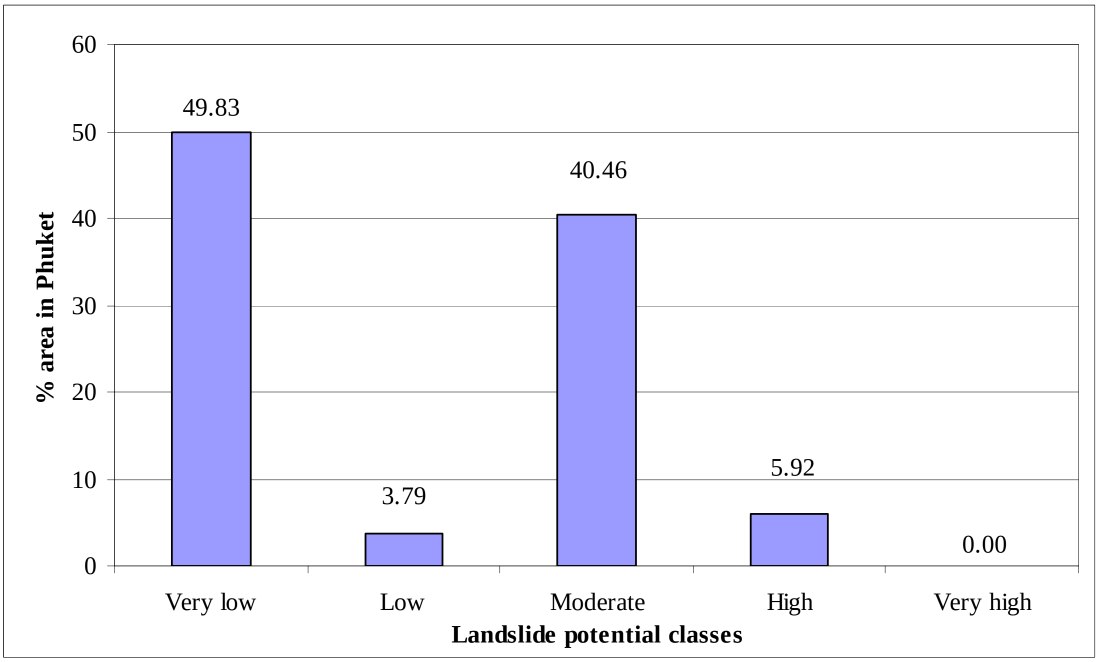
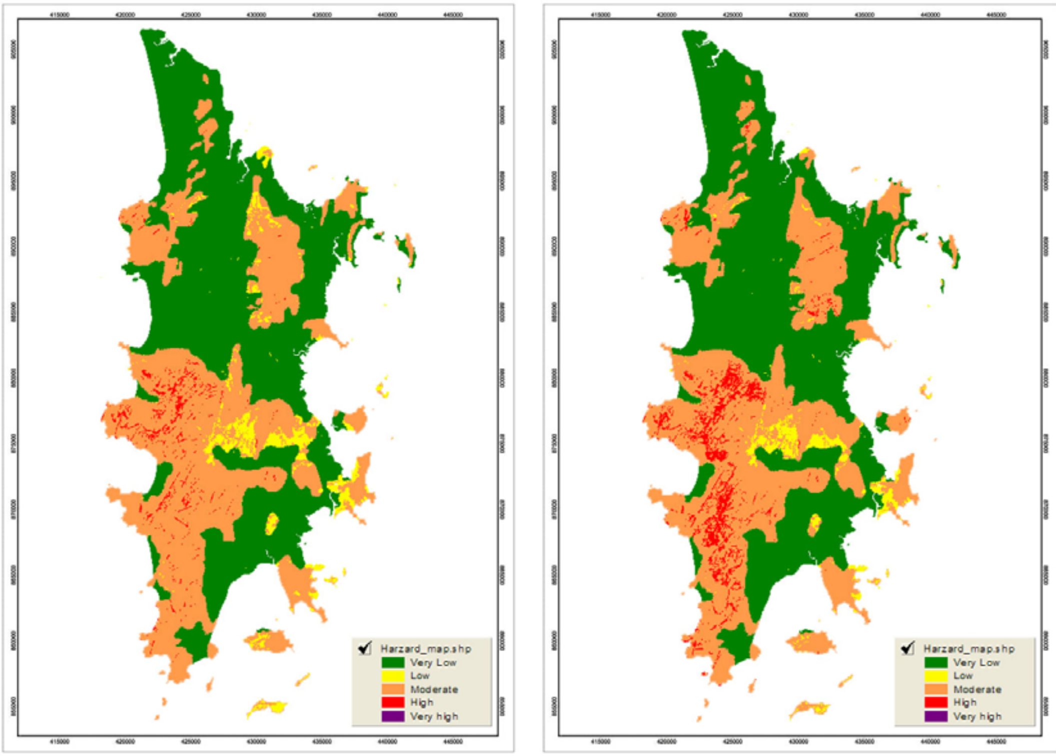


Figure 58 Area of landslide classes considered by including 7 related factors and SMR factor



(a) 7 factors and RMR factor (b) 7 factors and SMR factor

Figure 59 Comparison between the landslide susceptibility map

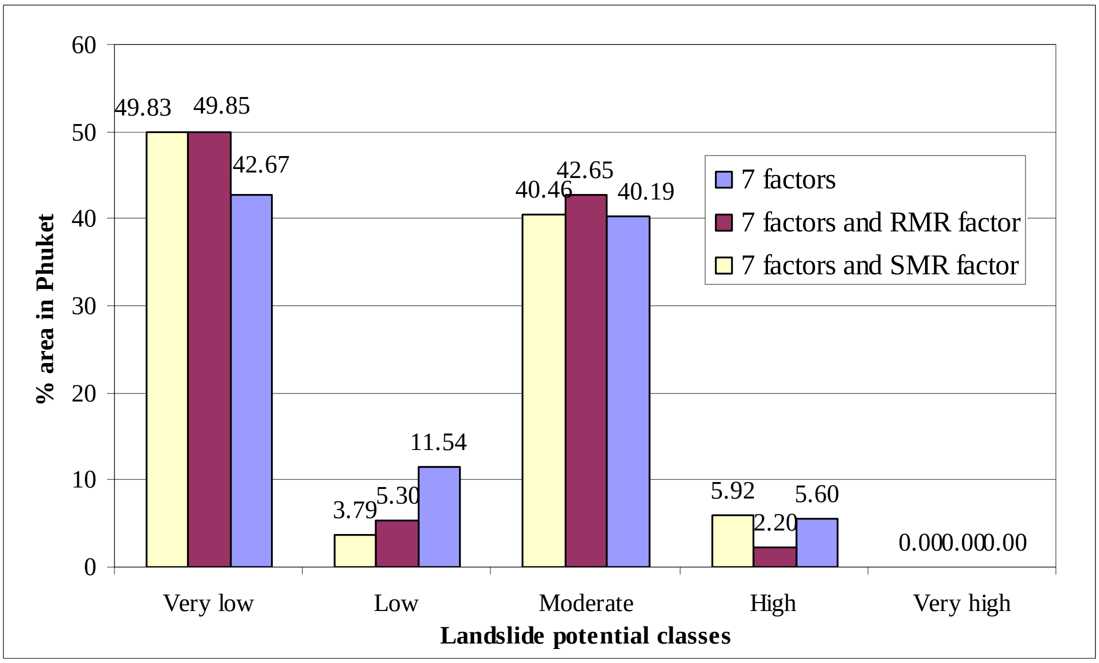
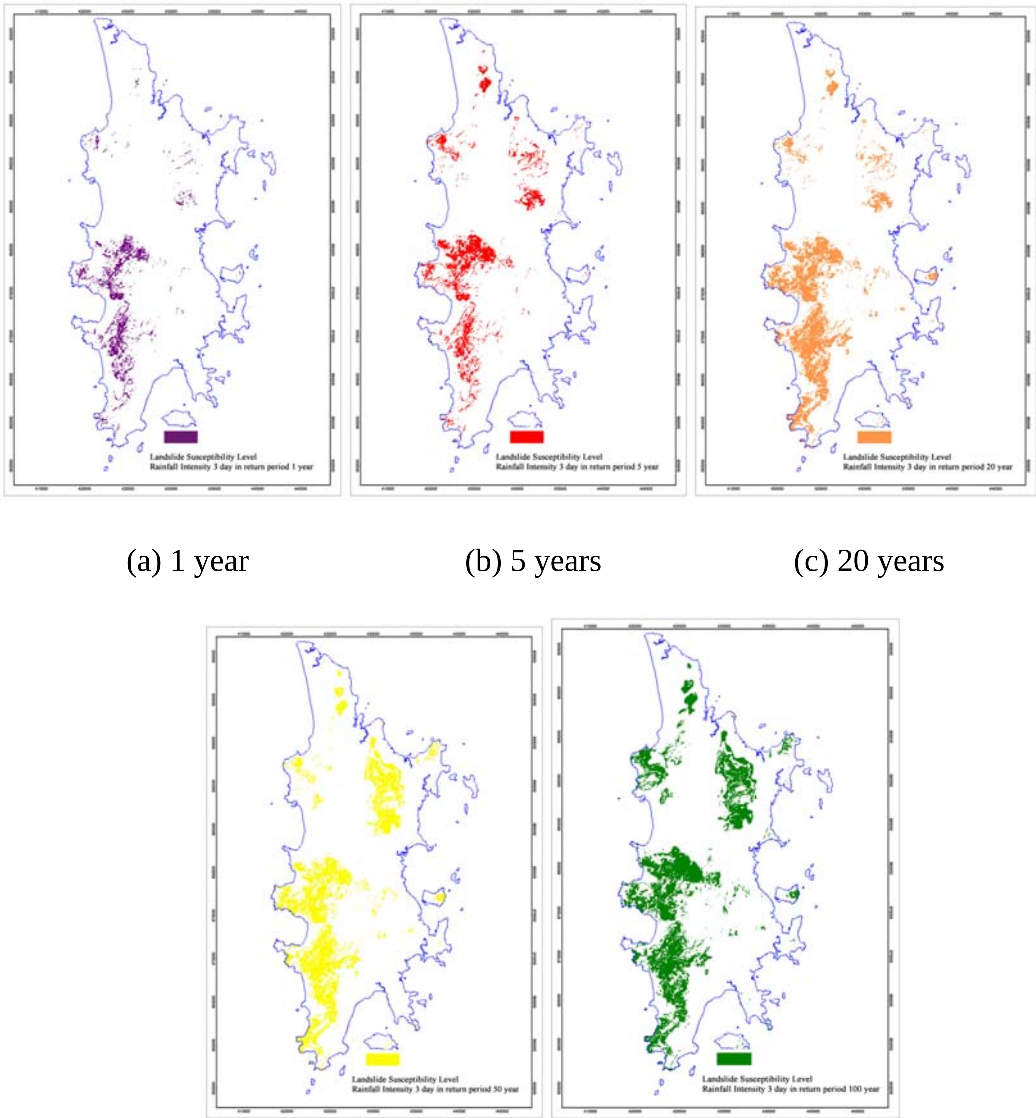


Figure 60 Comparison of landslide classes



(a) 1 year (b) 5 years (c) 20 years

(d) 50 years (e) 100 years

Figure 61 The landslide hazard map in Phuket shown by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (SMR factor included)

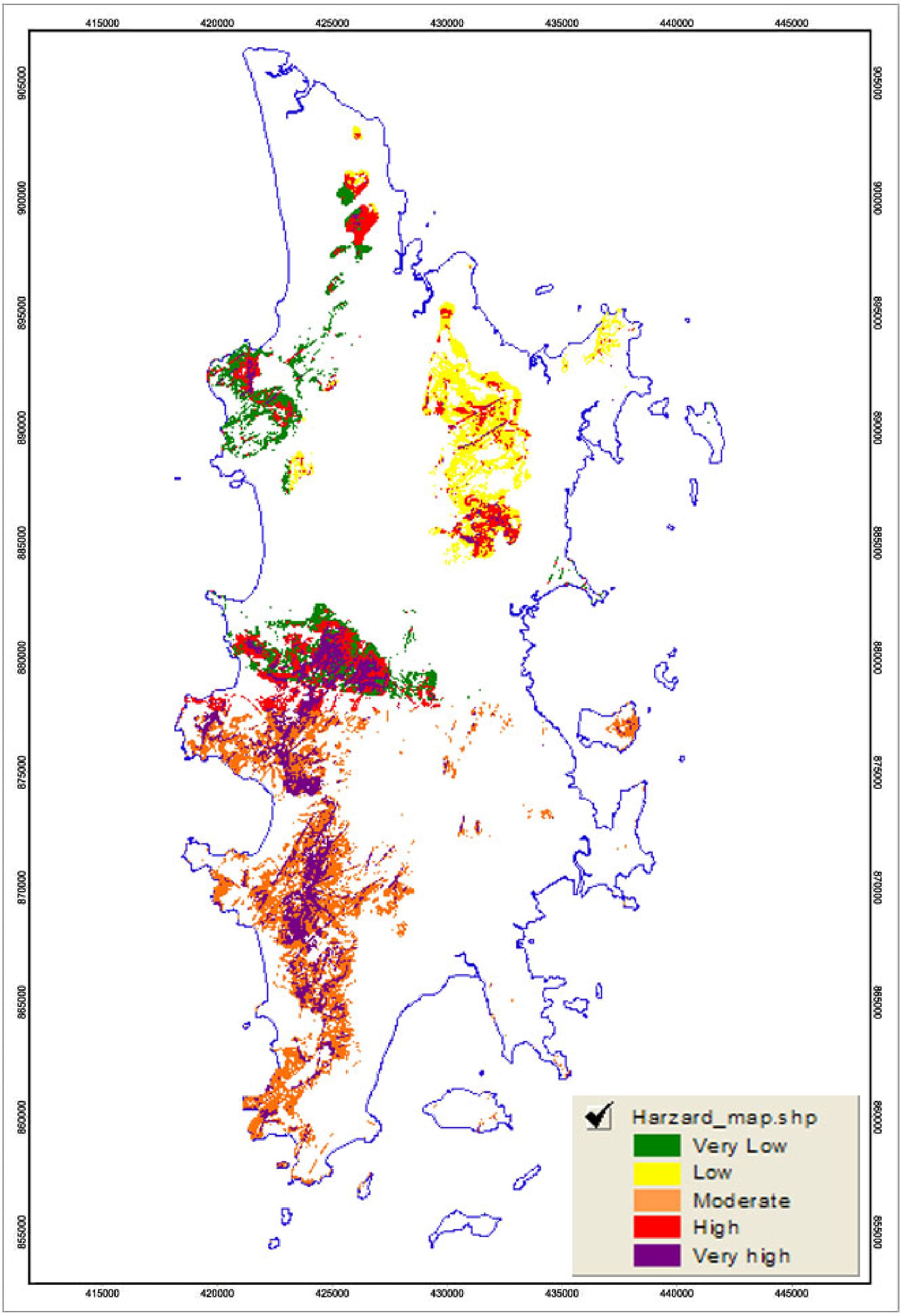


Figure 62 The landslide hazard map in Phuket by rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (SMR factor included)

Table 47 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and SMR factor

Return period of rainfall	Landslide classify	pixel	Area (km^2)	%
1	Fail	52,061	32.54	5.93
	No fail	826,356	516.47	94.07
5	Fail	79,189	49.49	9.01
	No fail	799,228	499.52	90.99
20	Fail	128,843	80.53	14.67
	No fail	749,574	468.48	85.33
50	Fail	159,130	99.46	18.12
	No fail	719,287	449.55	81.88
100	Fail	118,602	74.13	13.50
	No fail	759,815	474.88	86.50

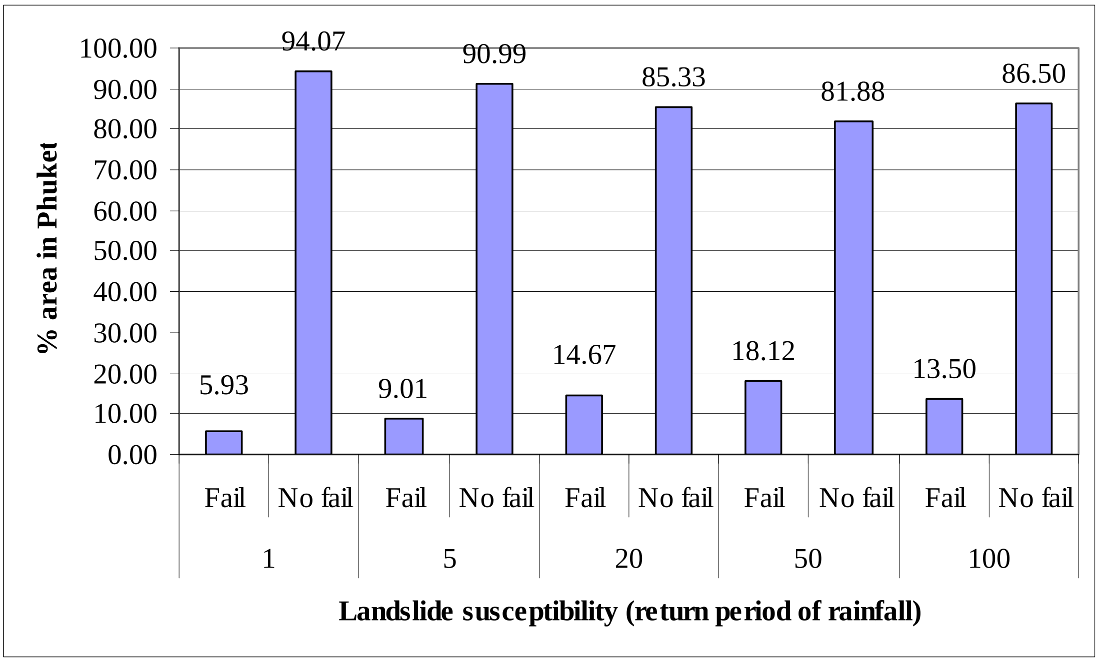
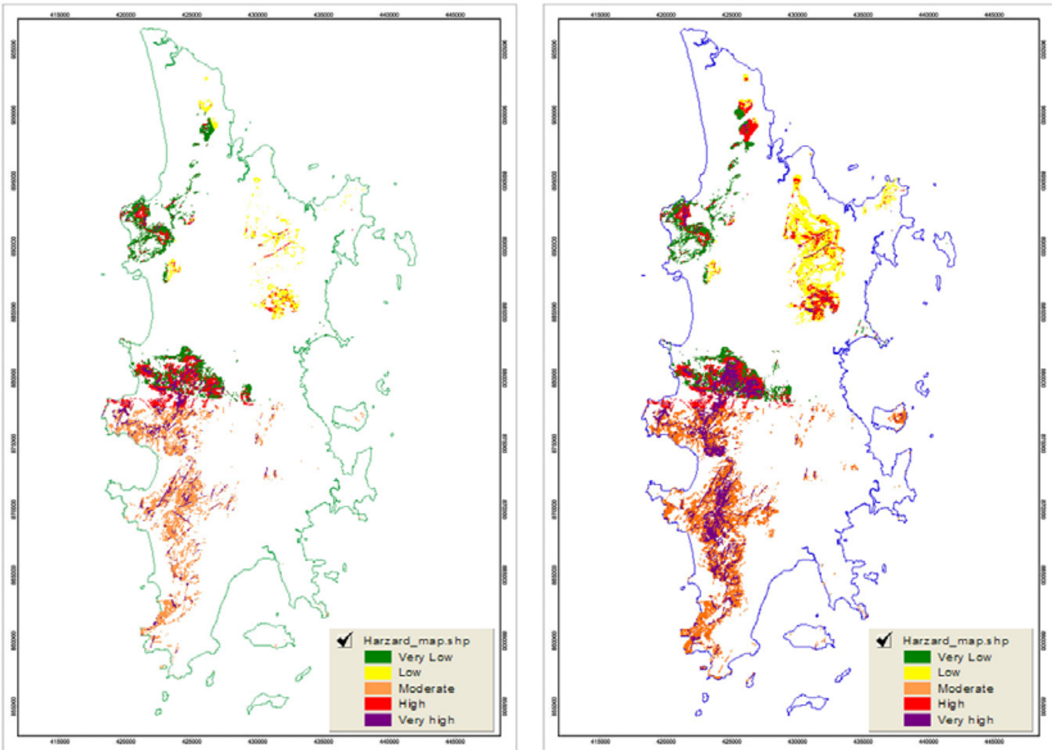


Figure 63 Predicted landslide hazard area for 5 return periods of rainfall including 7 related factors and RMR factor



(a) 7 factors and RMR factor (b) 7 factors and SMR factor

Figure 64 Comparison between the landslide hazard map

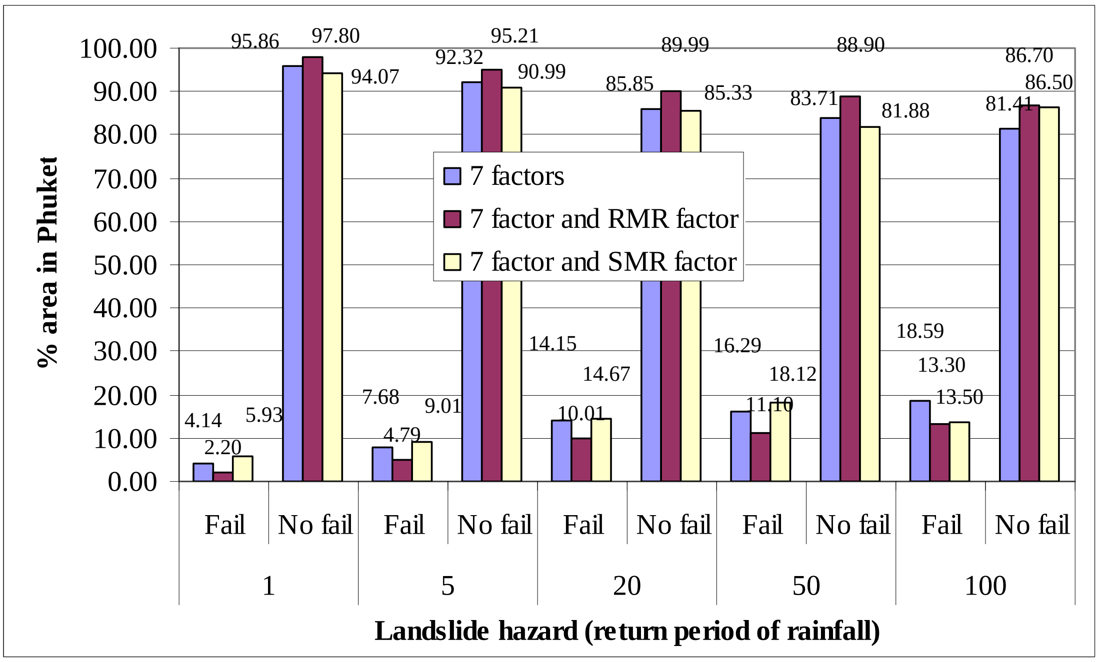


Figure 65 Comparison of landslide hazard

Collect Slope Condition Data from Field Investigation

Appendix table 2 shows slope condition data from field investigation. The slope condition was used for classification potential of cut slope failure.

Failure Verification (RMR included)

Fig 66 shows relationship between failure of cut slope and RMR factor. Fig 67 shows relationship between non failure of cut slope and RMR factor. Fig 68 shows normal distribution of total score considered 7 related factors and RMR factor to classify by slope condition.

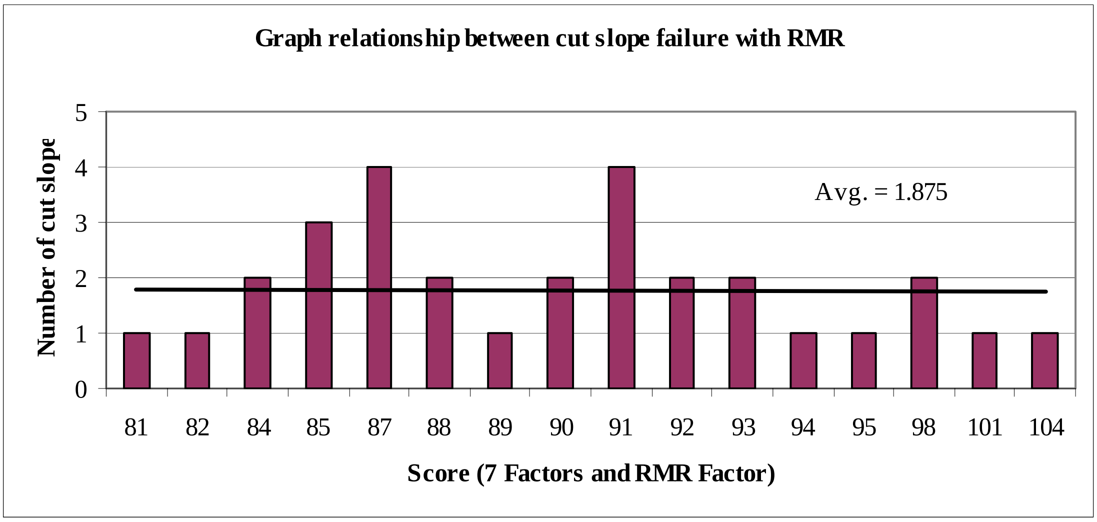


Figure 66 Graph relationships between failure of cut slope and RMR factor

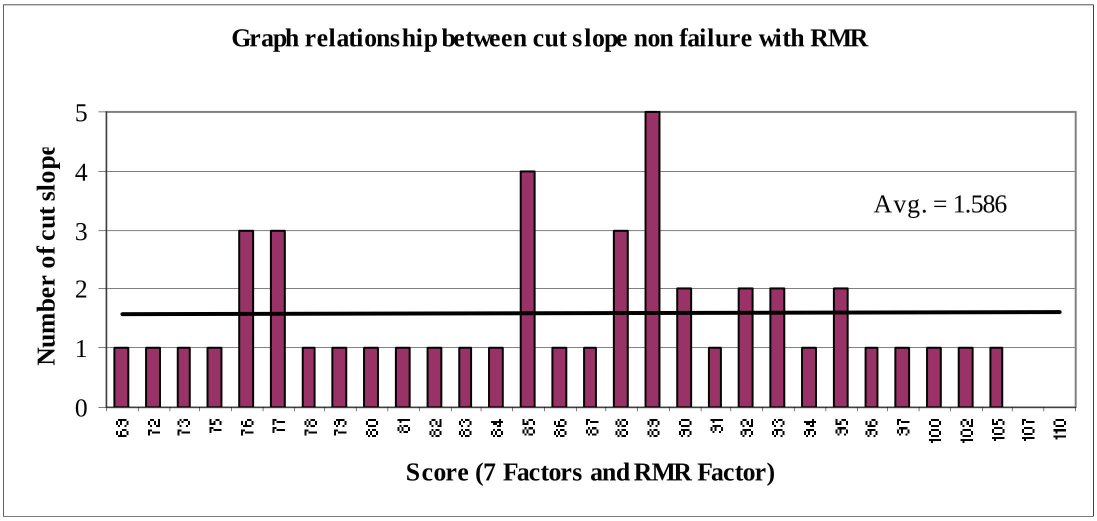


Figure 67 Graph Relationships between non failure of cut slope and RMR factor

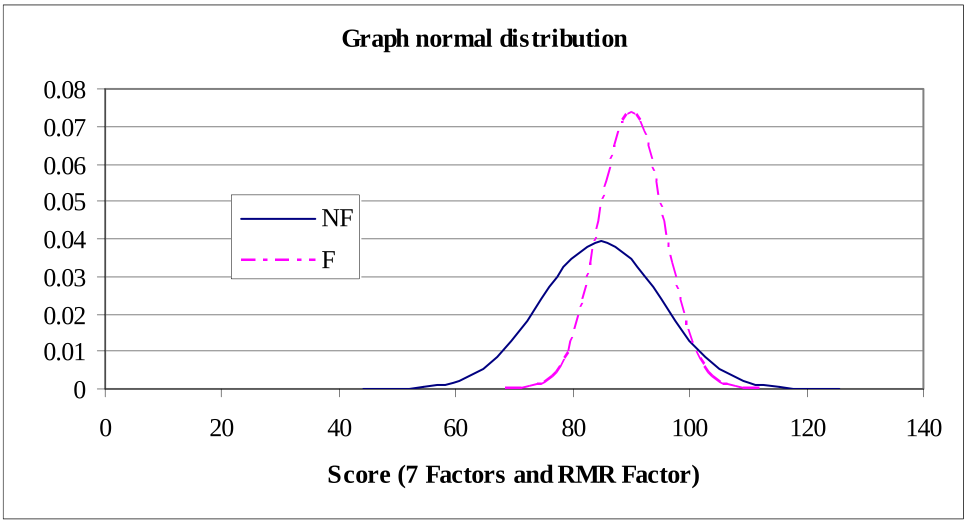


Figure 68 Normal distribution of total score (7 related factors and RMR factor) classified by slope condition

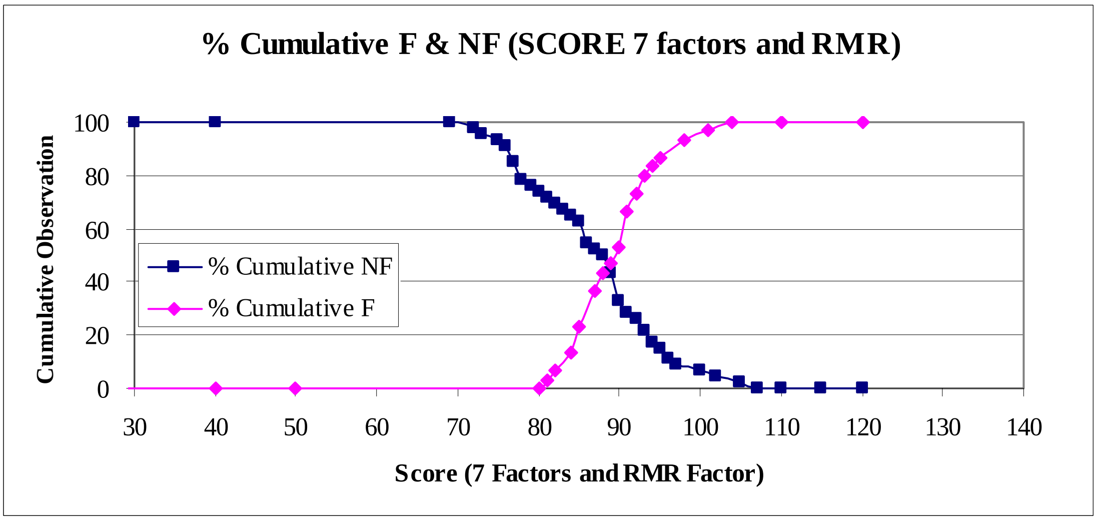


Figure 69 Cumulative frequency of total score (7 related factors and RMR factor) classified by slope condition

Fig 69 shows cumulative frequency of total score considered 7 related factors and RMR factor to classify by slope condition. Fig 70 shows cut slope failure potential classified by 7 related factors and RMR factor.

Table 48 shows the landslide potential and the range of total score considering RMR factor for all return periods of rainfall which considered from cumulative of failure and non-failure frequency (Fig 70).

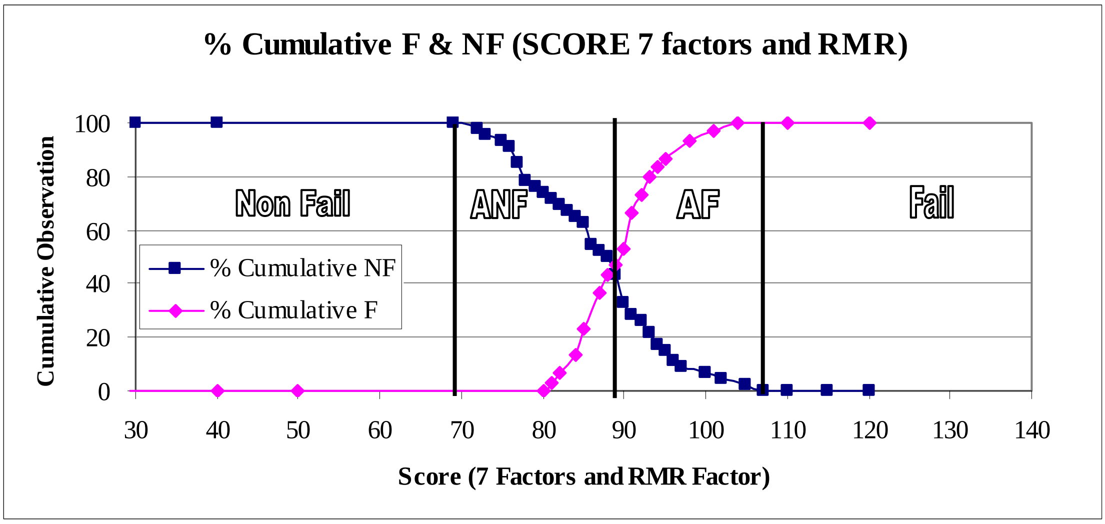


Figure 70 Cut slope failure potential classified by 7 related factors and RMR factor

Table 48 The landslide potential and the range of total score considering RMR factor for all return periods of rainfall

Cut slope failure classes	Range of score
Very high potential	107-140
High potential	89-107
Low potential	69-89
Very low potential	30-69

Processing Cut Slope Failure and Hazard Map by Considering RMR Factor Included

In this section, the processing of landslide hazard map due to cut slope determined the numerical rating of 7 related factors and RMR factor following weighting factor method (Table 40). The weight-rating values of each parameter determined in each 25x25 square meter grid cell, in which the summation of weight-rating values were classified range of score by cut slope failure classes (Table 48). The result are shown in Fig 71. Table 49 and Fig 72 show area of cut slope failure classes considered by 7 related factors and RMR factor included.

Fig 73 (a) to (e) shows the results of processing of landslide hazard map due to cut slope considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by cumulative of failure and non-failure frequency that was 89 score. Fig 73 shows landslide hazard map due to cut slope using 1, 5, 20, 50 and 100 years return period of rainfall considered 7 related factors and RMR factor included. Predicted landslide hazard area due to cut slope for 5 return period of rainfall considered 7 related factors and RMR factor shown in Table 50 and Fig 74. The plan area of landslide hazard due to cut slope was 0.71%, 2.03%, 4.44%, 5.01% and 7.06% for 1, 5, 20, 50 and 100 years return period of rainfall.

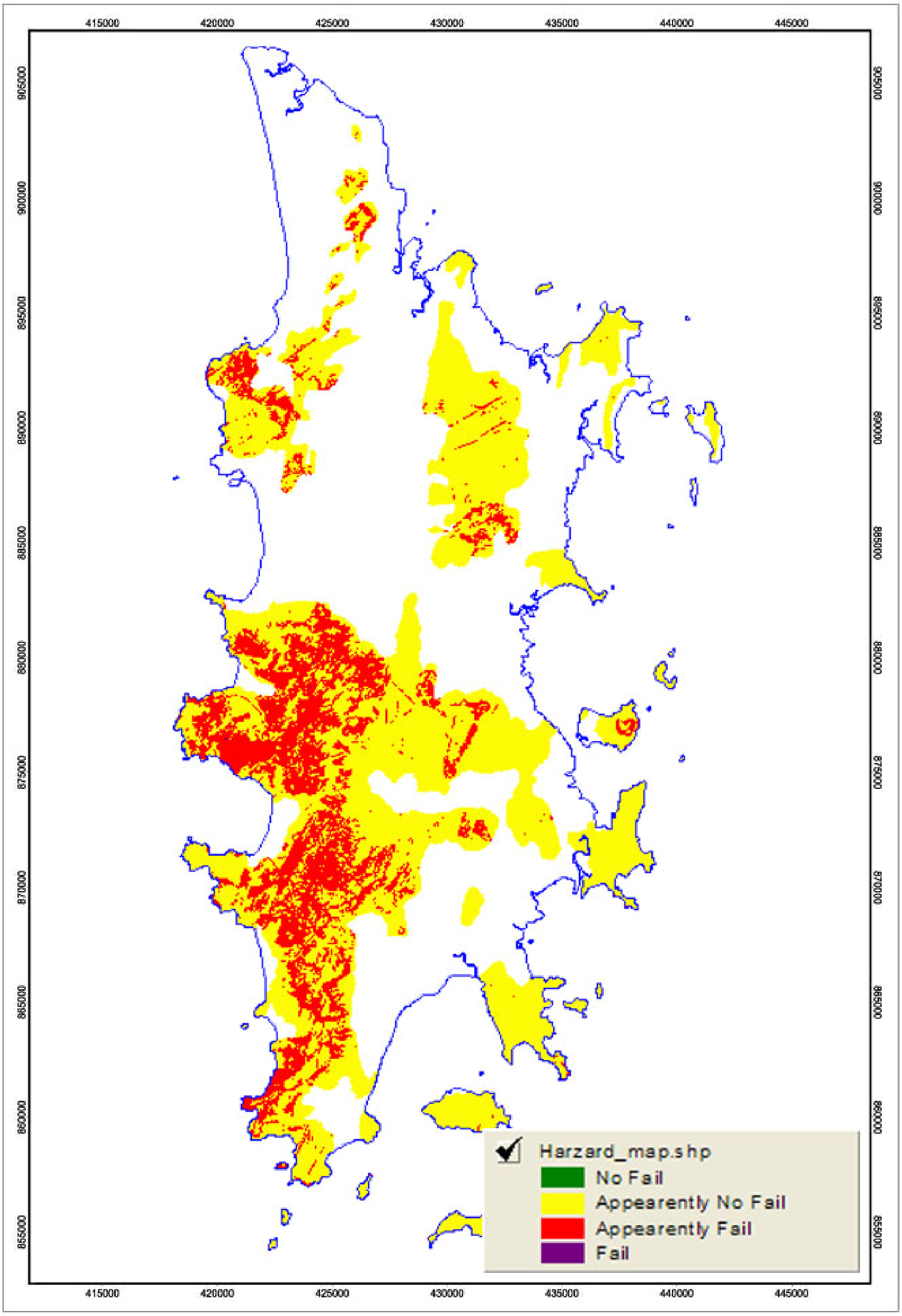


Figure 71 Area of failure cut slope classes considered by including 7 related factors and RMR factor

Table 49 Area of failure cut slope classes considered by including 7 related factors and RMR factor

Score	Failure cut slope Classes	pixel	Area (km^2)	%
96 - 118	Fail	121	0.08	0.01
74 - 96	Apparently fail	119,134	74.46	13.56
69 - 74	Apparently no fail	321,283	200.80	36.58
30 - 69	No fail	437,879	273.67	49.85
	Sum	878,417	549.01	100.00

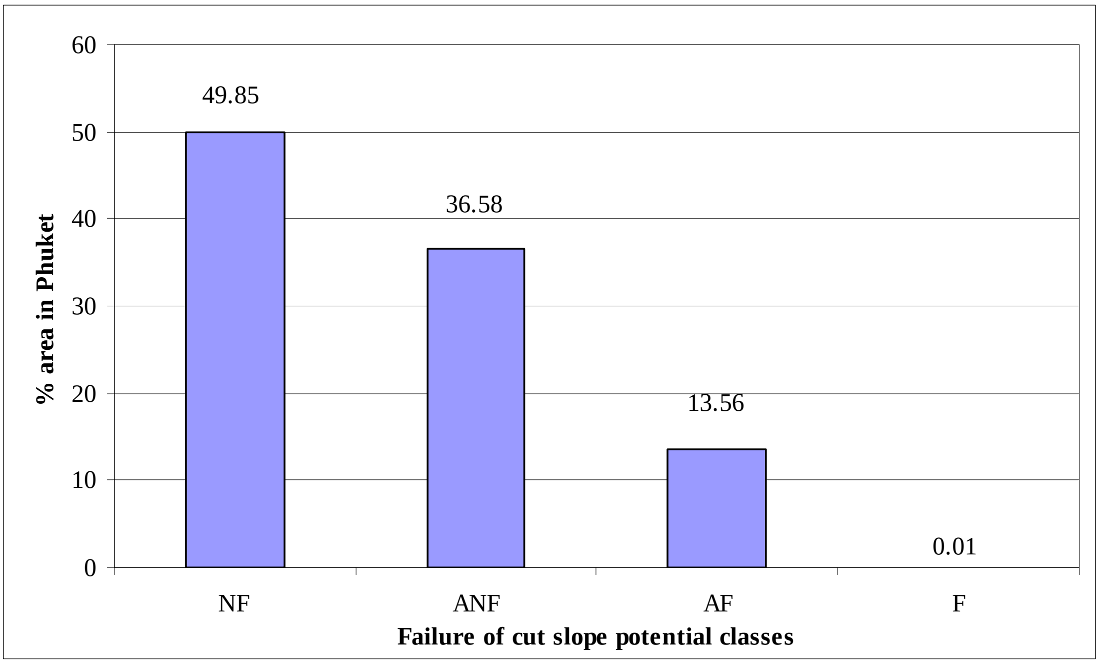
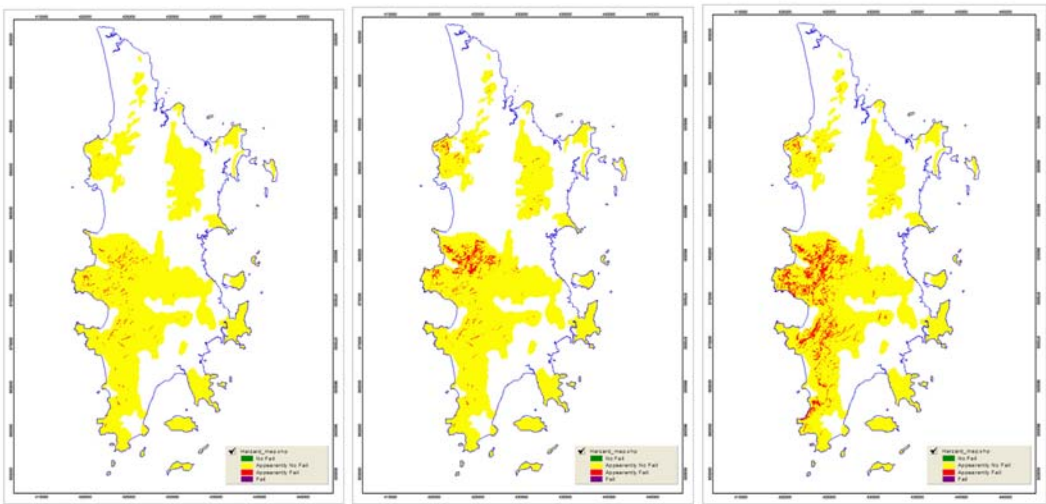
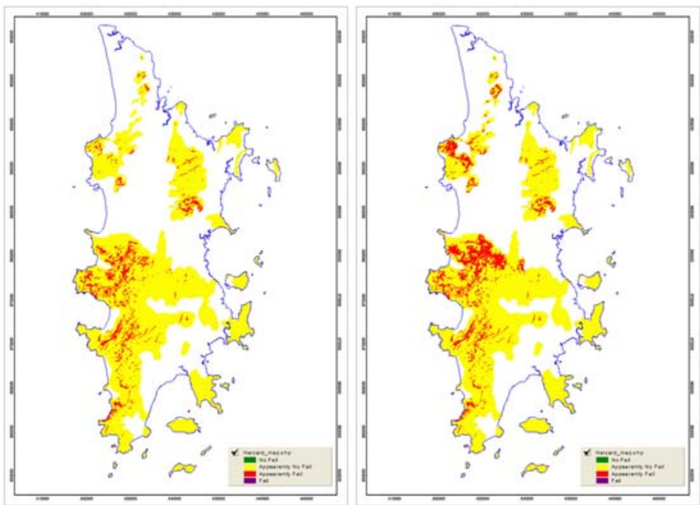


Figure 72 Area of failure cut slope classes considered by including 7 related factors and RMR factor



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 73 The failure cut slope of hazard map in Phuket showning rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (RMR factor included)

Table 50 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and RMR factor

Return period of rainfall year	Landslide classify	pixel	Area (km^2)	%
1	Fail	6,264	3.92	0.71
	No fail	872,153	545.10	99.29
5	Fail	17,828	11.14	2.03
	No fail	860,589	537.87	97.97
20	Fail	38,968	24.36	4.44
	No fail	839,449	524.66	95.56
50	Fail	44,010	27.51	5.01
	No fail	834,407	521.50	94.99
100	Fail	62,019	38.76	7.06
	No fail	816,398	510.25	92.94

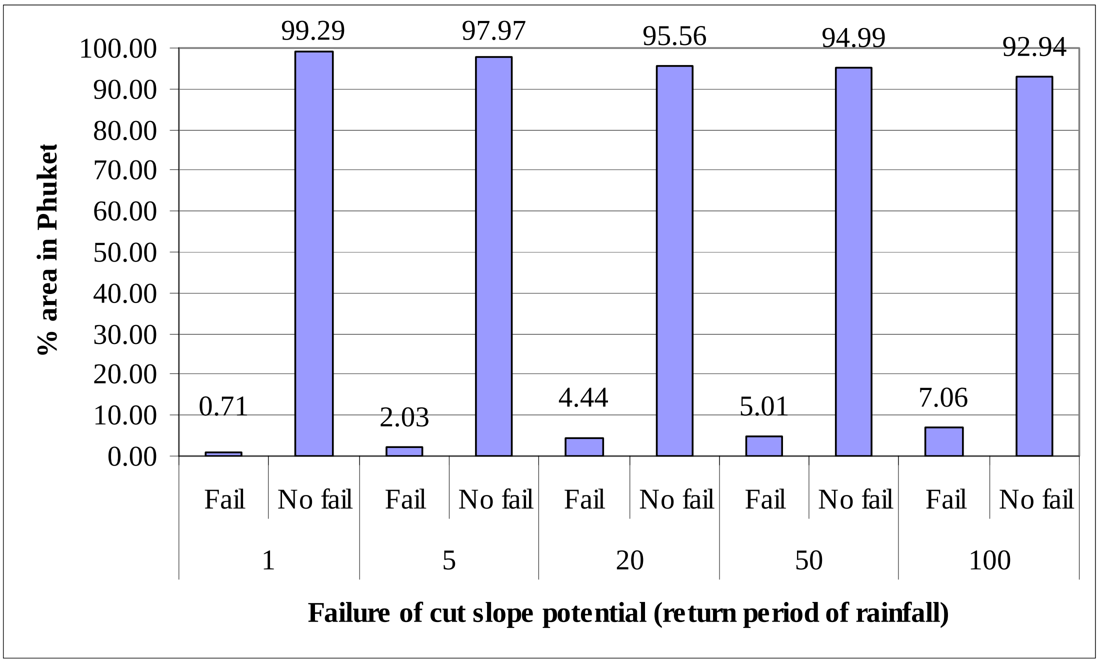


Figure 74 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and RMR factor

Failure Verification (SMR included)

Fig 75 shows relationship between failure of cut slope and SMR factor. Fig 76 shows relationship between non failure of cut slope and SMR factor. Fig 77 shows normal distribution of total score considered 7 related factors and SMR factor to classify by slope condition.

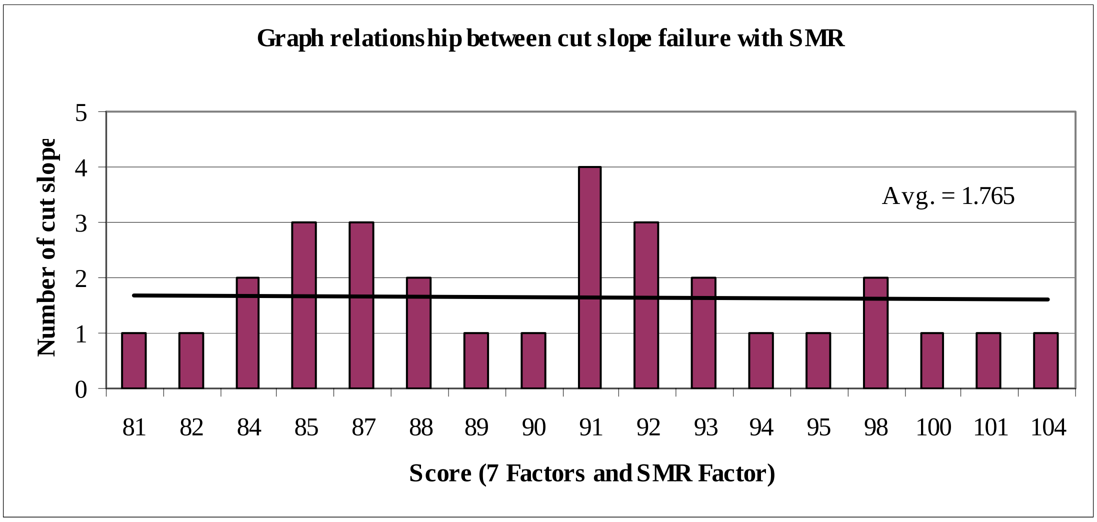


Figure 75 Graph relationships between cut slope failures and SMR factor

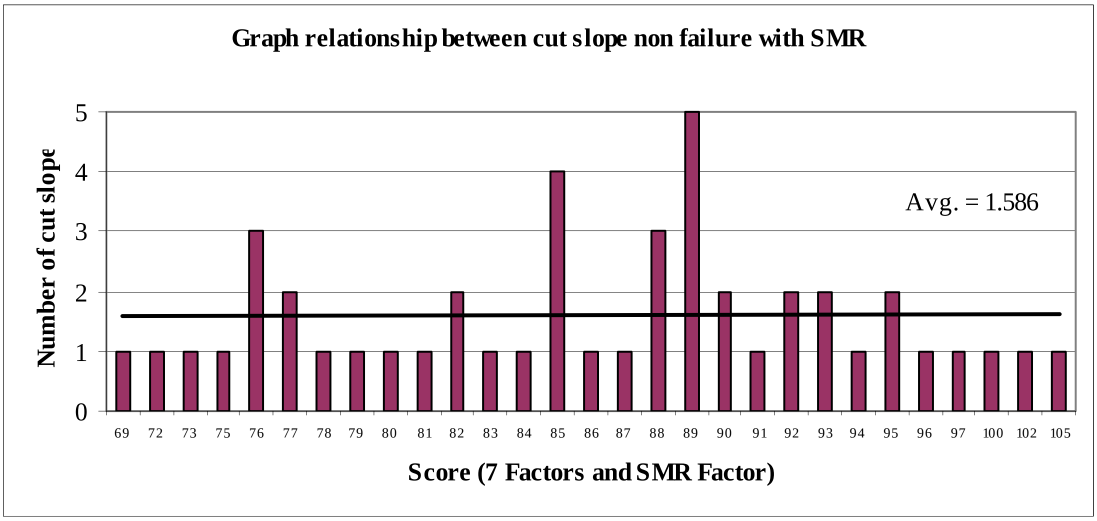


Figure 76 Graph relationships between cut slope non failures and SMR factor

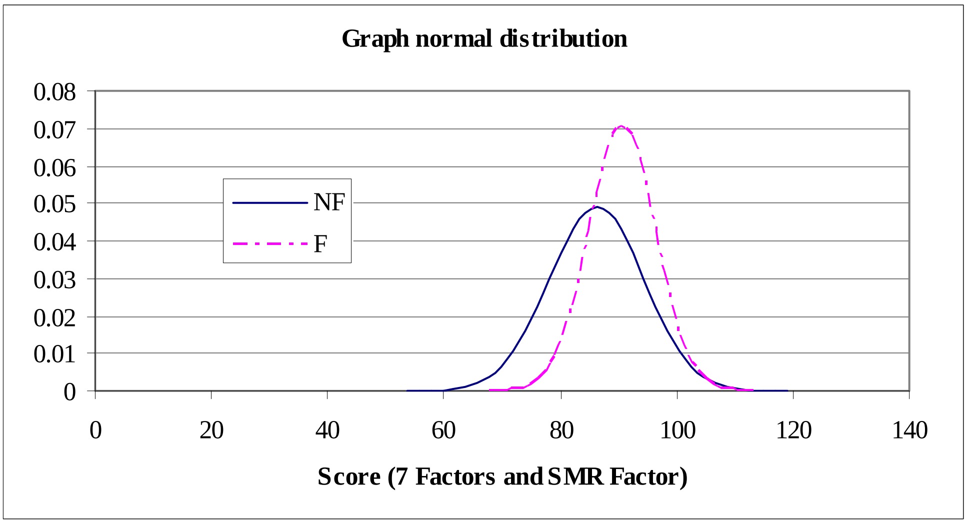


Figure 77 Normal distribution of total score (7 related factors and SMR factor) classified by slope condition

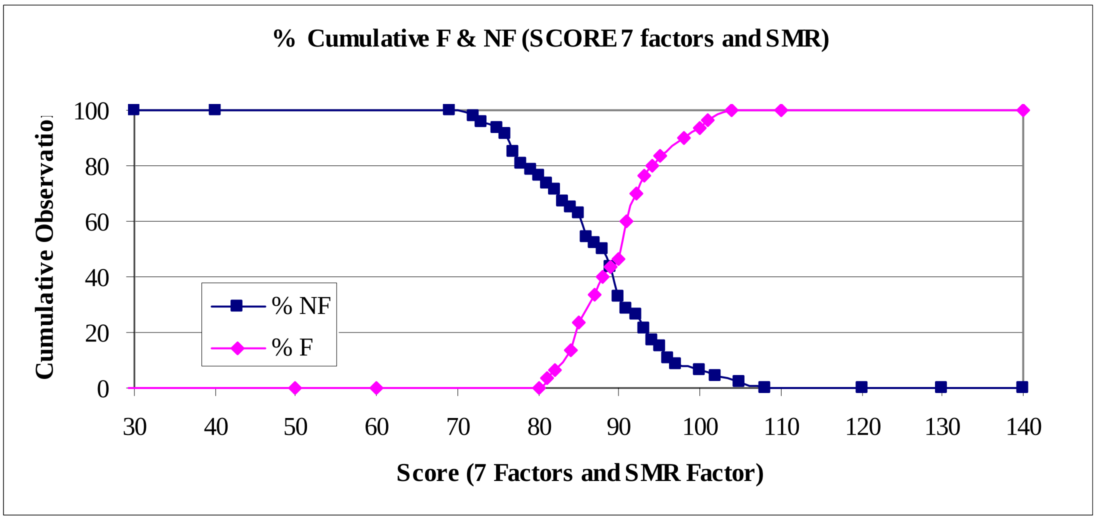


Figure 78 Cumulative frequency of total score (7 related factors and SMR factor) classified by slope condition

Fig 78 shows cumulative frequency of total score considered 7 related factors and SMR factor to classify by slope condition. Fig 79 shows cut slope failure potential classified by 7 related factors and SMR factor.

Table 51 shows the landslide potential and the range of total score considering RMR factor for all return periods of rainfall which considered from cumulative of failure and non-failure frequency (Fig 79).

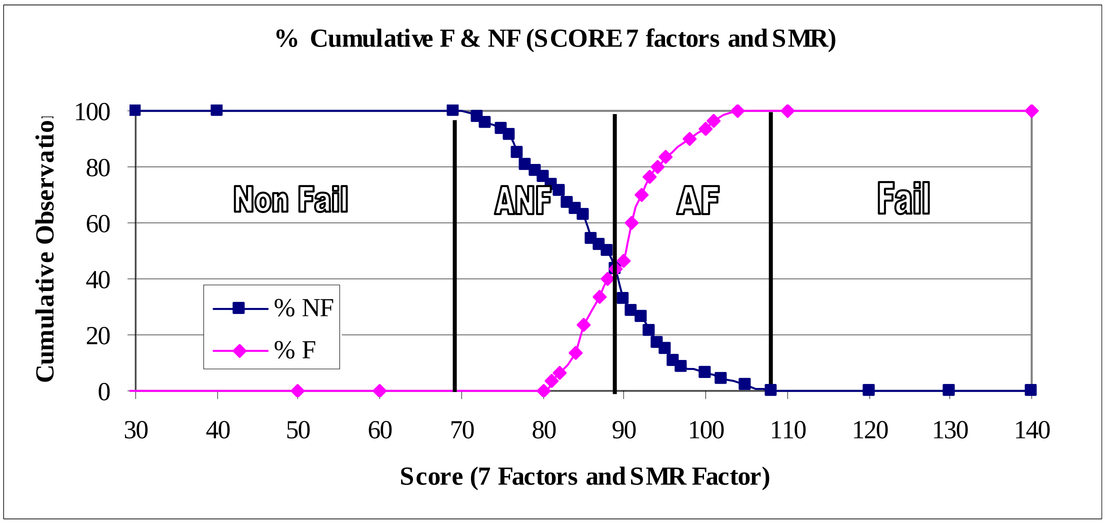


Figure 79 Cut slope failure potential classified by 7 related factors and SMR factor

Table 51 The landslide potential and the range of total score considering SMR factor for all rainfall return period.

Failure cut slope Classes	Range of Score
Very high potential	107-140
High potential	89-107
Low potential	69-89
Very low potential	30-69

Processing Cut Slope Failure Map and Hazard Map by Considering SMR Factor Included

In this section, the processing of landslide hazard map due to cut slope determined the numerical rating of 7 related factors and SMR factor following weighting factor method (Table 40). The weight-rating values of each parameter determined in each 25x25 square meter grid cell, in which the summation of weight-rating values were classified range of score by cut slope failure classes (Table 42). The result are shown in Fig 80. Table 52 and Fig 82 show area of cut slope failure classes considered by 7 related factors and SMR factor included.

Fig 84 (a) to (e) shows the results of processing of landslide hazard map due to cut slope considered by weighting factor analysis in term probability of return period of rainfall. Scores were classified by cumulative of failure and non-failure frequency which was 89 score. Fig 84 shows landslide hazard map due to cut slope using 1, 5, 20, 50 and 100 years return periods of rainfall considered 7 related factors and SMR factor included. Predicted landslide hazard area due to cut slope for 5 return periods of rainfall considered 7 related factors and SMR factor is shown in Table 53 and Fig 85. The plan area of landslide hazard due to cut slope was 2.09%, 4.05%, 8.75%, 10.64% and 12.71% for 1, 5, 20, 50 and 100 years return period of rainfall.

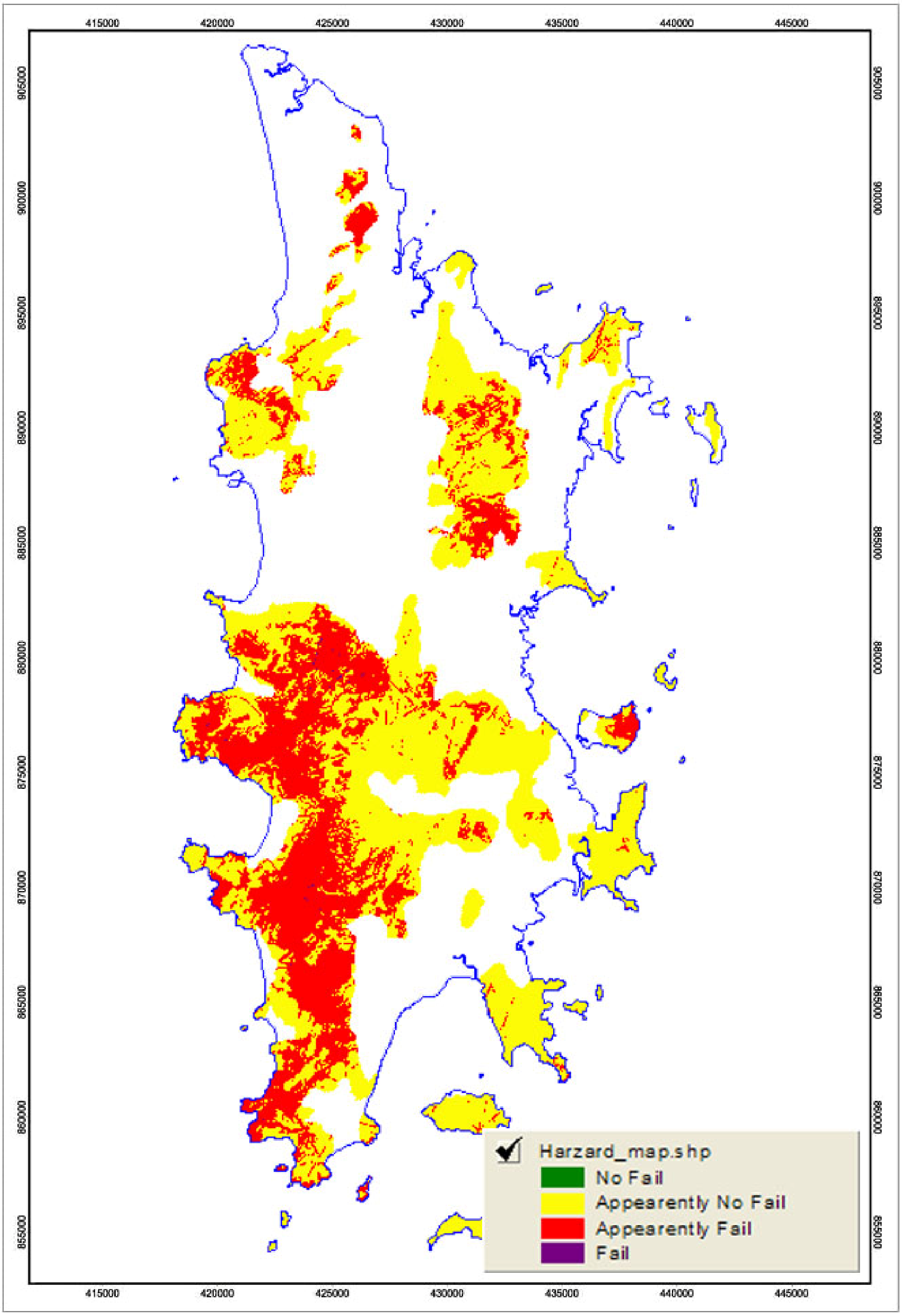
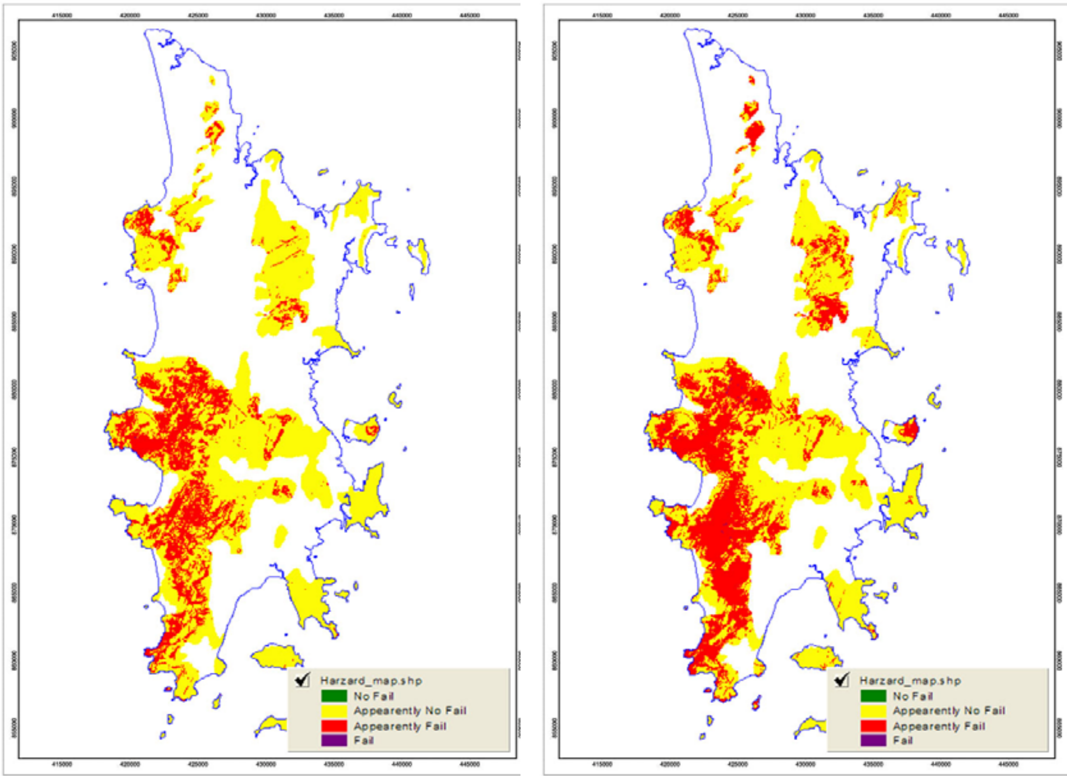


Figure 80 Area of failure cut slope classes considered by including 7 related factors and SMR factor

Table 52 Area of failure cut slope classes considered by including 7 related factors and SMR factor

Score	Failure cut slope Classes	pixel	Area (km^2)	%
96 - 118	Fail	604	0.38	0.07
74 - 96	Apparently fail	169,851	106.16	19.34
69 - 74	Apparently no fail	270,209	168.88	30.76
30 - 69	No fail	437,753	273.60	49.83
	Sum	878,417	549.01	100.00

Figure 81 Area of failure cut slope classes considered by including 7 related factors and SMR factor



(a) 7 factors and RMR factor (b) 7 factors and SMR factor

Figure 82 Comparing between the failure cut slope hazard map

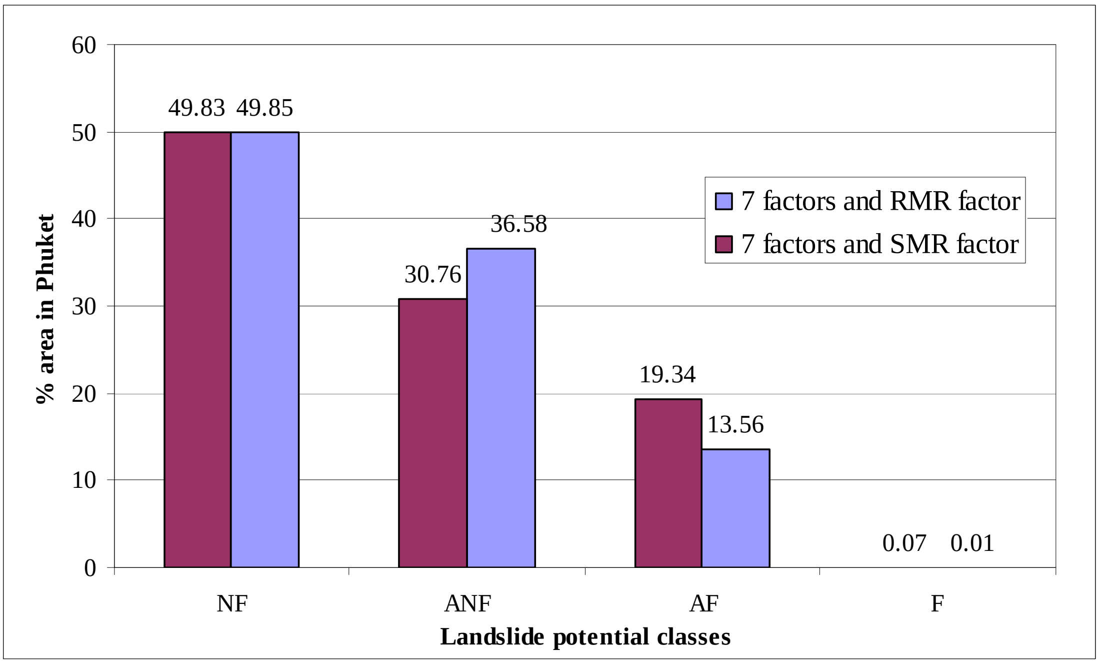
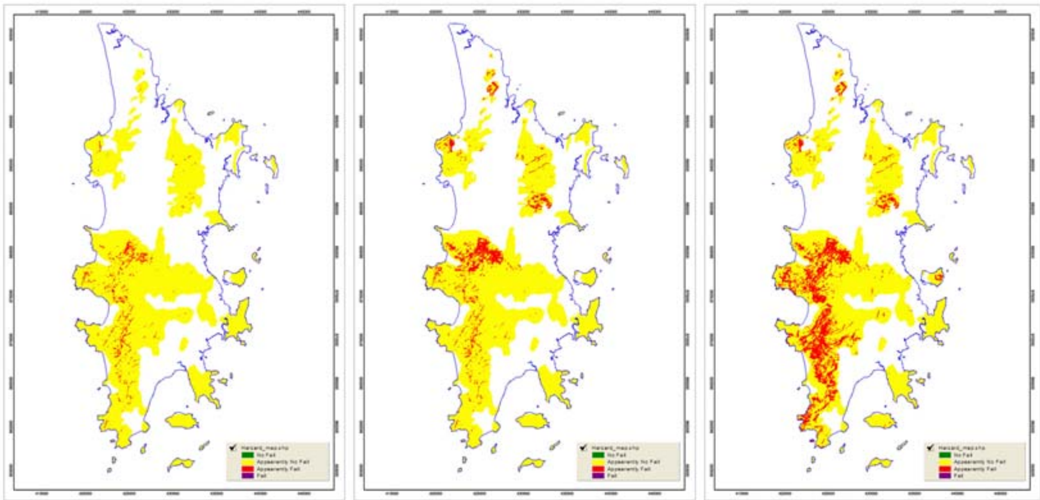
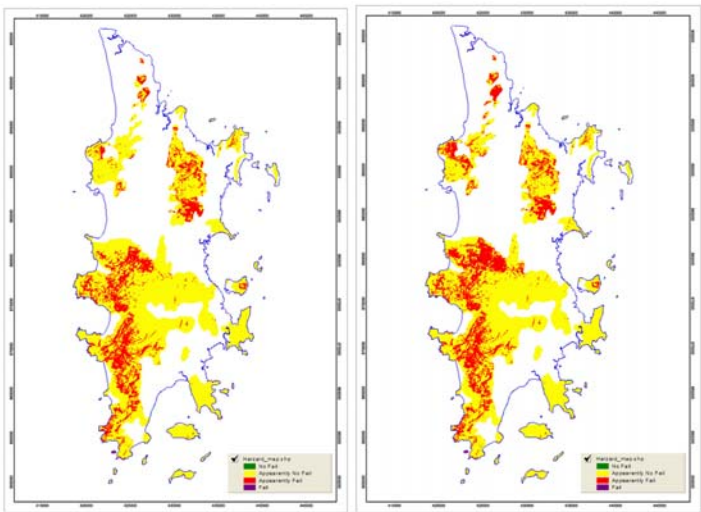


Figure 83 Comparison of failure cut slope hazard classes



(a) 1 year (b) 5 years (c) 20 years



(d) 50 years (e) 100 years

Figure 84 The failure cut slope of hazard map in Phuket showing rainfall intensity return period of 1, 5, 20, 50 and 100 years respectively (SMR factor included)

Table 53 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and SMR factor

Return period of rainfall year	Landslide classify	pixel	Area (km^2)	%
1	Fail	18,360	11.48	2.09
	No fail	860,057	537.54	97.91
5	Fail	35,577	22.24	4.05
	No fail	842,840	526.78	95.95
20	Fail	76,879	48.05	8.75
	No fail	801,538	500.96	91.25
50	Fail	93,461	58.41	10.64
	No fail	784,956	490.60	89.36
100	Fail	111,674	69.80	12.71
	No fail	766,743	479.21	87.29

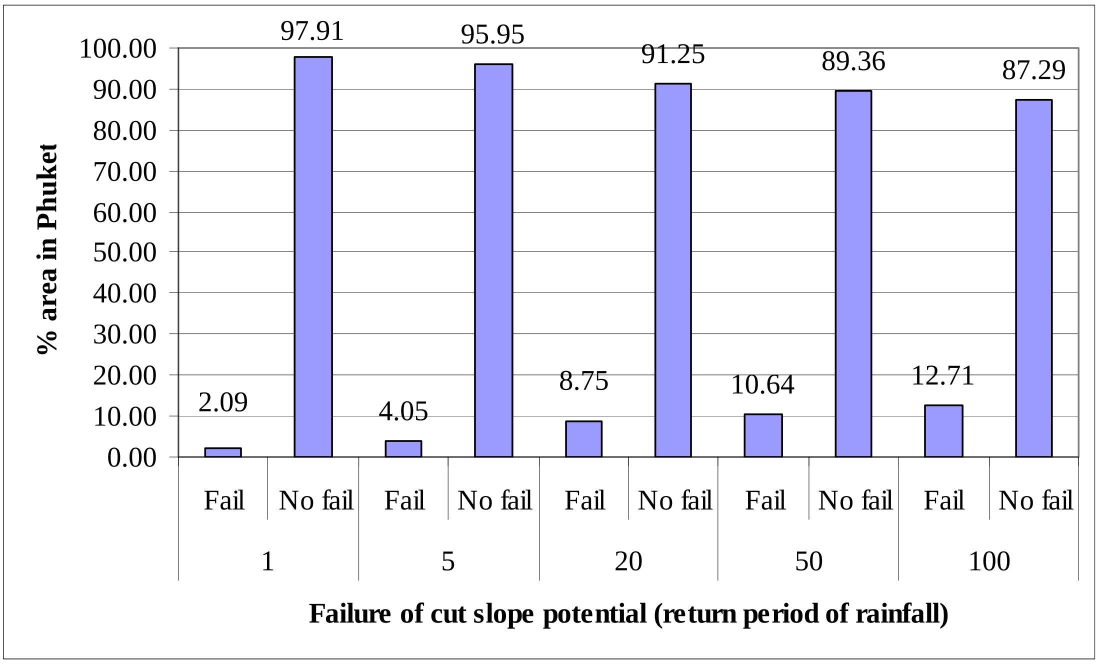


Figure 85 Predicted failure cut slope hazard area for 5 return periods of rainfall including 7 related factors and SMR factor

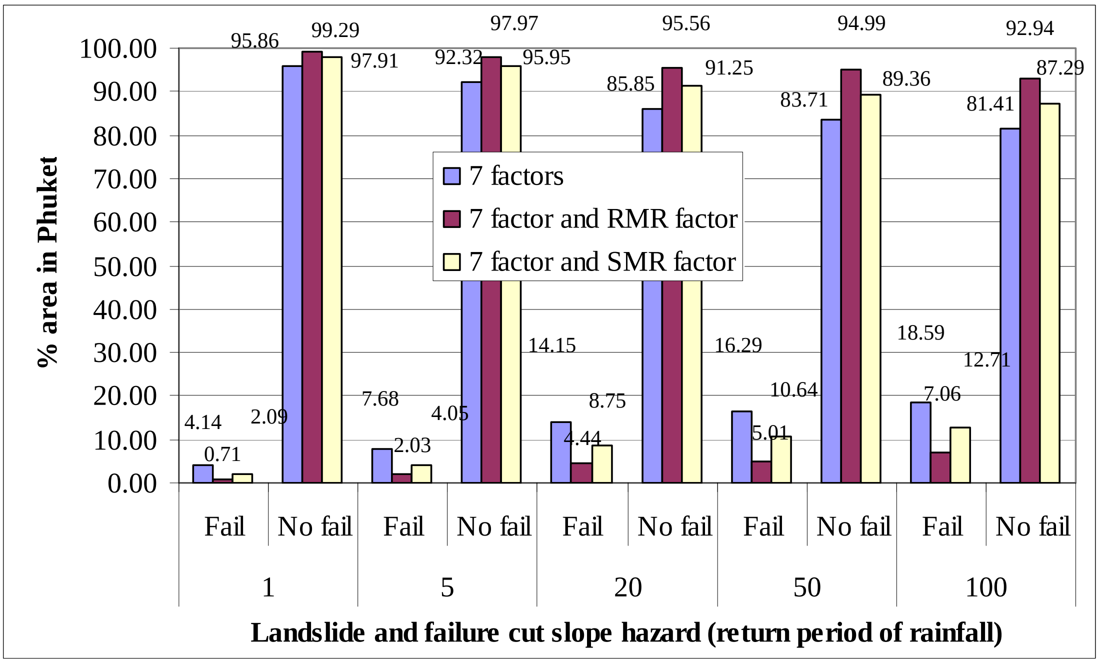


Figure 86 Comparison of landslide hazard

Fig 86 shows comparison between the landslide hazard map which considered only 7 related factors, 7 related factors and RMR factor included and 7 related factors and SMR factor included. The results were slightly different.

Logistic Multiple Regression Analysis (RMR factors included)

The linear logistic modal was represented by the equation:

For cumulative rainfall intensity 3 days

Y = -4.86459 + (6.14587*[W_eng])-(0.14011*[Rmr])
+ (0.001097*[Slope_val]) + (0.061088*[W_landuse])
- (0.26825*[W_drain]) - (0.00103*[Ele_value])
+ (0.101402*[W_linea]) + (0.068205*[Intensity])
- (0.04469*[W_soil]) - (4.45102*[W_rocktype])

For cumulative rainfall intensity 3 days (100 year return period)

Y = 7.706127 + (6.1245*[W_eng]) - (0.14707*[Rmr]) -
(0.0097*[Slope_val])
- (0.00849*[W_landuse]) - (0.3332*[W_drain]) - (0.0015*[Ele_value])
+ (0.07567*[W_linea]) - (0.00602*[Intensity]) - (0.21034*[W_soil])
- (4.30685*[W_rocktype])

and

P = 1/(1+exp(-Y))

Is the estimated probability of failure of cut slope at a given cell.

When	W_rocktype	= weight factor index of rock type (discrete value)
	W_linea	= weight factor index of lineament zone (discrete value)
	Slope_val	= slope in degree (continues value)
	Ele_value	= elevation in meter (continues value)
	W_landuse	= weight factor index of land use (discrete value)
	W_drain	= weight factor index of drainage zone (discrete value)
	W_soil	= weight factor index of soil characteristic (discrete value)
	W_eng	= weight factor index of engineering properties (discrete value)
	Intensity	= rainfall intensity in mm. (continues value)
	Rmr	= rock mass rating value (continues value)
	Y	= slope condition
	P	= probability

Table 54 Variable means between failure and non-failure of cut slope

Factors	Fail			No Fail		
	Mean	Std. Deviation	N	Mean	Std. Deviation	N
DRAINAGE	1.536	1.170	28	2.114	1.471	35
ELEVATION	116.008	102.658	28	98.442	48.686	35
ENGINEERING	3.964	0.189	28	3.686	0.758	35
INTENSITY (1 year)	138.214	4.756	28	133.286	6.636	35
INTENSITY (100 year)	406.250	33.765	28	421.071	50.345	35
LAND USE	3.000	1.247	28	3.229	1.262	35
LINEAMENT	1.857	1.671	28	2.486	1.961	35
ROCKTYPE	4.964	0.189	28	4.657	0.906	35
SLOPE	20.750	6.709	28	21.749	6.546	35
SOILTEXTURE	2.857	0.356	28	2.571	0.698	35
RMR	35.250	9.724	28	55.171	9.913	35

Table 55 Result of linear regression analysis for cumulative rainfall intensity 3 days (RMR factors included)

SUMMARY OUTPUT RMR (Cumulative rainfall intensity 3 days)

Regression Statistics	
Multiple R	0.7722
R Square	0.5962
Adjusted R Square	0.5186
Standard Error	2.0505
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	322.8620	32.28620	7.6792	2.20303E-07
Residual	52	218.6269	4.20436		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-4.86459	8.04871	-0.60439	0.54821	-21.01550	11.28632
ENGINEERING	6.14587	4.91512	1.25040	0.21675	-3.71703	16.00877
RMR	-0.14011	0.02113	-6.63047	0.00000	-0.18252	-0.09771
SLOPE	0.00110	0.04339	0.02529	0.97992	-0.08596	0.08816
LANDUSE	0.06109	0.22690	0.26923	0.78882	-0.39422	0.51640
DRAINAGE	-0.26825	0.22376	-1.19882	0.23603	-0.71726	0.18076
ELEVATION	-0.00103	0.00389	-0.26380	0.79298	-0.00884	0.00679
LINEAMENT	0.10140	0.16195	0.62611	0.53398	-0.22358	0.42639
INTENSITY	0.06820	0.05159	1.32212	0.19191	-0.03531	0.17172
SOILTEXTURE	-0.04469	0.72928	-0.06128	0.95137	-1.50810	1.41872
ROCKTYPE	-4.45102	4.09832	-1.08606	0.28246	-12.67491	3.77286

Table 56 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	1.742
ELEVATION	0.049
ENGINEERING	0.000
INTENSITY (1 year)	1.947
LANDUSE	0.023
LINEAMENT	1.987
RMR	12.478
ROCKTYPE	0.000
SOILTEXTURE	0.234
SLOPE	0.033

Table 57 Result of linear regression analysis for cumulative rainfall intensity 3 days, 100 years return period (RMR factors included)

SUMMARY OUTPUT RMR (100 Years return period of rainfall)

Regression Statistics	
Multiple R	0.7673
R Square	0.5888
Adjusted R Square	0.5097
Standard Error	2.0694
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	318.8034	31.88034	7.4445	3.38983E-07
Residual	52	222.6855	4.28241		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	7.70613	4.03613	1.90928	0.06175	-0.39297	15.80522
ENGINEERING	6.12450	5.12974	1.19392	0.23793	-4.16907	16.41807
RMR	-0.14707	0.02019	-7.28557	0.00000	-0.18758	-0.10656
SLOPE	-0.00970	0.04323	-0.22439	0.82333	-0.09645	0.07705
LANDUSE	-0.00849	0.22495	-0.03773	0.97005	-0.45988	0.44290
DRAINAGE	-0.33322	0.21886	-1.52255	0.13393	-0.77240	0.10595
ELEVATION	-0.00150	0.00393	-0.38155	0.70435	-0.00938	0.00638
LINEAMENT	0.07567	0.16162	0.46820	0.64160	-0.24864	0.39998
INTENSITY	-0.00602	0.00687	-0.87658	0.38475	-0.01981	0.00776
SOILTEXTURE	-0.21034	0.74511	-0.28229	0.77884	-1.70550	1.28483
ROCKTYPE	-4.30685	4.24387	-1.01484	0.31488	-12.82280	4.20910

Table 58 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	3.146
ELEVATION	0.580
ENGINEERING	0.000
INTENSITY (1 year)	0.199
LANDUSE	0.579
LINEAMENT	1.049
RMR	13.298
ROCKTYPE	0.000
SOILTEXTURE	0.001
SLOPE	0.205

Table 54 shows variable means between failure and non-failure of cut slope. Table 55 shows result of linear regression analysis for cumulative rainfall intensity 3 days (RMR factors included). Table 57 shows result of linear regression analysis for cumulative rainfall intensity 3 days, 100 year return period (RMR factors included). Table 56 and Table 58 show results of enter logistic procedure in which RMR factor was 68.63 time higher than other variables. Therefore, RMR factor may overwhelm the effects of the other variables in predicting landslide of cut slope.

Processing Cut Slope Probability of Failure Map by Considering RMR Factor Included

Fig 87 shows probability of failure of sensitive area for cut slope for 1 year rainfall return period. Fig 88 shows probability of failure of sensitive area for cut slope for 100 year rainfall return period by considering RMR factor. Table 59 shows parameter means and distribution of predictive failure of cut slope (RMR included).

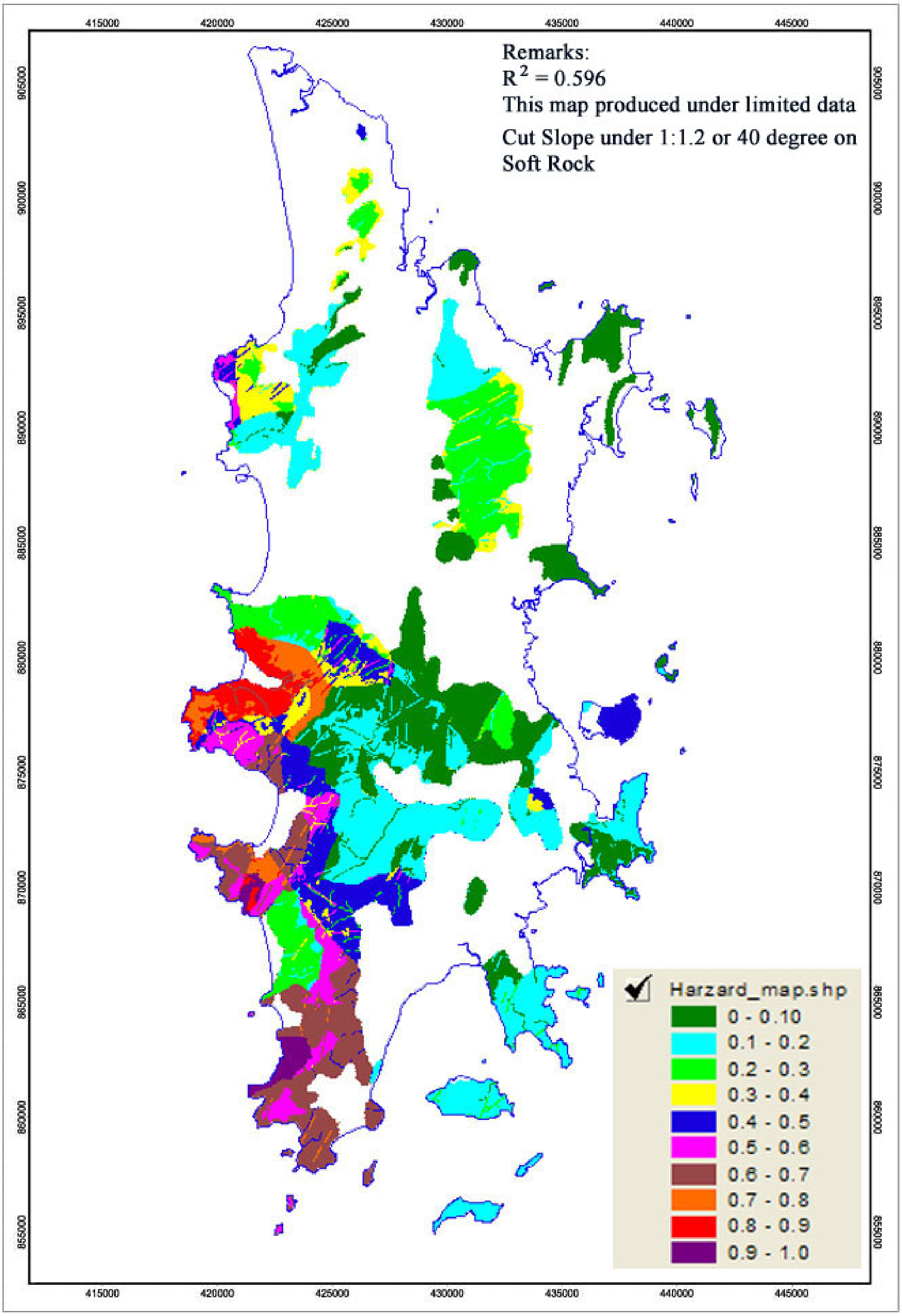


Figure 87 Probability of failure of sensitive area for cut slope for 1 year rainfall return period (RMR factor included)

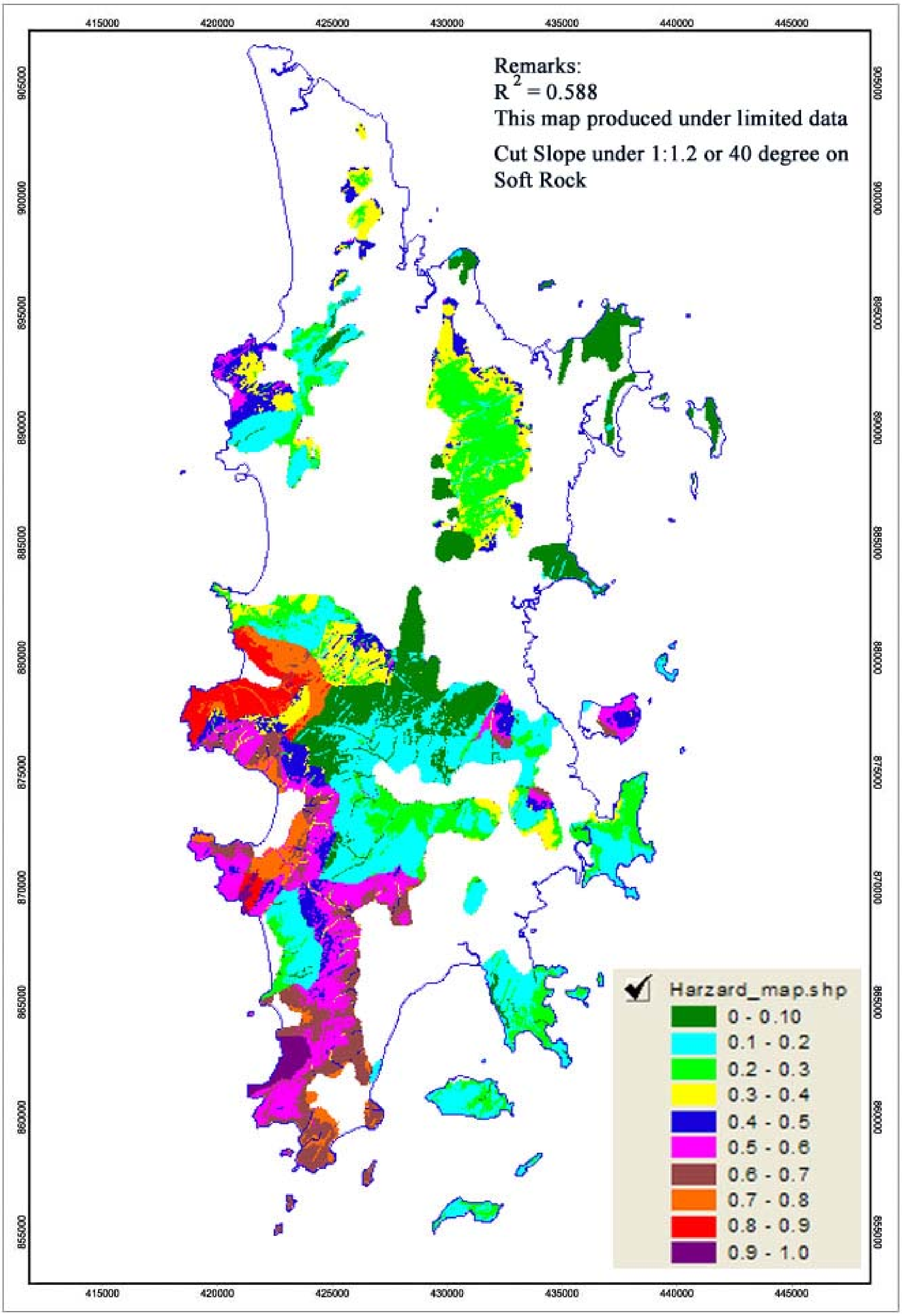


Figure 88 Probability of failure of sensitive area for cut slope for 100 years rainfall return period (RMR factor included)

Table 59 Parameter means and distribution of predictive failure of cut slope (RMR included)

RMR cumulative rainfall intensity 3 days

Probability	Parameter 1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	11.9	10.6	101.0	100.0	4.3	0.5	1.0	0.4	1.1	0.5	2.1	0.6	3.2	1.2	3.3	0.5	128.1	5.2	53.7	5.3	-2.7095	0.062	90,970
0.1-0.2	11.1	10.6	87.5	82.8	4.8	0.4	1.2	0.8	1.0	0.4	2.3	0.7	3.2	1.2	3.8	0.4	129.3	7.4	54.1	5.1	-1.8624	0.134	124,573
0.2-0.3	15.6	10.5	155.7	103.5	5.0	0.2	1.1	0.5	1.1	0.5	2.8	0.5	2.4	1.4	4.0	0.2	131.2	8.2	51.1	4.6	-1.1043	0.249	62,063
0.3-0.4	14.5	10.3	129.4	108.5	5.0	0.0	1.1	0.7	1.1	0.6	2.6	0.5	3.4	1.2	4.0	0.0	128.4	4.9	47.8	1.2	-0.6836	0.335	24,406
0.4-0.5	16.0	10.6	162.2	117.8	5.0	0.0	1.1	0.6	1.1	0.6	2.8	0.5	3.6	0.9	4.0	0.0	135.1	1.8	47.4	1.1	-0.2068	0.448	40,430
0.5-0.6	15.3	9.7	158.9	93.3	5.0	0.0	1.3	1.0	1.0	0.1	2.9	0.3	3.1	1.3	4.0	0.0	140.2	5.0	47.0	1.3	0.2265	0.556	21,976
0.6-0.7	11.9	10.3	71.0	62.7	5.0	0.0	1.1	0.6	1.0	0.4	2.6	0.5	3.5	1.0	4.0	0.0	143.2	3.8	46.6	2.4	0.5713	0.639	42,021
0.7-0.8	16.1	10.8	218.5	141.2	5.0	0.0	1.3	1.0	1.0	0.2	2.9	0.3	2.5	1.5	4.0	0.0	137.7	4.5	37.9	3.8	1.2202	0.772	12,878
0.8-0.9	15.2	10.9	84.2	74.8	5.0	0.0	1.2	0.8	1.0	0.0	2.8	0.4	3.0	1.3	4.0	0.0	135.6	2.3	35.5	0.5	1.5753	0.829	14,072
0.9-1.0	15.9	9.0	90.3	61.4	5.0	0.0	1.0	0.4	1.0	0.0	3.0	0.2	3.3	1.1	4.0	0.0	145.0	0.0	32.7	1.2	2.6046	0.931	5,842

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

RMR cumulative rainfall intensity 3 days , 100 year return period

Probability	Parameter 1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	15.4	11.0	136.5	120.8	4.4	0.5	1.0	0.4	1.2	0.8	2.4	0.5	3.3	1.2	3.4	0.5	467.0	48.6	54.6	5.5	-2.5232	0.074	54,139
0.1-0.2	11.5	10.8	95.5	84.4	4.5	0.5	1.1	0.8	1.1	0.5	2.2	0.7	3.1	1.2	3.5	0.5	430.2	48.3	54.4	4.3	-1.7559	0.147	112,521
0.2-0.3	10.6	10.8	105.0	113.2	4.7	0.4	1.2	0.8	1.1	0.4	2.3	0.7	2.7	1.3	3.7	0.4	434.3	84.4	52.2	5.0	-1.1622	0.238	79,043
0.3-0.4	14.3	10.8	127.9	98.9	5.0	0.1	1.1	0.5	1.1	0.6	2.7	0.5	3.0	1.3	4.0	0.1	480.2	53.6	49.2	3.5	-0.6974	0.332	39,958
0.4-0.5	14.0	10.7	148.1	126.4	5.0	0.0	1.1	0.7	1.1	0.6	2.6	0.5	3.6	0.9	4.0	0.0	440.6	57.4	47.5	1.0	-0.2119	0.447	30,489
0.5-0.6	15.9	9.4	135.6	82.4	5.0	0.0	1.1	0.6	1.0	0.3	2.8	0.5	3.3	1.2	4.0	0.0	375.0	35.7	47.3	1.2	0.2102	0.552	45,915
0.6-0.7	9.2	8.7	62.4	62.7	5.0	0.0	1.1	0.8	1.0	0.2	2.5	0.6	3.4	1.0	4.0	0.0	359.3	29.3	46.8	2.1	0.6301	0.653	32,169
0.7-0.8	11.8	11.8	146.3	146.6	5.0	0.0	1.1	0.8	1.1	0.5	2.7	0.5	3.2	1.2	4.0	0.0	404.1	46.2	40.5	4.8	1.0777	0.746	19,095
0.8-0.9	14.2	10.1	87.4	73.6	5.0	0.0	1.1	0.7	1.0	0.0	2.8	0.4	2.7	1.4	4.0	0.0	430.9	24.8	35.5	0.6	1.7287	0.849	15,668
0.9-1.0	14.6	8.9	85.7	60.4	5.0	0.0	1.1	0.6	1.0	0.0	3.0	0.2	3.3	1.1	4.0	0.0	342.8	32.5	1.0	5.5	7.2847	0.999	5,233

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

Logistic Multiple Regression Analysis by SMR Factor Included

The linear logistic modal was represented by the equation:

For cumulative rainfall intensity 3 days

Y = -2.57172 + (8.51002*[W_eng]) - (0.1337*[Smr]) - (0.0132*[Slope_val])
- (0.05934*[W_landuse]) - (0.1908*[W_drain]) - (0.00177*[Ele_value])
+ (0.042322*[W_linea]) + (0.056058*[Intensity]) - (0.04864*[W_soil])
- (6.42077*[W_rocktype])

For cumulative rainfall intensity 3 days (100 year return period)

Y = 6.892795 + (8.07922*[W_eng]) - (0.14059*[Smr])
- (0.0221*[Slope_val]) - (0.11774*[W_landuse]) - (0.24265*[W_drain])
- (0.00252*[Ele_value]) + (0.00734*[W_linea]) - (0.00282*[Intensity])
- (0.14739*[W_soil]) - (5.97485*[W_rocktype])

and

P = 1/(1+exp(-Y))

Is the estimated probability of failure of cut slope at a given cell.

When W_rocktype = weight factor index of rock type (discrete value)
W_linea = weight factor index of lineament zone (discrete value)
Slope_val = slope in degree (continues value)
Ele_value = elevation in meter (continues value)
W_landuse = weight factor index of land use (discrete value)
W_drain = weight factor index of drainage zone (discrete value)
W_soil = weight factor index of soil characteristic (discrete value)
W_eng = weight factor index of engineering properties (discrete value)
Intensity = rainfall intensity in mm. (continues value)
Rmr = rock mass rating value (continues value)
Y = slope condition
P = probability

Table 60 Variable means between failure and non-failure of cut slope

Factors	Fail			No Fail		
	Mean	Std. Deviation	N	Mean	Std. Deviation	N
DRAINAGE	1.536	1.170	28	2.114	1.471	35
ELEVATION	116.008	102.658	28	98.442	48.686	35
ENGINEERING	3.964	0.189	28	3.686	0.758	35
INTENSITY (1 year)	138.214	4.756	28	133.286	6.636	35
INTENSITY (100 year)	406.250	33.765	28	421.071	50.345	35
LANDUSE	3.000	1.247	28	3.229	1.262	35
LINEAMENT	1.857	1.671	28	2.486	1.961	35
ROCKTYPE	4.964	0.189	28	4.657	0.906	35
SLOPE	20.750	6.709	28	21.749	6.546	35
SOILTEXTURE	2.857	0.356	28	2.571	0.698	35
SMR	33.227	9.723	28	53.451	10.879	35

Table 61 Result of linear regression analysis for cumulative rainfall intensity 3 days (SMR factors included)

SUMMARY OUTPUT   SMR (Cumulative rainfall intensity 3 days)

Regression Statistics	
Multiple R	0.7642
R Square	0.5840
Adjusted R Square	0.5040
Standard Error	2.0814
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	316.2238	31.62238	7.2997	4.43655E-07
Residual	52	225.2651	4.33202		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.57172	8.36155	-0.30757	0.75964	-19.35038	14.20694
ENGINEERING	8.51002	4.97672	1.70996	0.09323	-1.47650	18.49654
SMR	-0.13370	0.02085	-6.41367	0.00000	-0.17553	-0.09187
SLOPE	-0.01320	0.04396	-0.30016	0.76525	-0.10141	0.07502
LANDUSE	-0.05934	0.23041	-0.25754	0.79778	-0.52168	0.40301
DRAINAGE	-0.19080	0.22673	-0.84155	0.40390	-0.64577	0.26416
ELEVATION	-0.00177	0.00399	-0.44303	0.65958	-0.00977	0.00623
LINEAMENT	0.04232	0.16487	0.25670	0.79842	-0.28851	0.37315
INTENSITY	0.05606	0.05324	1.05301	0.29721	-0.05077	0.16288
SOILTEXTURE	-0.04864	0.74049	-0.06569	0.94788	-1.53454	1.43726
ROCKTYPE	-6.42077	4.14554	-1.54884	0.12749	-14.73941	1.89787

Table 62 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	0.855
ELEVATION	0.355
ENGINEERING	0.000
INTENSITY (1 year)	0.661
LANDUSE	0.408
LINEAMENT	0.646
ROCKTYPE	0.000
SOILTEXTURE	0.144
SLOPE	0.188
SMR	11.700

Table 63 Result of linear regression analysis for cumulative rainfall intensity 3 days, 100 years return period (SMR factors included)

SUMMARY OUTPUT SMR (100 Years return period of rainfall)

Regression Statistics	
Multiple R	0.7592
R Square	0.5764
Adjusted R Square	0.4950
Standard Error	2.1002
Observations	63

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	312.1199	31.21199	7.0760	6.75662E-07
Residual	52	229.3690	4.41094		
Total	62	541.4889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	6.89279	4.09276	1.68414	0.09815	-1.31992	15.10551
ENGINEERING	8.07922	5.20070	1.55349	0.12637	-2.35675	18.51519
INTENSITY	-0.00282	0.00708	-0.39824	0.69209	-0.01702	0.01138
LANDUSE	-0.11774	0.22689	-0.51892	0.60602	-0.57302	0.33755
DRAINAGE	-0.24265	0.22283	-1.08895	0.28120	-0.68979	0.20449
SMR	-0.14059	0.01988	-7.07232	0.00000	-0.18048	-0.10070
SLOPE	-0.02210	0.04368	-0.50588	0.61508	-0.10975	0.06555
ELEVATION	-0.00252	0.00402	-0.62659	0.53367	-0.01059	0.00555
LINEAMENT	0.00734	0.16392	0.04477	0.96446	-0.32160	0.33628
SOILTEXTURE	-0.14739	0.75579	-0.19501	0.84615	-1.66400	1.36922
ROCKTYPE	-5.97485	4.30110	-1.38915	0.17071	-14.60562	2.65593

Table 64 Results of enter logistic procedure

Variable Entered	Wald Chi square
DRAINAGE	1.844
ELEVATION	1.051
ENGINEERING	0.000
INTENSITY (100 year)	0.161
LANDUSE	0.771
LINEAMENT	0.190
ROCKTYPE	0.000
SOILTEXTURE	0.299
SLOPE	0.295
SMR	11.838

Table 60 shows variable means between failure and non-failure of cut slope. Table 61 shows result of linear regression analysis for cumulative rainfall intensity 3 days (SMR factors included). Table 63 shows result of linear regression analysis for cumulative rainfall intensity 3 days, 100 year return period (SMR factors included). Table 62 and Table 64 show results of enter logistic procedure in which SMR factor was 75.10 time higher than other variables. Therefore, SMR factor may overwhelm the effects of the other variables in predicting landslide of cut slope.

Processing Cut Slope Probability of Failure Map by Considering SMR Factor Included

Fig 89 shows probability of failure of sensitive area for cut slope for 1 year rainfall return period. Fig 90 shows probability of failure of sensitive area for cut slope for 100 year rainfall return period by considering SMR factor. Table 65 shows parameter means and distribution of predictive failure of cut slope (SMR included).

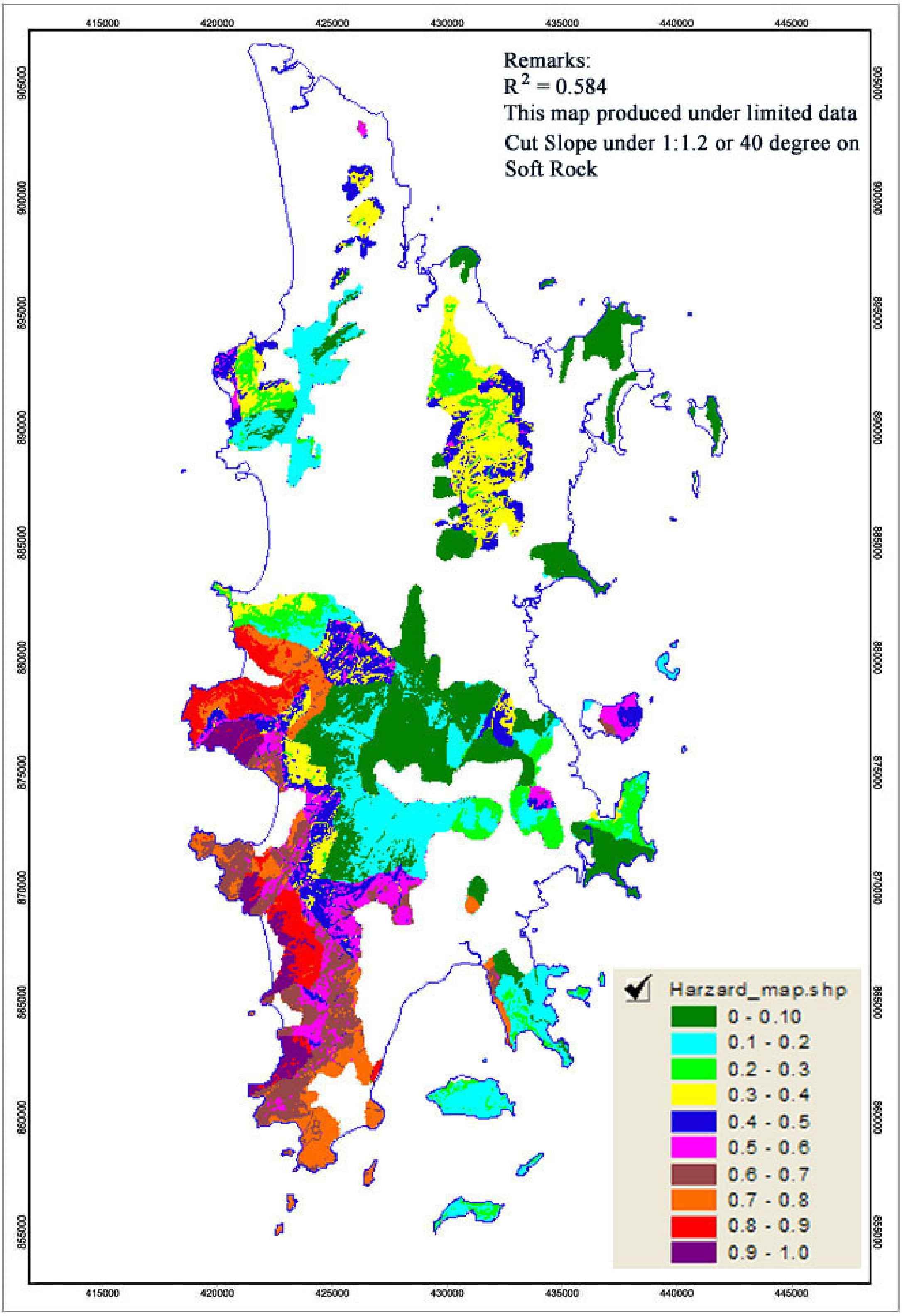


Figure 89 Probability of failure of sensitive area for cut slope for 1 year rainfall return period (SMR factor included)

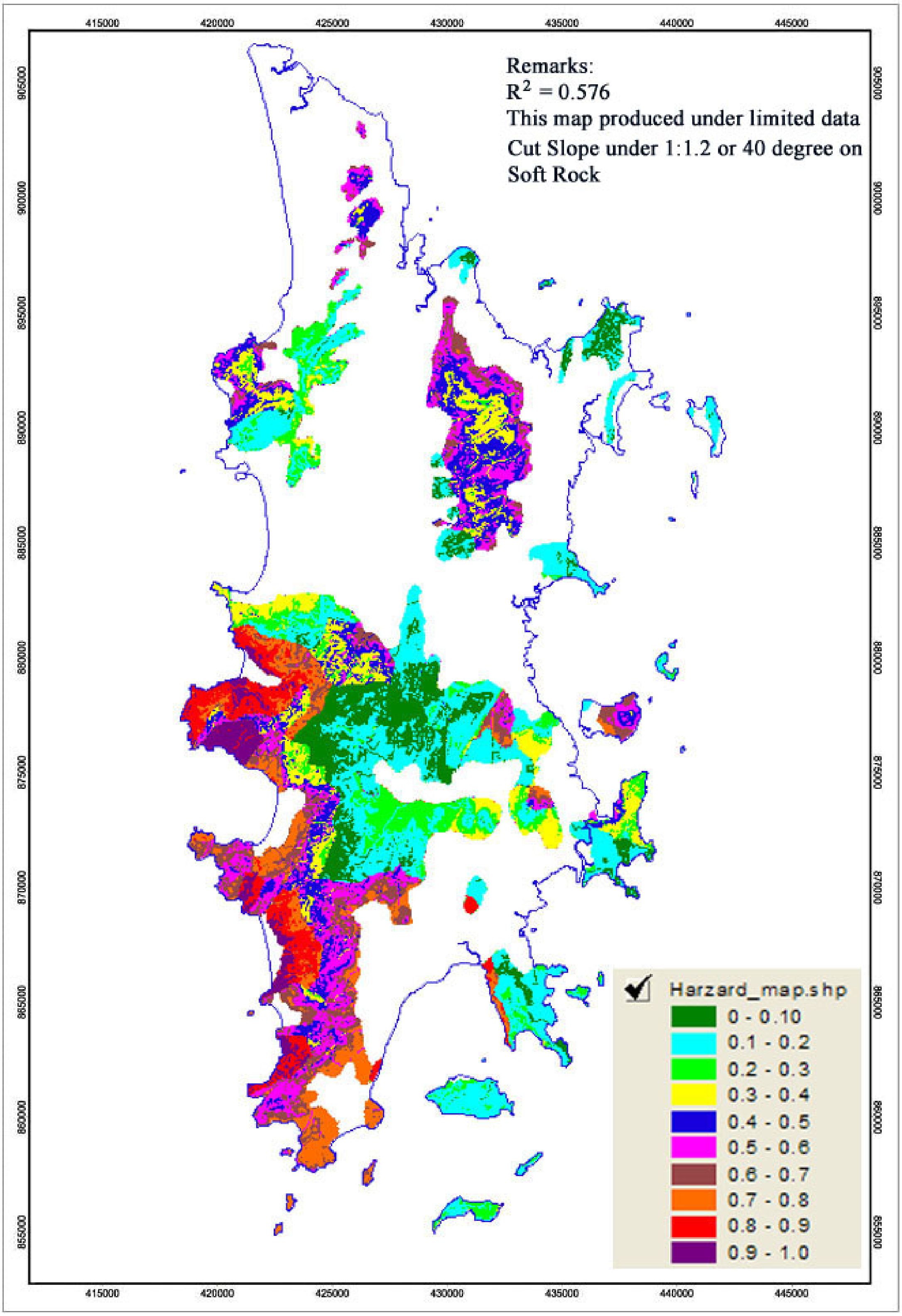


Figure 90 Probability of failure of sensitive area for cut slope for 100 years rainfall return period (SMR factor included)

Table 65 Parameter means and distribution of predictive failure of cut slope (SMR included)

SMR cumulative rainfall intensity 3 days

Probability	1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	13.0	10.9	102.7	100.5	4.3	0.4	1.1	0.6	1.1	0.5	2.1	0.6	3.4	1.1	3.3	0.4	128.6	5.3	51.1	5.9	-2.5854	0.070	95,313
0.1-0.2	11.0	10.5	92.8	79.8	4.8	0.4	1.1	0.7	1.0	0.4	2.3	0.7	3.2	1.2	3.8	0.4	132.7	5.8	55.8	5.5	-1.8023	0.142	77,573
0.2-0.3	9.3	10.9	76.0	101.1	4.5	0.5	1.1	0.5	1.1	0.5	2.6	0.5	2.5	1.4	3.5	0.5	135.1	9.5	47.7	5.3	-1.1274	0.245	48,001
0.3-0.4	16.7	10.6	179.4	122.1	5.0	0.2	1.1	0.5	1.1	0.6	2.8	0.5	2.6	1.4	4.0	0.2	127.4	7.0	45.3	2.4	-0.6156	0.351	48,120
0.4-0.5	14.5	10.3	142.1	93.8	5.0	0.0	1.1	0.7	1.1	0.5	2.7	0.6	3.1	1.3	4.0	0.0	130.9	5.2	44.8	0.9	-0.2133	0.447	44,364
0.5-0.6	13.4	9.9	120.2	89.4	5.0	0.0	1.2	0.8	1.1	0.5	2.8	0.5	3.4	1.1	4.0	0.0	137.6	4.7	44.7	1.6	0.2102	0.552	26,053
0.6-0.7	14.1	9.9	102.5	83.4	5.0	0.1	1.1	0.7	1.1	0.4	2.8	0.5	3.2	1.2	4.0	0.1	142.5	4.3	43.8	3.3	0.6126	0.649	32,544
0.7-0.8	10.2	10.8	109.5	129.0	4.9	0.2	1.1	0.6	1.1	0.4	2.5	0.5	3.2	1.1	3.9	0.2	141.2	4.9	39.6	5.9	1.0557	0.742	30,345
0.8-0.9	15.0	10.1	108.7	85.5	5.0	0.1	1.1	0.6	1.1	0.5	2.8	0.4	3.0	1.3	4.0	0.1	139.2	4.9	33.7	2.0	1.7513	0.852	23,338
0.9-1.0	11.8	9.1	79.6	62.0	5.0	0.0	1.1	0.6	1.0	0.3	2.9	0.3	3.2	1.1	4.0	0.0	141.5	4.8	30.6	3.2	2.4372	0.920	13,581

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

SMR cumulative rainfall intensity 3 days , 100 year return period

Probability	1		2		3		4		5		6		7		8		9		10		Y	P	pixel
	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ	mean	σ			
0-0.1	20.2	9.7	178.7	120.2	4.5	0.5	1.2	0.8	1.2	0.7	2.5	0.6	3.4	1.2	3.5	0.5	385.6	45.9	54.1	6.2	-2.4174	0.082	46,982
0.1-0.2	10.0	10.0	83.1	78.7	4.4	0.5	1.1	0.6	1.0	0.3	2.2	0.7	3.3	1.2	3.4	0.5	405.7	41.4	52.1	5.5	-1.6939	0.155	100,560
0.2-0.3	7.1	9.9	61.3	92.9	4.6	0.5	1.1	0.6	1.1	0.4	2.4	0.7	2.7	1.3	3.6	0.5	354.0	58.7	51.3	6.4	-1.0016	0.269	52,601
0.3-0.4	15.3	12.6	167.7	135.7	4.9	0.3	1.1	0.6	1.1	0.6	2.6	0.5	3.0	1.2	3.9	0.3	399.8	53.6	47.2	5.3	-0.479	0.382	39,551
0.4-0.5	18.6	8.9	179.4	86.5	5.0	0.1	1.1	0.7	1.1	0.6	2.9	0.4	2.8	1.4	4.0	0.1	412.2	60.5	44.7	1.3	-0.05	0.488	44,378
0.5-0.6	14.3	9.0	123.2	76.2	5.0	0.1	1.1	0.6	1.1	0.5	2.8	0.5	3.0	1.4	4.0	0.1	382.0	64.0	44.6	1.3	0.3263	0.581	47,606
0.6-0.7	9.9	9.2	79.8	84.5	5.0	0.1	1.1	0.5	1.0	0.4	2.6	0.6	3.1	1.3	4.0	0.1	365.8	55.8	43.9	2.9	0.7231	0.673	38,381
0.7-0.8	9.2	10.5	95.9	116.5	5.0	0.2	1.1	0.6	1.0	0.3	2.5	0.6	3.3	1.1	4.0	0.2	340.7	36.3	40.5	5.3	1.1828	0.765	32,263
0.8-0.9	15.4	9.5	102.7	75.4	4.9	0.3	1.1	0.6	1.1	0.5	2.8	0.4	3.0	1.3	3.9	0.3	357.6	38.3	33.0	2.6	1.8923	0.869	23,405
0.9-1.0	8.5	8.7	65.3	62.9	5.0	0.0	1.1	0.6	1.0	0.3	2.8	0.4	3.0	1.1	4.0	0.0	355.8	32.9	30.8	3.4	2.6471	0.934	13,503

1. SLOPE 2. ELEVATION 3. ROCKTYPE 4. LINEAMENT 5. DRAINAGE
6. SOILTEXTURE 7. LANDUSE 8. ENGINEERING 9. INTENSITY 10. RMR

CONCLUSIONS

Followings are conclusions on the research:

1. This study determines the sensitive areas of landslide and cut slope failure due to urban development in Phuket area. Weighting factor method was used through GIS application. Engineering soil properties were considered in weighting factor analyses and found to have great effect on landslide prediction. Furthermore, RMR and SMR were also considered in order to investigate the effect of rock mass quality and found to have effect to landslide prediction as well. However, verification needs to be done in the future.

2. The results of weighting factor method shows that RMR and SMR factors have slight effect on landslide hazard map.

3. Landslide potential classes done by cumulative frequency analysis gives more realistic result than using equal range of score concept.

4. RMR and SMR value show direct relation with the prediction of landslide for slope cutting.

5. As for rainfall intensity factor, the landslide potential map that considered 1 year return period of rainfall gives large difference compared to the map that used concept of 5 return periods of rainfall.

6. The cumulative frequency analysis of total score shows limited accuracy due to limited and slightly biased data.

7. RMR and SMR values have significant effect on landslide probability of failure when analyzed by logistic regression analysis.

8. Figure 91 and Figure 92 show the recommendation of landslide sensitive areas for cut slope by weighting factor method and logistic regression analysis respectively. The map is valid only for slope cutting that has angle of less than 1:1.2.

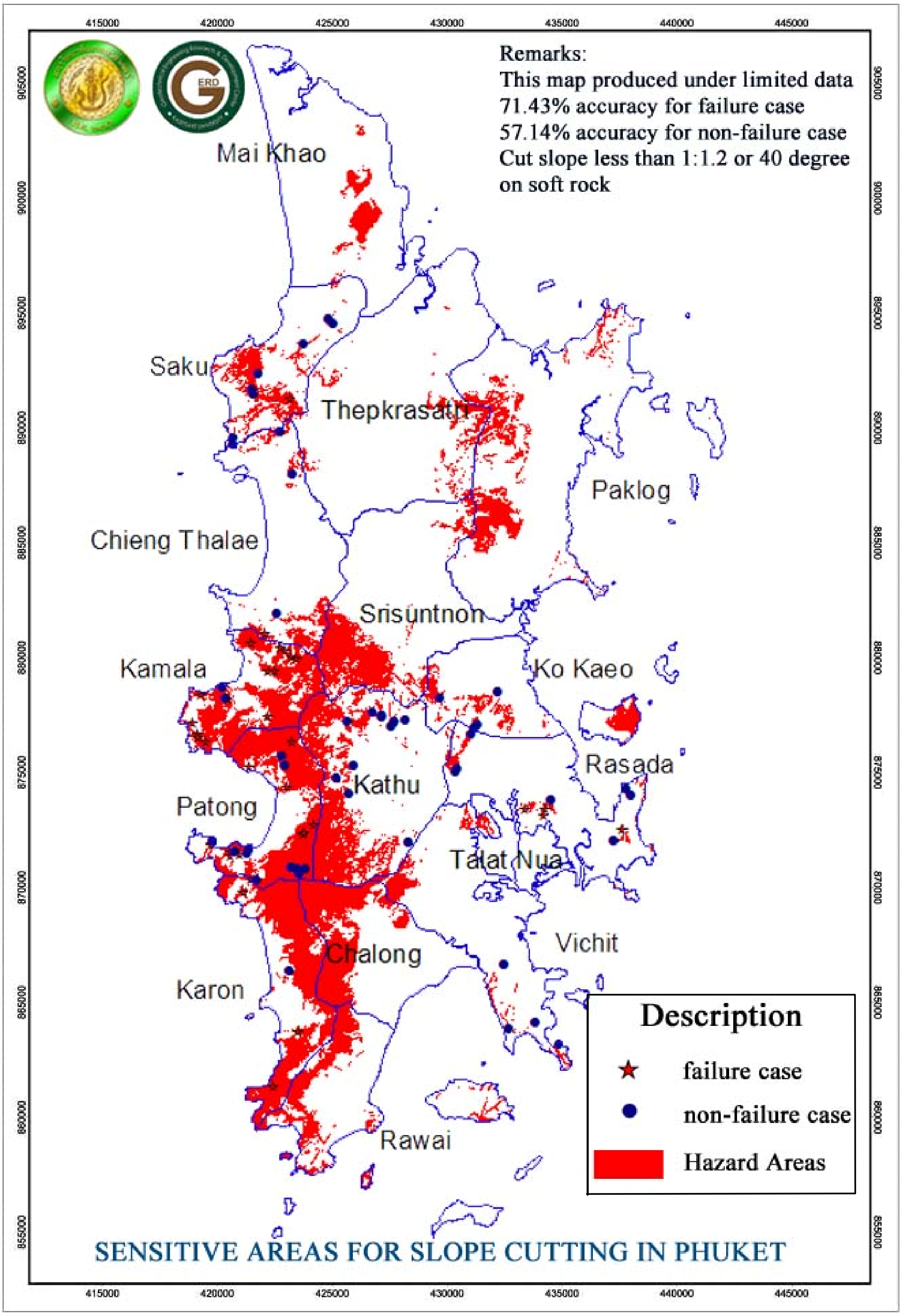


Figure 91 Recommendation of landslide sensitive area for cut slope by weighting factor analysis

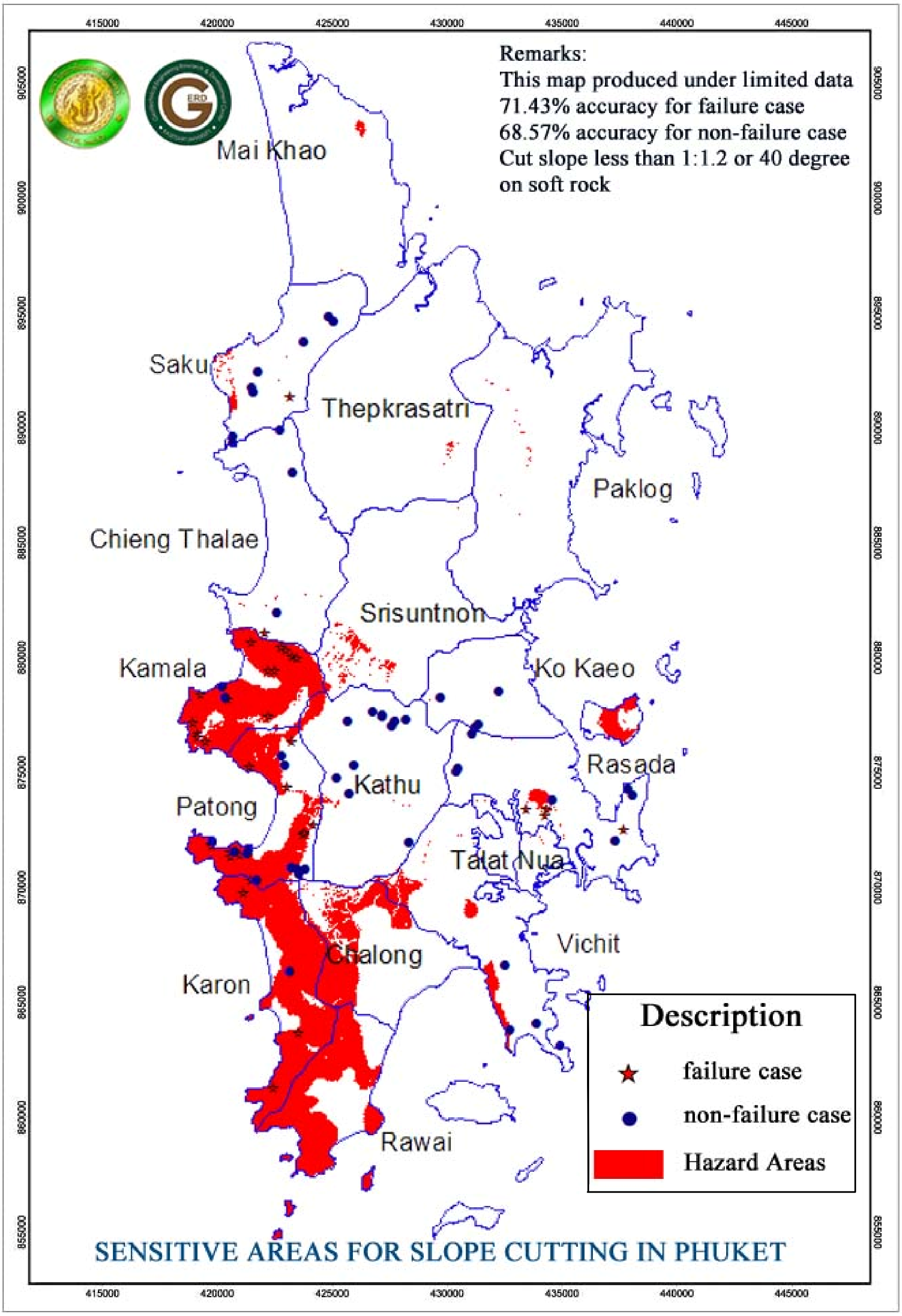


Figure 92 Recommendation of landslide sensitive areas for cut slope by logistic regression analysis

RECOMMENDATIONS

Recommendation for future research can be summarized as follows:

1. Watershed and accumulation of residual soil need to be included in the future analysis of landslide prediction.
2. The produced map shows only areas that can generate landslide hazard. Flow modeling needs to be done to predict affected areas.
3. Lesser biased SMR data and slope condition need to be added to improve accuracy of the analyses.

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APPENDIX

Appendix Table 1 Slope characteristics obtained from field investigation

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
1	PK01	873500	433250	Granite	Natural/Fail	65	30	3.00	000/00	000/00	000/00	single blow	4	MW	Wet
2	PK02	873450	434100	Granite& Mud Stone	Natural/Fail	60	12	0.50	067/55	080/88	000/00	nail	4	HW	Wet
3	PK03	873200	434050	Granite	Cut Slope/Fail	60	20	0.50	000/00	000/00	025/45	nail	4	HW	Damp
4	PK04	873800	434350	Granite	Cut Slope/Non	75	17	0.50	N/A	N/A	N/A	single blow	6	SW	Dry
5	PK05	872042	437044	Mud Stone	Cut Slope/Non	75	25	0.00	000/00	000/00	000/00	many blows	8	Fresh	Dry
6	PK06	872597	437468	Mud Stone	Cut Slope/Fail	65	20	2.00	000/00	324/40	183/88 073/69 026/45 130/64 215/18	pocket knife	6	MW	Wet
7	PK07	874313	437598	Mud Stone	Cut Slope/Non	30	15	0.00	N/A	N/A	N/A	nail	8	MW	Dry
8	PK08	873985	437773	Mud Stone	Cut Slope/Non	5	20	0.00	N/A	N/A	N/A	nail	8	SW	Dry
9	PK09	875000	430200	Granite	Cut Slope/Non	65	18	N/A	N/A	N/A	N/A	many blows	8	SW	Dry
10	PK10	881850	422450	Granite	Cut Slope/Non	60	10	N/A	N/A	N/A	N/A	single blow	6	SW	Dry
11	PK11	881043	421990	Granite	Natural/Fail	30	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A
12	PK12	880650	421400	Granite	Natural/Fail	30	20	1.00	000/00	000/00	135/60 100/45 317/55	pocket knife	4	MW	Damp
13	PK13	880450	422650	Granite	Cut Slope/Fail	50	6	2.00	000/00	000/00	270/35 017/87 256/87	pocket knife	4	MW	Damp
14	PK14	880425	422670	Granite	Cut Slope/Fail	55	10	0.50	000/00	000/00	000/00	pocket knife	4	MW	Wet
15	PK15	880350	422900	Granite	Cut Slope/Fail	60	30	0.00	000/00	000/00	000/00	nail	4	MW	Wet
16	PK16	880075	423125	Granite	Cut Slope/Fail	75	5	0.50	000/00	000/00	000/00	nail	4	MW	Wet
17	PK17	880000	423380	Granite	Natural/Fail	65	20	0.50	000/00	000/00	000/00	nail	6	MW	Damp

Appendix Table 1 Slope characteristics obtained from field investigation (Continued)

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
18	PK18	879450	422400	Granite	Natural/Fail	38	60	0.50	000/00	000/00	248/73 175/35	pocket knife	6	MW	Flowing
19	PK19	879450	422120	Granite	Cut Slope/Fail	45	18	10.00	072/73	000/00	268/38 063/79	single blow	4	MW	Wet
20	PK20	878200	420400	Granite	Cut Slope/Fail	45	30	2.00	000/00	000/00	000/00	pocket knife	8	MW	Damp
21	PK21	878250	420250	Granite	Cut Slope/Non	70	10	1.00	000/00	000/00	225/63 310/87	single blow	8	SW	Dry
22	PK22	878700	420100	Granite	Cut Slope/Non	55	50	1.00	N/A	N/A	N/A	single blow	4	MW	Dry
23	PK23	878223	429523	Mud Stone	Cut Slope/Non	70	20	2.70	000/00	025/20	056/45 106/89 225/46 312/64	single blow	8	Fresh	Dry
24	PK24	875276	422806	Granite	Cut Slope/Non	80	9	1.00	000/00	000/00	289/87 053/25 251/49 176/90	single blow	8	MW	Dry
25	PK25	877230	425520	Granite	Cut Slope/Non	45	8	0.00	000/00	000/00	050/60 065/88 125/75 225/60	many blows	10	Fresh	Flowing
26	PK26	875330	425780	Granite	Cut Slope/Non	80	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27	PK27	874750	425050	Granite	Cut Slope/Non	75	70	2.00	225/50	000/00	005/85 025/60 070/85 105/78	many blows	8	SW	Damp
28	PK28	874070	425570	Granite	Cut Slope/Non	70	30	1.00	N/A	N/A	N/A	many blows	8	Fresh	Dry
29	PK29	875320	421300	Granite	Cut Slope/Fail	30	25	1.20	000/00	000/00	213/50 337/70 125/70	many blows	3	MW	Flowing
30	PK30	871970	428200	Granite	Natural/Non	60	20	0.00	N/A	N/A	N/A	many blows	8	SW	Damp
31	PK31	870880	423090	Granite	Cut Slope/Non	85	35	0.00	000/00	000/00	000/00	nail	6	SW	Dry

Appendix Table 1 Slope characteristics obtained from field investigation (Continued)

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
32	PK32	870435	421425	Granite	Cut Slope/Fail	60	45	4.00	000/00	000/00	228/53 145/90 358/58	single blow	5	MW	Damp
33	PK33	870350	421600	Granite	Cut Slope/Non	60	25	0.00	000/00	000/00	270/72	pocket knife	8	MW	Damp
34	PK34	866420	423000	Granite	Cut Slope/Non	70	40	0.00	N/A	N/A	N/A	many blows	8	SW	Damp
35	PK35	863850	423400	Granite	Cut Slope/Fail	65	25	2.00	N/A	N/A	N/A	many blows	8	MW	Wet
36	PK36	878400	419200	Granite	Cut Slope/Fail	70	5	1.00	000/00	000/00	000/00	nail	4	MW	Damp
37	PK37	877210	418860	Granite	Cut Slope/Fail	65	6	1.00	000/00	000/00	000/00	pocket knife	4	CW	Damp
38	PK38	876700	419075	Granite	Cut Slope/Fail	70	12	1.00	000/00	000/00	000/00	many blows	4	MW	Damp
39	PK39	876570	419110	Granite	Cut Slope/Fail	70	10	1.00	000/00	000/00	000/00	many blows	4	MW	Damp
40	PK40	876360	419400	Granite	Cut Slope/Fail	65	9	1.00	000/00	000/00	195/40	single blow	8	MW	Damp
41	PK41	870800	423380	Granite	Cut Slope/Non	65	8	2.00	000/00	000/00	020/68 133/50 035/80 190/90 080/80 135/80	single blow	6	MW	Dripping
42	PK42	872800	424125	Granite	Natural/Fail	55	15	3.00	000/00	000/00	160/45 135/90 190/90 225/70 280/85	single blow	5	MW	Damp
43	PK43	870850	423700	Granite	Cut Slope/Non	65	15	3.00	150/50	000/00	090/90	pocket knife	8	MW	Damp
44	PK44	870650	423400	Granite	Cut Slope/Non	30	15	0.00	000/00	000/00	000/00	pocket knife	6	SW	Damp
45	PK45	894409	424903	Granite	Cut Slope/Non	45	17	2.50	000/00	000/00	088/48	many blows	8	SW	Damp
46	PK46	894618	424687	Granite	Cut Slope/Non	75	30	3.50	000/00	000/00	073/75	single blow	8	SW	Damp

Appendix Table 1 Slope characteristics obtained from field investigation (Continued)

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
47	PK47	871622	421253	Granite	Cut Slope/Fail	50	5	2.00	000/00	000/00	000/00	single blow	8	MW	Damp
48	PK48	871534	421160	Granite	Cut Slope/Non	45	6	2.00	000/00	000/00	000/00	many blows	8	SW	Damp
49	PK49	871500	420900	Granite	Cut Slope/Fail	65	4	2.00	000/00	000/00	000/00	single blow	8	MW	Damp
50	PK50	871459	420533	Granite	Cut Slope/Fail	50	5	1.50	000/00	000/00	000/00	single blow	8	MW	Damp
51	PK51	871650	420500	Granite	Cut Slope/Fail	45	4	2.00	000/00	000/00	000/00	single blow	8	MW	Damp
52	PK52	871552	420650	Granite	Cut Slope/Non	40	6	2.00	000/00	000/00	000/00	single blow	8	MW	Damp
53	PK53	872021	419685	Granite	Cut Slope/Non	50	8	1.50	000/00	000/00	225/50 342/73 088/65	many blows	5	MW	Dry
54	PK54	871959	419670	Granite	Cut Slope/Fail	45	4.5	2.00	000/00	000/00	000/00	many blows	4	MW	Dry
55	PK55	871881	419667	Granite	Cut Slope/Fail	45	6	2.00	000/00	000/00	000/00	nail	4	MW	Damp
56	PK56	876400	423150	Granite	Cut Slope/Fail	45	7	2.50	000/00	000/00	024/71 316/68 285/80 348/65 192/50 232/37	many blows	5	Fresh	Flowing
57	PK57	875681	422660	Granite	Cut Slope/Non	45	15	0.00	000/00	000/00	000/00	many blows	8	Fresh	Damp
58	PK58	869876	421058	Granite	Cut Slope/Fail	35	20	4.00	000/00	000/00	005/35 274/40 135/85 327/89 341/85	single blow	4	MW	Flowing
59	PK59	877455	422171	Granite	Cut Slope/Fail	65	12	2.00	000/00	000/00	227/20 247/20 300/90 005/55	single blow	6	SW	Damp

Appendix Table 1 Slope characteristics obtained from field investigation (Continued)

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
60	PK60	893550	423650	Granite	Cut Slope/Non	70	20	7.00	028/70 135/75 208/87	000/00	037/62 285/80 000/70 247/80 140/70	single blow	8	SW	Damp
61	PK61	892210	421650	Granite	Cut Slope/Non	55	18	2.50	000/00	000/00	000/00	single blow	8	SW	Damp
62	PK62	891193	423100	Granite	Cut Slope/Fail	45	35	N/A	N/A	N/A	N/A	single blow	8	MW	Damp
63	PK63	866700	432300	Mud Stone	Cut Slope/Non	75	25	2.50	xxx/145	108/15	115/90 218/83 255/85	pocket knife	6	Fresh	Dry
64	PK64	864200	433650	Mud Stone	Cut Slope/Non	65	10	N/A	N/A	N/A	N/A	pocket knife	8	SW	Damp
65	PK65	863250	434650	Mud Stone	Cut Slope/Non	60	35	N/A	N/A	N/A	N/A	pocket knife	8	SW	Damp
66	PK66	863900	432500	Mud Stone	Cut Slope/Non	75	23	1.50	000/00	225/35	125/70 183/90 259/42 109/50 043/78	many blows	4	Fresh	Damp
67	PK67	861459	422344	Granite	Cut Slope/Fail	60	15	1.00	000/00	000/00	250/77 193/70 245/60	pocket knife	4	MW	Damp
68	PK68	877600	426640	Granite	Cut Slope/Non	65	30	3.50	000/00	000/00	000/00	single blow	8	MW	Dry
69	PK69	877477	427027	Granite	Cut Slope/Non	65	8	3.00	000/00	000/00	000/00	single blow	8	MW	Damp
70	PK70	877431	427044	Granite	Cut Slope/Non	65	10	3.00	000/00	000/00	000/00	single blow	8	MW	Damp
71	PK71	877018	427424	Mud Stone	Cut Slope/Non	65	20	3.00	258/63 049/90 011/90 084/90	172/50	220/90 180/80	single blow	6	MW	Dry
72	PK72	877208	427584	Mud Stone	Cut Slope/Non	55	10	N/A	N/A	N/A	N/A	single blow	6	SW	Damp
73	PK73	877246	428056	Mud Stone	Cut Slope/Non	70	20	0.00	000/00	000/00	245/63 345/75	single blow	6	SW	Damp

Appendix Table 1 Slope characteristics obtained from field investigation (Continued)

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
74	PK74	874421	422964	Granite	Cut Slope/Fail	65	6	2.50	000/00	000/00	143/60 068/60 225/45 055/45	single blow	4	MW	Damp
75	PK75	872366	423631	Granite	Cut Slope/Fail	55	15	3.00	000/00	000/00	000/00	many blows	4	MW	Flowing
76	PK76	872480	423685	Granite	Cut Slope/Fail	50	20	4.50	010/20 232/75	000/00	285/77 185/50 230/20	many blows	4	SW	Damp
77	PK77	891543	421419	Granite	Cut Slope/Non	75	45	4.00	000/00	000/00	055/70 142/80 080/90 240/70 285/85	single blow	6	SW	Damp
78	PK78	891364	421488	Granite	Cut Slope/Non	75	20	3.00	000/00	000/00	055/70 142/80 080/90 240/70 285/85	single blow	6	SW	Damp
79	PK79	889448	420550	Granite	Cut Slope/Non	75	13	3.00	000/00	000/00	000/00	single blow	8	SW	Damp
80	PK80	889178	420594	Granite	Cut Slope/Non	75	10	2.50	000/00	000/00	000/00	single blow	8	SW	Damp
81	PK81	889746	422597	Granite	Cut Slope/Non	45	38	N/A	N/A	N/A	N/A	single blow	8	SW	Damp
82	PK82	887936	423160	Granite	Cut Slope/Non	45	40	N/A	N/A	N/A	N/A	many blows	8	SW	Damp
83	PK83	878459	432044	Granite	Cut Slope/Non	30	6	2.00	000/00	000/00	063/90 095/88 045/75 035/25 190/50 005/50	many blows	8	SW	Damp
84	PK84	877093	431184	Granite	Cut Slope/Non	75	6	3.50	000/00	000/00	000/00	many blows	8	SW	Dry

Appendix Table 1 Slope characteristics obtained from field investigation (Continued)

No.	STATION	N	E	ROCK	DESCRIPTION	SLOPE	SLOPE HEIGTH (m)	SOIL DEPTH (m)	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition
85	PK85	876928	431043	Granite	Cut Slope/Non	75	15	5.00	000/00	000/00	080/15 000/80 142/80	many blows	8	SW	Damp
86	PK86	876634	430878	Granite	Cut Slope/Non	65	10	3.50	000/00	000/00	080/15 000/80 142/80	many blows	8	SW	Damp
87	PK87	875161	430289	Mud Stone	Cut Slope/Non	85	29	2.00	090/86 165/60	000/00	210/80 266/80 357/75 100/20 170/65 325/50	many blows	6	SW	Damp

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR

No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
1	PK01	Granite	Natural/ Fail	000/00	000/00	000/00	single blow	4	MW	Wet	29	29.0
2	PK02	Granite& Mud Stone	Natural/ Fail	067/55	080/88	000/00	nail	4	HW	Wet	16	16.0
3	PK03	Granite	Cut Slope/Fail	000/00	000/00	025/45	nail	4	HW	Damp	19	18.1
4	PK04	Granite	Cut Slope/Non	N/A	N/A	N/A	single blow	6	SW	Dry	56	56.0
5	PK05	Mud Stone	Cut Slope/Non	000/00	000/00	000/00	many blows	8	Fresh	Dry	72	72.0
6	PK06	Mud Stone	Cut Slope/Fail	000/00	324/40	183/88 073/69 026/45 130/64 215/18	pocket knife	6	MW	Wet	27	23.8
7	PK07	Mud Stone	Cut Slope/Non	N/A	N/A	N/A	nail	8	MW	Dry	43	43.0
8	PK08	Mud Stone	Cut Slope/Non	N/A	N/A	N/A	nail	8	SW	Dry	48	48.0
9	PK09	Granite	Cut Slope/Non	N/A	N/A	N/A	many blows	8	SW	Dry	77	77.0
10	PK10	Granite	Cut Slope/Non	N/A	N/A	N/A	single blow	6	SW	Dry	53	53.0
11	PK11	Granite	Natural/Fail	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A
12	PK12	Granite	Natural/Fail	000/00	000/00	135/60 100/45 317/55	pocket knife	4	MW	Damp	31	30.1
13	PK13	Granite	Cut Slope/Fail	000/00	000/00	270/35 017/87 256/87	pocket knife	4	MW	Damp	31	24.6
14	PK14	Granite	Cut Slope/Fail	000/00	000/00	000/00	pocket knife	4	MW	Wet	26	26.0
15	PK15	Granite	Cut Slope/Fail	000/00	000/00	000/00	nail	4	MW	Wet	25	25.0

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
16	PK16	Granite	Cut Slope/Fail	000/00	000/00	000/00	nail	4	MW	Wet	25	25.0
17	PK17	Granite	Natural/Fail	000/00	000/00	000/00	nail	6	MW	Damp	31	31.0
18	PK18	Granite	Natural/Fail	000/00	000/00	248/73 175/35	pocket knife	6	MW	Flowing	23	16.6
19	PK19	Granite	Cut Slope/Fail	072/73	000/00	268/38 063/79	single blow	4	MW	Wet	33	26.6
20	PK20	Granite	Cut Slope/Fail	000/00	000/00	000/00	pocket knife	8	MW	Damp	34	34.0
21	PK21	Granite	Cut Slope/Non	000/00	000/00	225/63 310/87	single blow	8	SW	Dry	60	60.0
22	PK22	Granite	Cut Slope/Non	N/A	N/A	N/A	single blow	4	MW	Dry	40	40.0
23	PK23	Mud Stone	Cut Slope/Non	000/00	025/20	056/45 106/89 225/46 312/64	single blow	8	Fresh	Dry	60	56.4
24	PK24	Granite	Cut Slope/Non	000/00	000/00	289/87 053/25 251/49 176/90	single blow	8	MW	Dry	52	47.8
25	PK25	Granite	Cut Slope/Non	000/00	000/00	050/60 065/88 125/75 225/60	many blows	10	Fresh	Flowing	61	61.0
26	PK26	Granite	Cut Slope/Non	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27	PK27	Granite	Cut Slope/Non	225/50	000/00	005/85 025/60 070/85 105/78	many blows	8	SW	Damp	60	59.1
28	PK28	Granite	Cut Slope/Non	N/A	N/A	N/A	many blows	8	Fresh	Dry	70	70.0

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
29	PK29	Granite	Cut Slope/Fail	000/00	000/00	213/50 337/70 125/70	many blows	3	MW	Flowing	31	30.1
30	PK30	Granite	Natural/Non	N/A	N/A	N/A	many blows	8	SW	Damp	60	60.0
31	PK31	Granite	Cut Slope/Non	000/00	000/00	000/00	nail	6	SW	Dry	46	46.0
32	PK32	Granite	Cut Slope/Fail	000/00	000/00	228/53 145/90 358/58	single blow	5	MW	Damp	37	37.0
33	PK33	Granite	Cut Slope/Non	000/00	000/00	270/72	pocket knife	8	MW	Damp	42	42.0
34	PK34	Granite	Cut Slope/Non	N/A	N/A	N/A	many blows	8	SW	Damp	60	60.0
35	PK35	Granite	Cut Slope/Fail	N/A	N/A	N/A	many blows	8	MW	Wet	47	47.0
36	PK36	Granite	Cut Slope/Fail	000/00	000/00	000/00	nail	4	MW	Damp	28	28.0
37	PK37	Granite	Cut Slope/Fail	000/00	000/00	000/00	pocket knife	4	CW	Damp	22	22.0
38	PK38	Granite	Cut Slope/Fail	000/00	000/00	000/00	many blows	4	MW	Damp	37	37.0
39	PK39	Granite	Cut Slope/Fail	000/00	000/00	000/00	many blows	4	MW	Damp	37	37.0
40	PK40	Granite	Cut Slope/Fail	000/00	000/00	195/40	single blow	8	MW	Damp	45	26.9
41	PK41	Granite	Cut Slope/Non	000/00	000/00	020/68 133/50 035/80 190/90 080/80 135/80	single blow	6	MW	Dripping	32	31.1

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
42	PK42	Granite	Natural/Fail	000/00	000/00	160/45 135/90 190/90 225/70 280/85	single blow	5	MW	Damp	38	37.1
43	PK43	Granite	Cut Slope/Non	150/50	000/00	090/90	pocket knife	8	MW	Damp	42	41.1
44	PK44	Granite	Cut Slope/Non	000/00	000/00	000/00	pocket knife	6	SW	Damp	50	50.0
45	PK45	Granite	Cut Slope/Non	000/00	000/00	088/48	many blows	8	SW	Damp	60	59.1
46	PK46	Granite	Cut Slope/Non	000/00	000/00	073/75	single blow	8	SW	Damp	55	55.0
47	PK47	Granite	Cut Slope/Fail	000/00	000/00	000/00	single blow	8	MW	Damp	45	45.0
48	PK48	Granite	Cut Slope/Non	000/00	000/00	000/00	many blows	8	SW	Damp	60	60.0
49	PK49	Granite	Cut Slope/Fail	000/00	000/00	000/00	single blow	8	MW	Damp	45	45.0
50	PK50	Granite	Cut Slope/Fail	000/00	000/00	000/00	single blow	8	MW	Damp	50	50.0
51	PK51	Granite	Cut Slope/Fail	000/00	000/00	000/00	single blow	8	MW	Damp	45	45.0
52	PK52	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	MW	Damp	50	50.0
53	PK53	Granite	Cut Slope/Non	000/00	000/00	225/50 342/73 088/65	many blows	5	MW	Dry	48	47.1
54	PK54	Granite	Cut Slope/Fail	000/00	000/00	000/00	many blows	4	MW	Dry	53	53.0
55	PK55	Granite	Cut Slope/Fail	000/00	000/00	000/00	nail	4	MW	Damp	28	28.0

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
56	PK56	Granite	Cut Slope/Fail	000/00	000/00	024/71 316/68 285/80 348/65 192/50 232/37	many blows	5	Fresh	Flowing	51	44.6
57	PK57	Granite	Cut Slope/Non	000/00	000/00	000/00	many blows	8	Fresh	Damp	68	68.0
58	PK58	Granite	Cut Slope/Fail	000/00	000/00	005/35 274/40 135/85 327/89 341/85	single blow	4	MW	Flowing	25	18.6
59	PK59	Granite	Cut Slope/Fail	000/00	000/00	227/20 247/20 300/90 005/55	single blow	6	SW	Damp	48	44.4
60	PK60	Granite	Cut Slope/Non	028/70 135/75 208/87	000/00	037/62 285/80 000/70 247/80 140/70	single blow	8	SW	Damp	57	57.0
61	PK61	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	SW	Damp	50	50.0
62	PK62	Granite	Cut Slope/Fail	N/A	N/A	N/A	single blow	8	MW	Damp	45	45.0
63	PK63	Mud Stone	Cut Slope/Non	xxx/145	108/15	115/90 218/83 255/85	pocket knife	6	Fresh	Dry	55	53.7
64	PK64	Mud Stone	Cut Slope/Non	N/A	N/A	N/A	pocket knife	8	SW	Damp	47	47.0
65	PK65	Mud Stone	Cut Slope/Non	N/A	N/A	N/A	pocket knife	8	SW	Damp	47	47.0

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

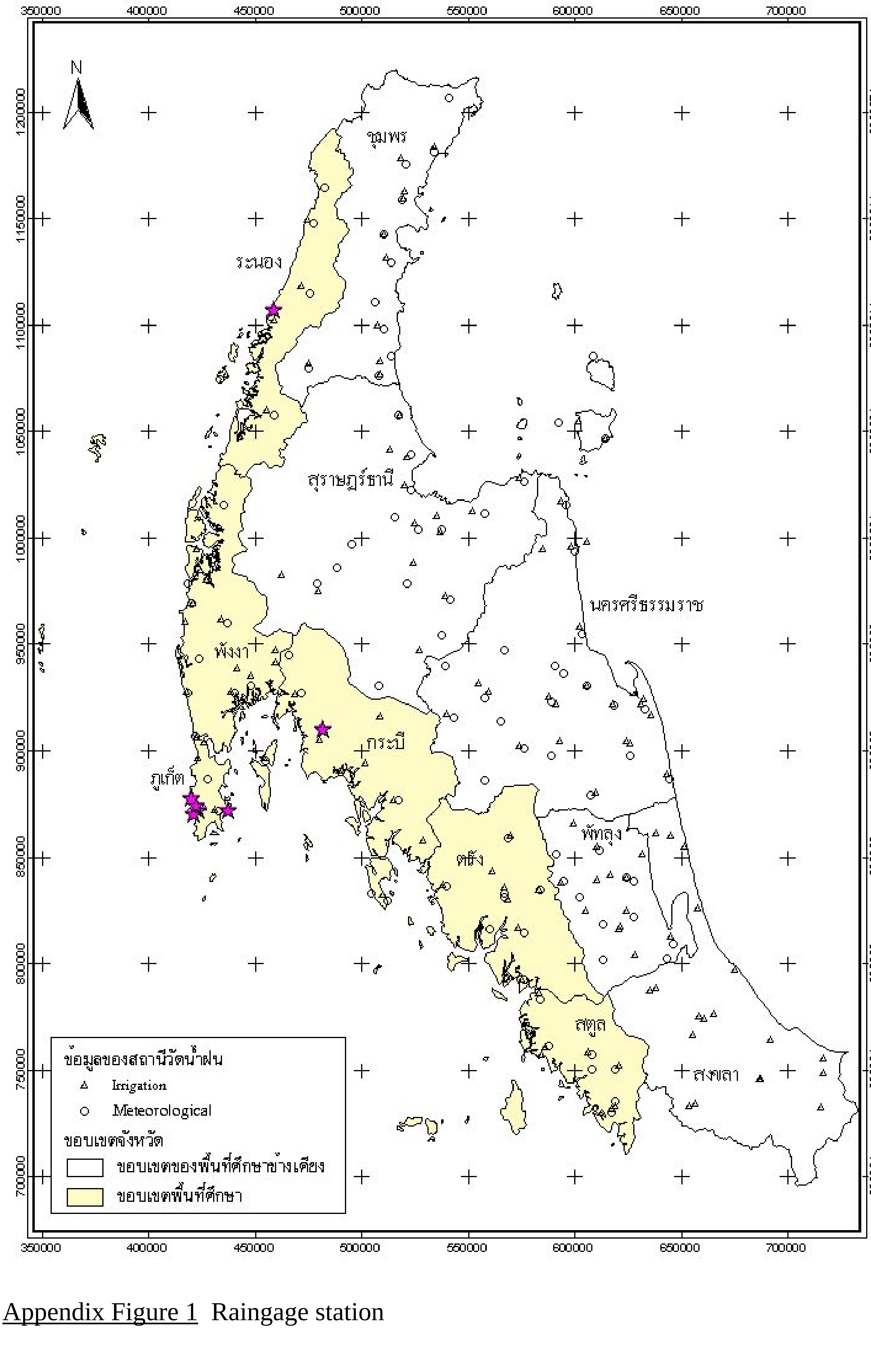
No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
66	PK66	Mud Stone	Cut Slope/Non	000/00	225/35	125/70 183/90 259/42 109/50 043/78	many blows	4	Fresh	Damp	55	25.3
67	PK67	Granite	Cut Slope/Fail	000/00	000/00	250/77 193/70 245/60	pocket knife	4	MW	Damp	32	32.0
68	PK68	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	MW	Dry	52	52.0
69	PK69	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	MW	Damp	47	47.0
70	PK70	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	MW	Damp	47	47.0
71	PK71	Mud Stone	Cut Slope/Non	258/63 049/90 011/90 084/90	172/50	220/90 180/80	single blow	6	MW	Dry	43	42.1
72	PK72	Mud Stone	Cut Slope/Non	N/A	N/A	N/A	single blow	6	SW	Damp	48	48.0
73	PK73	Mud Stone	Cut Slope/Non	000/00	000/00	245/63 345/75	single blow	6	SW	Damp	48	48.0
74	PK74	Granite	Cut Slope/Fail	000/00	000/00	143/60 068/60 225/45 055/45	single blow	4	MW	Damp	32	31.1
75	PK75	Granite	Cut Slope/Fail	000/00	000/00	000/00	many blows	4	MW	Flowing	30	30.0
76	PK76	Granite	Cut Slope/Fail	010/20 232/75	000/00	285/77 185/50 230/20	many blows	4	SW	Damp	46	42.4

Appendix Table 2 Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

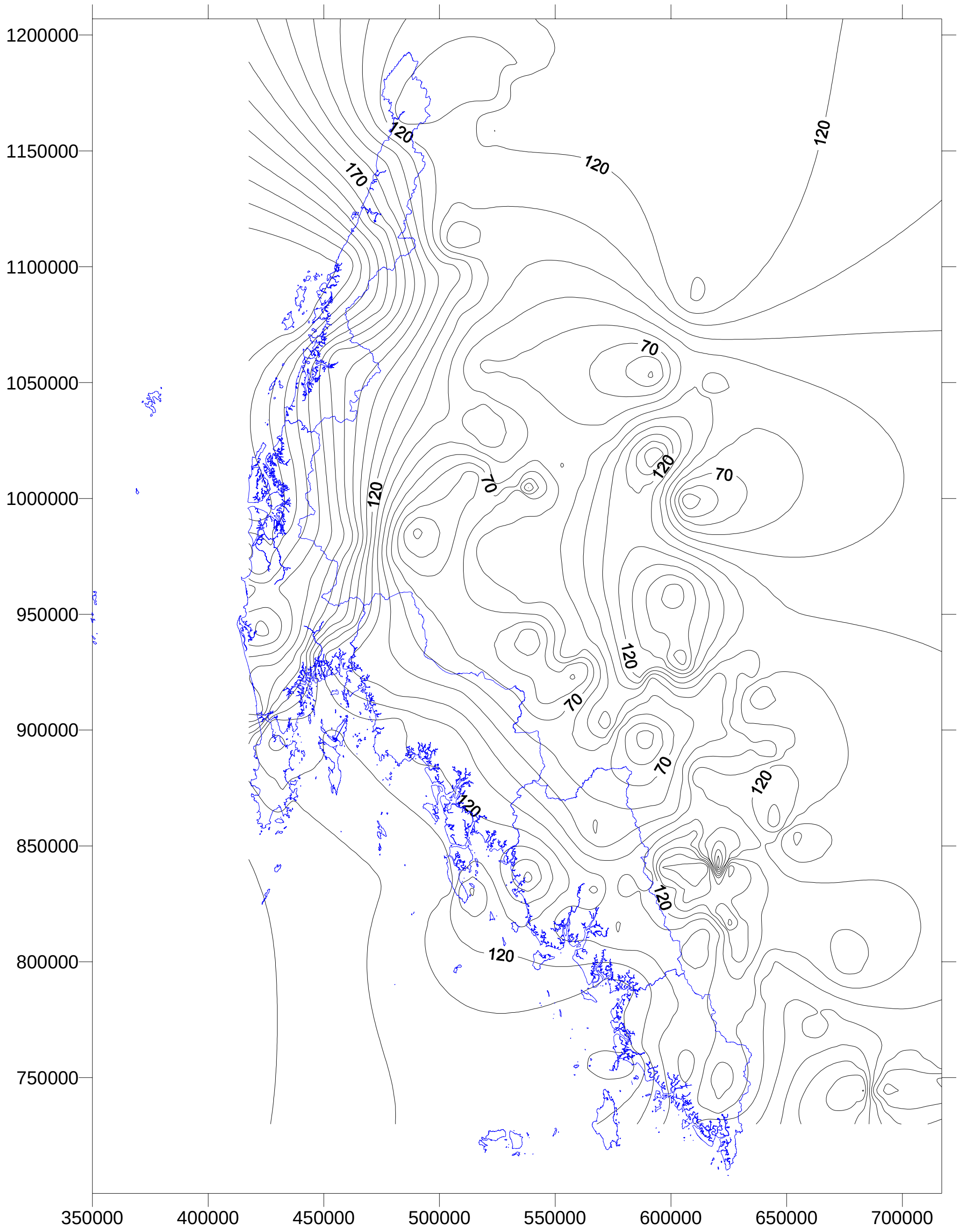
No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
77	PK77	Granite	Cut Slope/Non	000/00	000/00	055/70 142/80 080/90 240/70 285/85	single blow	6	SW	Damp	48	48.0
78	PK78	Granite	Cut Slope/Non	000/00	000/00	055/70 142/80 080/90 240/70 285/85	single blow	6	SW	Damp	48	48.0
79	PK79	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	SW	Damp	57	57.0
80	PK80	Granite	Cut Slope/Non	000/00	000/00	000/00	single blow	8	SW	Damp	57	57.0
81	PK81	Granite	Cut Slope/Non	N/A	N/A	N/A	single blow	8	SW	Damp	57	57.0
82	PK82	Granite	Cut Slope/Non	N/A	N/A	N/A	many blows	8	SW	Damp	55	55.0
83	PK83	Granite	Cut Slope/Non	000/00	000/00	063/90 095/88 045/75 035/25 190/50 005/50	many blows	8	SW	Damp	69	65.4
84	PK84	Granite	Cut Slope/Non	000/00	000/00	000/00	many blows	8	SW	Dry	77	77.0
85	PK85	Granite	Cut Slope/Non	000/00	000/00	080/15 000/80 142/80	many blows	8	SW	Damp	72	70.7

<u>Appendix Table 2</u> Slope characteristics obtained from field investigation for evaluated RMR and SMR (Continued)

No.	STATION	ROCK	DESCRIPTION	FAULT	BEDDING	FRACTURE	Field Estimate Rock Strength	Joint Spacing (cm)	Weathering	Ground Water Condition	RMR	SMR
86	PK86	Granite	Cut Slope/Non	000/00	000/00	080/15 000/80 142/80	many blows	8	SW	Damp	68	66.7
87	PK87	Mud Stone	Cut Slope/Non	090/86 165/60	000/00	210/80 266/80 357/75 100/20 170/65 325/50	many blows	6	SW	Damp	63	53.4

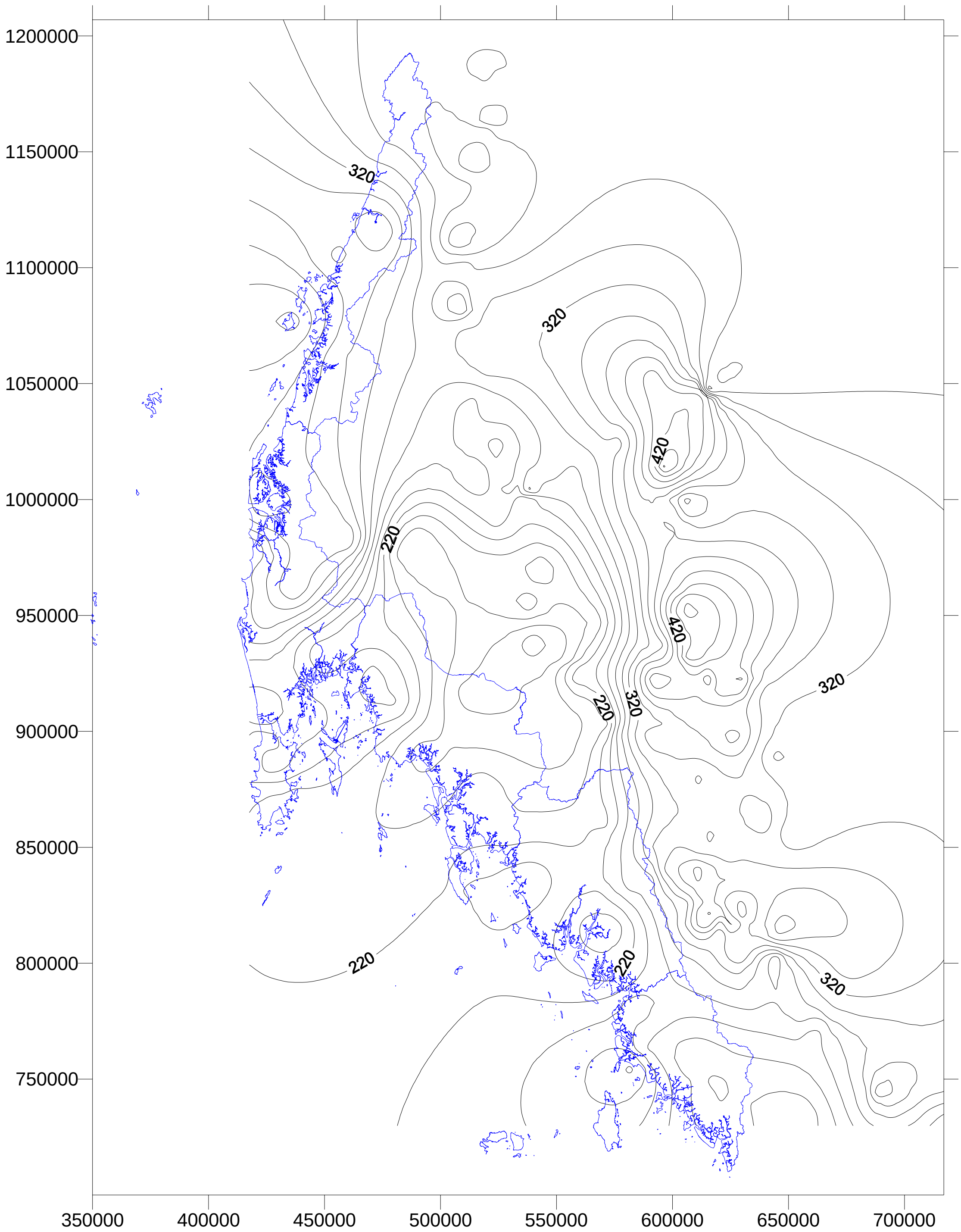


Appendix Figure 1 Raingage station



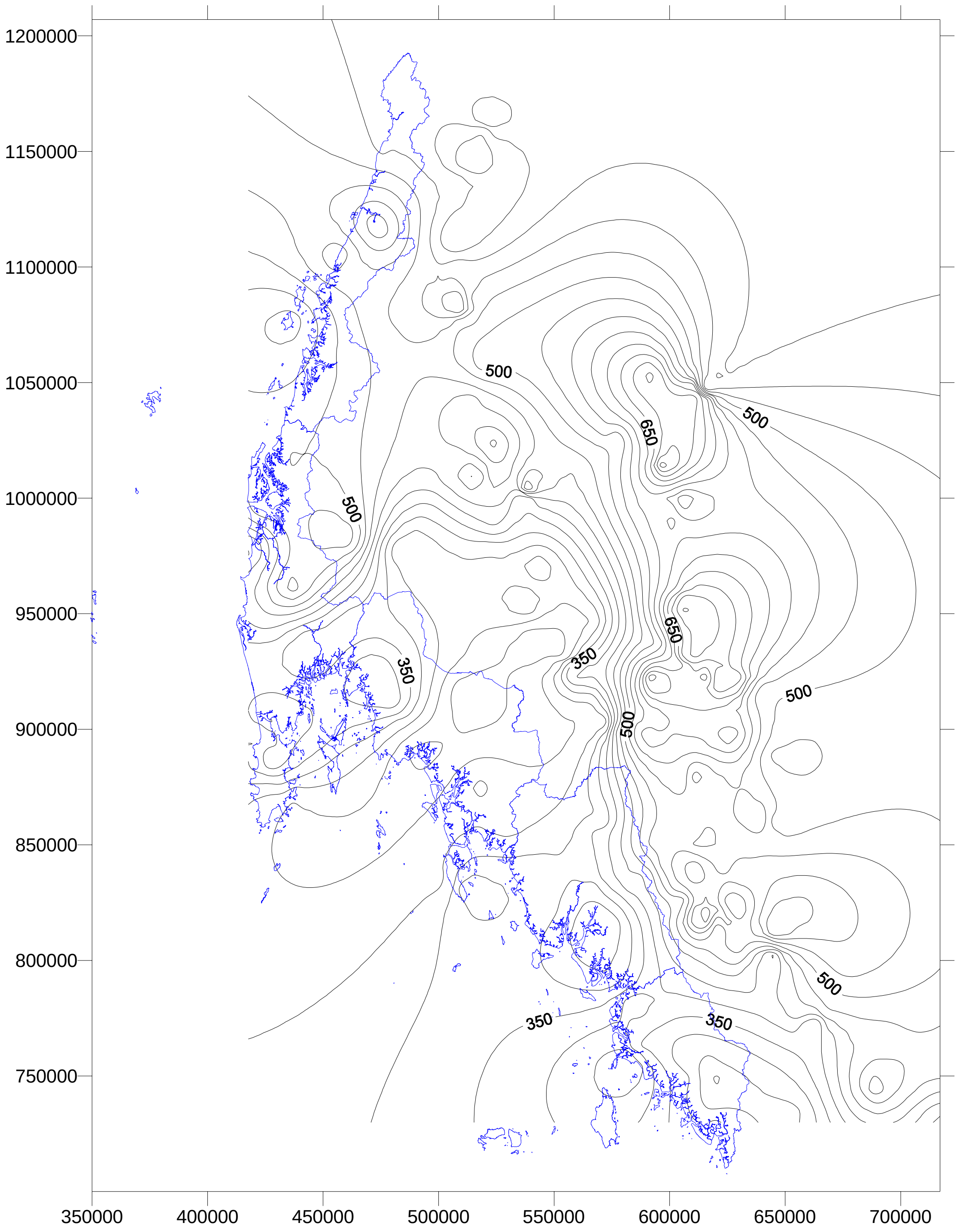
Contour Interval : 10 mm.

Appendix Figure 2 Cumulative rainfall intensity 3 days contour return period 1 years



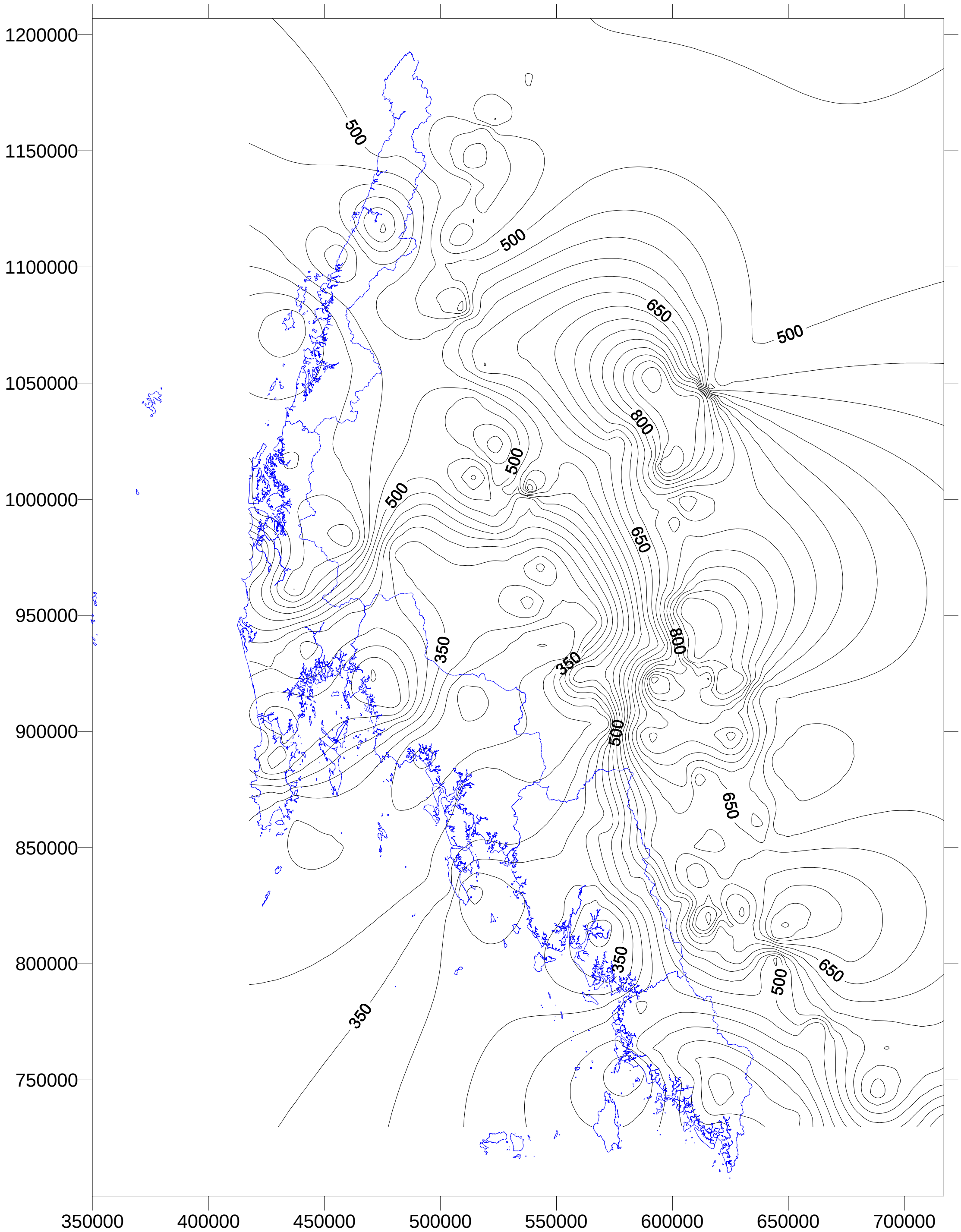
Contour Interval : 20 mm.

<u>Appendix Figure 3</u> Cumulative rainfall intensity 3 days contour return period 5 years

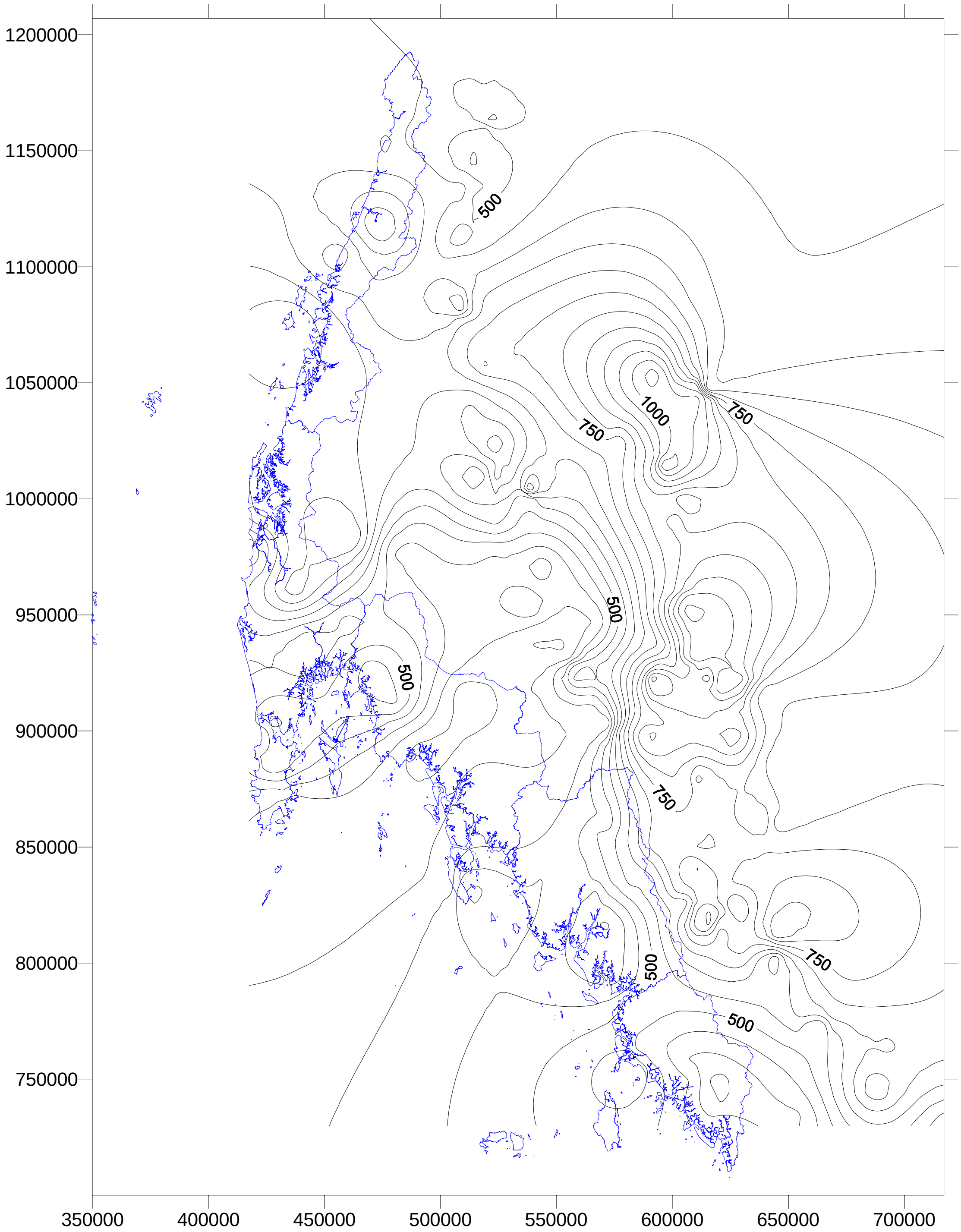


Contour Interval : 30 mm.

Appendix Figure 4 Cumulative rainfall intensity 3 days contour return period 20 years



Appendix Figure 5 Cumulative rainfall intensity 3 days contour return period 50 years



Contour Interval : 50 mm.

Appendix Figure 6 Cumulative rainfall intensity 3 days contour return period 100 years

Appendix Table 3 Conclusion of result USCS, Aterberg's limits, sieve analysis and direct shear test, Phuket
Source: Department of mineral resource (2006)

Position No.	Boring No.	USCS	Atterberg's Test			Sieve Analysis Test								Direct Shear Test			% Reduction of Shear strength τl
			LL	PL	PI	3/8"	#4	#8	#10	#30	#50	#100	#200	Initial water content Max. Shear Stress ksc.	Wet Soil Max. Shear Stress ksc.	SRI	
Phuket	SPK 2		26.60	17.29	9.31												
	SPK 02		24.69	15.80	8.89												
	SPK 03	ML	40.50	32.77	7.73	100.00	79.27	74.41	73.58	68.20	64.84	60.03	55.29	0.592	0.418	1.416	29
	SPK 03		42.17	20.49	21.68												
	SPK 03			NP													
	SPK 03		44.24	32.89	11.35												
	SPK 3					100.00	92.44	71.22	66.03	41.95	31.76	24.42	19.51				
	SPK 04			NP													
	SPK 04			NP													
	SPK 04			NP													
	SPK 06	SM		NP		100.00	99.65	98.74	97.84	88.01	82.65	74.88	68.26				
	SPK 07	SM		NP		100.00	98.20	83.07	77.44	46.88	35.71	25.79	18.67				
	SPK 09	SM		NP		100.00	88.44	74.18	69.05	42.16	33.22	25.98	20.75	0.658	0.460	1.430	30
	SPK 12	SM		NP		100.00	93.73	85.81	83.35	64.69	54.00	43.63	35.46	0.594	0.451	1.317	24
	SPK 13	SM		NP		100.00	96.13	79.86	76.70	65.33	60.34	54.35	48.99				
	SPK 14					100.00	88.50	70.16	66.33	49.69	43.52	37.49	32.28				
	SPK 18	SC	45.09	25.98	19.10	100.00	81.42	57.00	53.79	47.33	48.70	47.57	44.18	0.456	0.317	1.438	31
	SPK 20	MH	58.51	47.60	10.91	100.00	95.32	82.22	77.84	54.85	47.77	42.95	40.24				
	SPK 20	CL	34.85	16.21	18.64	100.00	98.53	97.02	96.57	77.60	61.15	49.19	40.73				
	SPK 20	SM		NP		100.00	98.00	88.13	83.96	52.47	38.21	27.97	20.92				
	SPK 20	SM		NP		100.00	97.96	96.56	96.00	72.79	51.73	38.13	30.25				
	SPK 20					100.00	99.94	99.00	98.64	83.02	70.31	62.26	55.81				
	SPK 20					100.00	89.68	72.78	67.62	39.19	30.73	25.64	22.64				
	SPK 21	SM		NP		100.00	93.36	83.92	79.27	42.04	29.42	22.98	19.88	0.423	0.389	1.087	8
	SPK 23	SM		NP		100.00	35.45	27.97	26.77	20.87	18.60	16.78	14.74	0.819	0.512	1.600	37
	SPK 24	SM		NP		100.00	100.00	99.82	99.66	88.13	60.43	38.74	26.66	0.391	0.619	0.632	37
	SPK 27	SM		NP		100.00	98.08	83.52	78.31	53.79	44.87	37.92	32.63				
	SPK 27	SM		NP		100.00	89.82	72.35	66.81	34.96	24.41	17.76	13.85				
	SPK 27					100.00	98.20	83.07	77.44	46.88	35.71	25.79	18.67				
	SPK 28	SM		NP		100.00	99.95	93.14	89.04	65.32	57.26	50.13	43.87	0.643	0.385	1.670	40
	SPK 29	SM		NP		100.00	99.46	97.67	96.16	69.98	49.79	34.61	25.87				
	SPK 32	SM		NP		100.00	99.19	93.64	89.13	48.05	32.67	22.28	16.47				
	SPK 32	CL	37.41	21.45	15.96	100.00	99.45	93.61	88.11	63.95	56.16	48.45	42.87				
	SPK 32.2			NP													
	SPK 32	CL	33.98	21.35	12.63	100.00	100.00	99.51	98.98	84.80	67.66	55.95	49.61				
	SPK 33	SM		NP		100.00	97.78	85.76	79.00	39.67	29.17	22.18	17.62				
	SPK 35													0.433	0.353	1.227	18
	SPK 40	SC	36.23	24.33	11.90	100.00	94.36	79.59	75.38	52.81	42.94	35.09	29.99	0.505	0.312	1.619	38
	SPK 41	SM		NP		100.00	82.99	60.00	54.72	34.83	27.81	22.43	18.63				
	SPK 42			NP		100.00	98.41	86.27	81.72	54.21	43.02	32.70	25.99				
	SPK 55	SM		NP		100.00	97.00	81.08	76.43	55.34	48.64	44.10	41.18	0.480	0.131	3.664	73
	SPK 58	CL	41.72	20.69	21.03	100.00	100.00	99.87	99.72	85.50	69.30	58.11	52.31	0.595	0.320	1.859	46
	SPK 60	SM		NP		100.00	95.83	81.50	76.36	45.61	34.41	29.27	23.90				
	SPK 63		38.65	33.18	5.47	100.00	97.86	95.81	95.31	90.72	85.48	75.57	67.17	0.496	0.468	1.060	6
	SPK 67	SM		NP		100.00	73.39	47.29	42.01	19.26	12.41	8.52	6.35				
	SPK 70			NP		100.00	94.14	82.52	79.48	61.94	53.11	44.19	36.24				
	SPK 71	SM		NP		100.00	99.80	97.69	96.43	77.36	63.12	49.65	39.14	0.550	0.437	1.259	21
	SPK 74		31.76	21.64	10.11												
	SPK 74	ML	44.61	25.84	18.77	100.00	95.38	89.08	87.48	71.18	60.57	53.67	48.65				
	SPK 74	ML	26.96	23.51	3.45	100.00	99.76	99.28	98.84	86.56	64.66	48.39	38.85				
	SPK 74	ML	25.36	22.09	3.27	100.00	98.47	96.14	95.62	77.29	53.07	38.42	31.74				
	SPK 74	SM		NP		100.00	99.60	98.89	98.62	80.31	55.54	35.12	23.81				
	SPK 74			NP													
	SPK 76	SM		NP		100.00	99.58	92.19	87.44	57.56	46.42	37.93	31.95				
	SPK 76	SM		NP		100.00	93.95	86.74	84.10	62.36	50.87	41.72	35.56				
	SKP 76					100.00	99.01	93.65	90.09	52.58	36.92	26.43	19.64				
	SKP 76					100.00	98.21	88.79	84.41	55.41	41.99	31.75	24.23				
	SPK 77													0.491	0.301	1.631	39

Appendix Table 4 Consistency index of soil following parent rock type

Rang Consistent	Rock Type	PI	Wet Sieve Analysis	USCS	% 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%

Source: Department of mineral resource (2006)

Appendix Table 5 Data failure slope condition for regression analysis

No.	STATION	CONDITION	ROCKTYPE	LINEAMENT	SLOPE (degree)	ELEVATION m.	DRAINAGE	LANDUSE	SOILTEXTURE	ENGINEERING	INTENSITY_001 mm.	INTENSITY_100 mm.	RMR	SMR
1	PK03	Fail	5	1	28	72.93	1	3	3	4	135	387.5	19	18.10
2	PK06	Fail	4	1	27	61.51	4	4	2	3	135	362.5	27	23.81
3	PK13	Fail	5	1	18	277.14	1	3	3	4	135	462.5	31	24.63
4	PK14	Fail	5	1	15	270.49	1	3	3	4	135	462.5	26	26.00
5	PK15	Fail	5	1	27	339.69	1	1	3	4	135	462.5	25	25.00
6	PK16	Fail	5	1	14	389.57	4	1	3	4	135	462.5	25	25.00
7	PK19	Fail	5	1	24	90.92	1	4	3	4	135	437.5	33	26.63
8	PK20	Fail	5	5	27	41.96	4	4	3	4	135	437.5	34	34.00
9	PK29	Fail	5	1	22	89.82	1	1	3	4	135	412.5	31	30.10
10	PK32	Fail	5	1	29	64.01	1	3	3	4	145	362.5	37	37.00
11	PK36	Fail	5	1	27	57.30	1	4	2	4	135	437.5	28	28.00
12	PK37	Fail	5	1	23	116.64	1	1	3	4	135	412.5	22	22.00
13	PK38	Fail	5	1	23	161.43	1	4	3	4	135	412.5	37	37.00
14	PK39	Fail	5	1	16	144.66	1	4	3	4	135	412.5	37	37.00
15	PK40	Fail	5	5	14	39.90	1	4	3	4	135	412.5	45	26.94
16	PK47	Fail	5	1	18	49.23	1	4	2	4	145	387.5	45	45.00
17	PK49	Fail	5	1	12	86.85	1	1	3	4	145	387.5	45	45.00
18	PK50	Fail	5	1	6	64.22	1	4	3	4	145	387.5	50	50.00
19	PK51	Fail	5	1	7	43.45	1	4	3	4	145	387.5	45	45.00
20	PK54	Fail	5	1	24	31.18	1	3	3	4	145	387.5	53	53.00
21	PK55	Fail	5	1	25	30.29	1	3	2	4	145	387.5	28	28.00
22	PK56	Fail	5	5	29	300.00	1	4	3	4	135	412.5	51	44.63
23	PK58	Fail	5	1	13	32.80	1	3	3	4	145	362.5	25	18.63
24	PK59	Fail	5	5	28	20.00	4	1	3	4	135	437.5	48	44.40
25	PK67	Fail	5	1	24	99.47	1	4	3	4	145	337.5	32	32.00
26	PK74	Fail	5	1	25	138.76	4	1	3	4	135	387.5	32	31.10
27	PK75	Fail	5	5	15	68.98	1	4	3	4	135	387.5	30	30.00
28	PK76	Fail	5	5	21	65.05	1	4	3	4	135	387.5	46	42.40

Appendix Table 6 Data non-failure slope condition for regression analysis

No.	STATION	CONDITION	ROCKTYPE	LINEAMENT	SLOPE	ELEVATION	DRAINAGE	LANDUSE	SOILTEXTURE	ENGINEERING	INTENSITY_001	INTENSITY_100	RMR	SMR
					(degree)	m.					mm.	mm.		
1	PK05	No Fail	4	1	33	34.72	1	3	2	3	135	337.5	72	72.00
2	PK21	No Fail	5	1	25	112.33	1	4	3	4	135	437.5	60	60.00
3	PK23	No Fail	5	5	28	109.37	1	4	3	4	125	437.5	60	56.40
4	PK24	No Fail	5	1	37	229.65	1	1	3	4	135	412.5	52	47.80
5	PK25	No Fail	5	5	19	168.97	1	1	3	4	135	437.5	61	61.00
6	PK27	No Fail	5	1	19	201.84	4	1	3	4	135	387.5	60	59.10
7	PK31	No Fail	5	1	16	95.74	4	4	3	4	135	362.5	46	46.00
8	PK33	No Fail	5	1	25	66.54	1	4	3	4	145	362.5	42	42.00
9	PK41	No Fail	5	5	11	140.00	4	4	3	4	135	362.5	32	31.10
10	PK43	No Fail	5	1	20	181.73	4	4	3	4	135	362.5	42	41.10
11	PK44	No Fail	5	1	20	140.54	1	4	3	4	135	362.5	50	50.00
12	PK45	No Fail	5	1	13	61.83	4	4	3	4	125	487.5	60	59.10
13	PK46	No Fail	5	1	23	71.57	1	1	3	4	125	487.5	55	55.00
14	PK48	No Fail	5	1	23	62.55	1	1	2	4	145	387.5	60	60.00
15	PK52	No Fail	5	1	16	60.00	1	1	3	4	145	387.5	50	50.00
16	PK53	No Fail	5	1	20	20.20	1	3	3	4	145	387.5	48	47.10
17	PK57	No Fail	5	1	17	162.61	4	4	3	4	135	412.5	68	68.00
18	PK60	No Fail	5	5	18	40.00	4	4	3	4	125	487.5	57	57.00
19	PK61	No Fail	0	5	22	109.64	1	4	0	0	125	487.5	50	50.00
20	PK63	No Fail	4	5	22	43.59	4	3	2	3	135	337.5	55	53.65
21	PK66	No Fail	4	1	30	102.78	1	4	2	3	145	312.5	55	25.25
22	PK68	No Fail	5	1	23	100.00	1	4	3	4	135	437.5	52	52.00
23	PK69	No Fail	4	5	31	108.09	1	1	2	3	135	437.5	47	47.00
24	PK70	No Fail	4	5	25	101.34	4	1	2	3	135	437.5	47	47.00
25	PK71	No Fail	4	5	9	60.00	4	4	2	3	135	437.5	43	42.10
26	PK73	No Fail	4	5	17	94.62	4	4	2	3	135	437.5	48	48.00
27	PK77	No Fail	5	5	22	121.50	1	4	3	4	125	487.5	48	48.00
28	PK78	No Fail	5	1	19	117.78	1	4	3	4	125	487.5	48	48.00

Appendix Table 6 Data non-failure slope condition for regression analysis (Continued)

No.	STATION	CONDITION	ROCKTYPE	LINEAMENT	SLOPE	ELEVATION	DRAINAGE	LANDUSE	SOILTEXTURE	ENGINEERING	INTENSITY_001	INTENSITY_100	RMR	SMR
					(degree)	m.					mm.	mm.		
29	PK79	No Fail	5	1	20	73.63	1	4	2	4	135	487.5	57	57.00
30	PK80	No Fail	5	1	23	44.62	4	4	2	4	135	487.5	57	57.00
31	PK83	No Fail	5	5	10	38.31	4	4	1	4	125	437.5	69	65.40
32	PK84	No Fail	5	1	30	74.98	1	4	3	4	125	437.5	77	77.00
33	PK85	No Fail	5	1	20	99.50	1	4	3	4	125	437.5	72	70.65
34	PK86	No Fail	5	1	22	102.70	1	4	3	4	125	437.5	68	66.65
35	PK87	No Fail	5	5	34	92.24	1	4	3	4	135	412.5	63	53.40

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