การประเมินศักยภาพของการเกิดแผ่นดินถล่ม บริเวณจังหวัดภูเก็ต

นางสาว หทัยทิพย์ ทัศนภักดิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2544

ISBN 974-03-0600-4

POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Miss Hathaithip Thassanapak

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Geology

Department of Geology

Faculty of Science

Chulalongkorn University

Academic Year 2001

ISBN 974-03-0600-4

Thesis Title	Potential Landslide Assessment of Changwat Phuket
By	Miss Hathaithip Thassanapak
Department	Geology
Thesis Advisor	Associate Professor Chaiyudh Khantaprab, Ph.D.
Thesis Co-advisor	Assistant Professor Sombat Yumuang, M.Sc.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master 's Degree

……………………………………………….. Dean of Faculty of Science
(Associate Professor Wanchai Phothiphichitr, Ph.D.)

THESIS COMMITTEE

……………………………………………….. Chairman
(Assistant Professor Somchai Nakapadungrat, Ph,D.)

……………………………………………….. Thesis Advisor
(Associate Professor Chaiyudh Khantaprab, Ph.D.)

……………………………………………….. Thesis Co-advisor
(Assistant Professor Sombat Yumuang, M.Sc.)

……………………………………………….. Member
(Assistant Professor Nopadon Muangnoicharoen, Ph.D.)

……………………………………………….. Member
(Associate Professor Kittitep Fuenkajorn, Ph.D.)

หทัยทิพย์ ทัศนภักดิ์ : การประเมินศักยภาพของการเกิดแผ่นถล่ม บริเวณจังหวัดภูเก็ต. (POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET) อ. ที่ปรึกษา : รศ.ดร. ชัยยุทธ ขันทปราบ, อ.ที่ปรึกษาร่วม : ผศ. สมบัติ อยู่เมือง 120 หน้า. ISBN 974-03-0600-4.

การประเมินศักยภาพการเกิดแผ่นดินถล่มอาศัยปัจจัยที่มีอิทธิพลต่อการเกิด ประกอบด้วย ลักษณะทางธรณีวิทยา(ชนิดหินและบริเวณกลุ่มรอยแตก) สภาพภูมิประเทศ(ความลาดชันและระดับความสูง) ระยะจากบริเวณน้ำผิวดิน การใช้ประโยชน์ที่ดิน คุณลักษณะของดิน และปริมาณฝน โดยนำเทคนิคการถ่วงน้ำหนักปัจจัยหาค่าความสัมพันธ์เชิงพื้นที่ แบ่งระดับโอกาสที่จะเกิดแผ่นดินถล่มได้เป็น 5 ระดับ คือ สูงที่สุด สูง ปานกลาง ต่ำ และต่ำมากจนถึงไม่มีโอกาสเกิดผลการศึกษาแสดงแทนในรูปแผนที่แสดงระดับศักยภาพของการเกิดแผ่นดินถล่ม พบว่าบริเวณที่ตั้งของโรงแรมและรีสอร์ทที่สำคัญหลายแห่ง ตั้งอยู่บริเวณที่มีระดับความเสี่ยงสูงถึงสูงมาก

ภาควิชา...... ธรณีวิทยา.......	ลายมือชื่อนิสิต...
สาขาวิชา..... ธรณีวิทยา.......	ลายมือชื่ออาจารย์ที่ปรึกษา......................................
ปีการศึกษา..... 2544..........	ลายมือชื่ออาจารย์ทีปรึกษาร่วม................................

4172522323 : MAJOR GEOLOGY

KEY WORD: PHUKET / LANDSLIDE ASSESSMENT/ NATURAL HAZARD / WEIGHT-RATING

HATHAITHIP THASSANAPAK: POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET. THESIS ADVISOR : ASSOC.PROF.CHAIYUDH KHANTAPRAB,Ph.D.,THESIS COADVISOR ASSIST.PROF.SOMBAT YUMAUNG,120 pp. ISBN 974-03-0600-4.

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The landslide assessment has been undertaken using the influencing parameters of geology including rock types and lineament zone, landform including slope gradient and elevation, surface drainage zone, land use and land cover, soil characteristics, and rainfall intensity. The relationship between these parameters and the spatial data are evaluated using the proposed weight-rating technique. Finally, the landslide potential map has been prepared against the socio-economic and physical environmental setting of the Phuket Island. Different degrees of susceptibility to landslide have been evaluated and illustrated in the landslide potential map. The findings of the present study reveal that most of the potential areas to be affected by very high and high susceptibility to landslide include the famous tourist resorts.

Departmen………..Geology………. Student's signature..

Field of study……..Geology………. Advisor's signature..

Academic year……..2001………… Co-advisor's signature..

ACKNOWLEDGMENT

The author wishes to express her profound gratitude and sincere appreciation to her advisor, Assoc.Prof.Dr. Chaiyudh Khantaprap for his invaluable guidance, encouragement, and constructive her criticism, throughout this study.

Appreciation for the assistance and support is extended to Assist. Prof. Sombat Yoomuang, the thesis co-advisor.

She is indebted to Mr.Naramase Teerarungsikul, Mr.Kasame Lekngam, Mr.Santi Sricham, and Mr.Pitsanupong Karnjanapayon for the assistance and support during the field investigation.

Special thanks are due to the staff of GisThai.com for their technical support. In addition, sincere thanks are also extended to all my friends for their encouragement and assistance in various aspects throughout the course of the study.

Last but not least, her respect and love are expressed to her parents for their continuous encouragement, and financial support, without which the study is almost impossible.

CONTENTS

PAGE

LIST OF FIGURES

Figure Page

Figure	Page

Figure | Page

LIST OF TABLES

Table | Page

CHAPTER I

INTRODUCTION

Generally, natural hazards are often responsible for loss of human life, property damage and environmental damage. The frequency of major disasters appears to have increased since 1960 (Bennett and Doyle, 1999). According to the Office of the United Nations Disaster Relief Coordinator, UNDRO, approximately 90 per cent of all reported natural hazards occur in Third World countries (Hashizume, 1989). The level of damages seems to be increasing. It has been estimated that in the last 25 years, more than of three million people have been killed and over US$ 1,000 billion worth of damage (Bennett and Doyle, 1999). Economic losses attributable to natural hazards in developing countries may represent as much as 1 to 2 per cent of the gross national product, GNP (van Westen, 1994). These statistics illustrate well the importance of hazard mitigation. Therefore, the 1990's has been proclaimed as the International Decade for Natural Disaster Reduction, IDNDR, by the General Assembly of the United Nations at its Assembly of December 11,1989.

Natural hazard means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomena (Varnes, 1984). Natural hazards range from high magnitude, low frequency events, such as volcanic eruptions and earthquakes to low magnitude, high frequency events, such as soil, fluvial and coastal erosion. Natural hazards are mostly related to geological processes. Research scientists from many countries study these geological processes and the effects of human actions on these processes in order to issue information and warnings on geological hazards.

A geological hazard is defined by the U.S. Geological Survey in 1977 as a geological condition, process or potential event that poses a threat to the health, safety, or welfare of a group of citizens or the functions or economy of a community or larger governmental entity. Note that the geological hazard is defined in terms of a threat to society and in terms of geological phenomena. Geological hazards are naturally occurring phenomena, which only become hazardous due to the presence of human settlement and infrastructure. The geological hazard, from another different point of view, can be defined as geological or geomorphological event, which has an adverse socio-economic impact on the human use system (Bennett and Doyle, 1999). Geological hazards can be categorized into two broad groups, namely, exogenic hazards and endogenic hazards. The exogenic hazards are caused by the operation of natural earth surface processes, such as flooding, soil erosion, river erosion, coastal erosion, landslide and mass wasting, collapse and subsidence, and tsunami. The endogenic hazards on the other hand result from internal earth processes, such as volcanic eruption and earthquake.

In Thailand, the most important natural hazards are flood, typhoon, drought, and landslide in their decreasing order of magnitude and frequency. During 19th-24th November 1988, the southern part of Thailand was under a prolonged heavy rainstorm. The mountainous areas of Changwat Nakhon Si Thammarat and Changwat Surat Thani especially in the vicinity of Khao Luang Mountain were seriously damaged by landslides and flash floods. Totally, more than 370 people were killed, 17,063 housing units were destroyed and the total damages were approximately 7 billion Baht. Recently, on the 10th August, 2001 the heavy rainfall in the mountainous areas of Amphoe Lom Sak, Changwat Phetchabun from the depression caused flash floods and debris flows in the foothill area of Tambon Nam Ko and Tambon Nam Chun. The devastating incident of Ban Nam Ko village in particular, had caused over 125 lives, over 8,000 homeless, 714 housing units were destroyed, and the total property damages were estimated to be 2 billion Baht.

These are among a few of hundred tragedies caused by landslide disasters that have occurred in many parts of the world. The zonations of landslide susceptibility is the basic tool for landslide mitigation and are necessary for planners and decision-makers in order to fully understand in the area development planing.

1.1 The Study Area

Changwat Phuket, the biggest island in Thailand, is situated in the Andaman Sea of the Indian Ocean close to the southwestern shore of peninsular Thailand. The Phuket Island lies between latitude $7^{\circ}\ 45'$ to $8^{\circ}\ 15'$ N and longitude $98^{\circ}\ 15'$ to $98^{\circ}\ 30'$ E. It is surrounded to the north by Changwat Phang-nga, to the east by Changwat Krabi to the south and to the west by the Andaman Sea. The total land area of Changwat Phuket is approximately 570 square kilometres whereas the area on the Phuket Island is approximately 543 square kilometres with the rest are other small neighbouring islands of Changwat Phuket. Its longest dimension from north to south is about 48.7 kilometres and its width from east to west is 21.3 kilometres. (Figures 1.1 and 1.2.a, 1.2.b)

Changwat Phuket has been chosen for the present study under various reasons, notably;

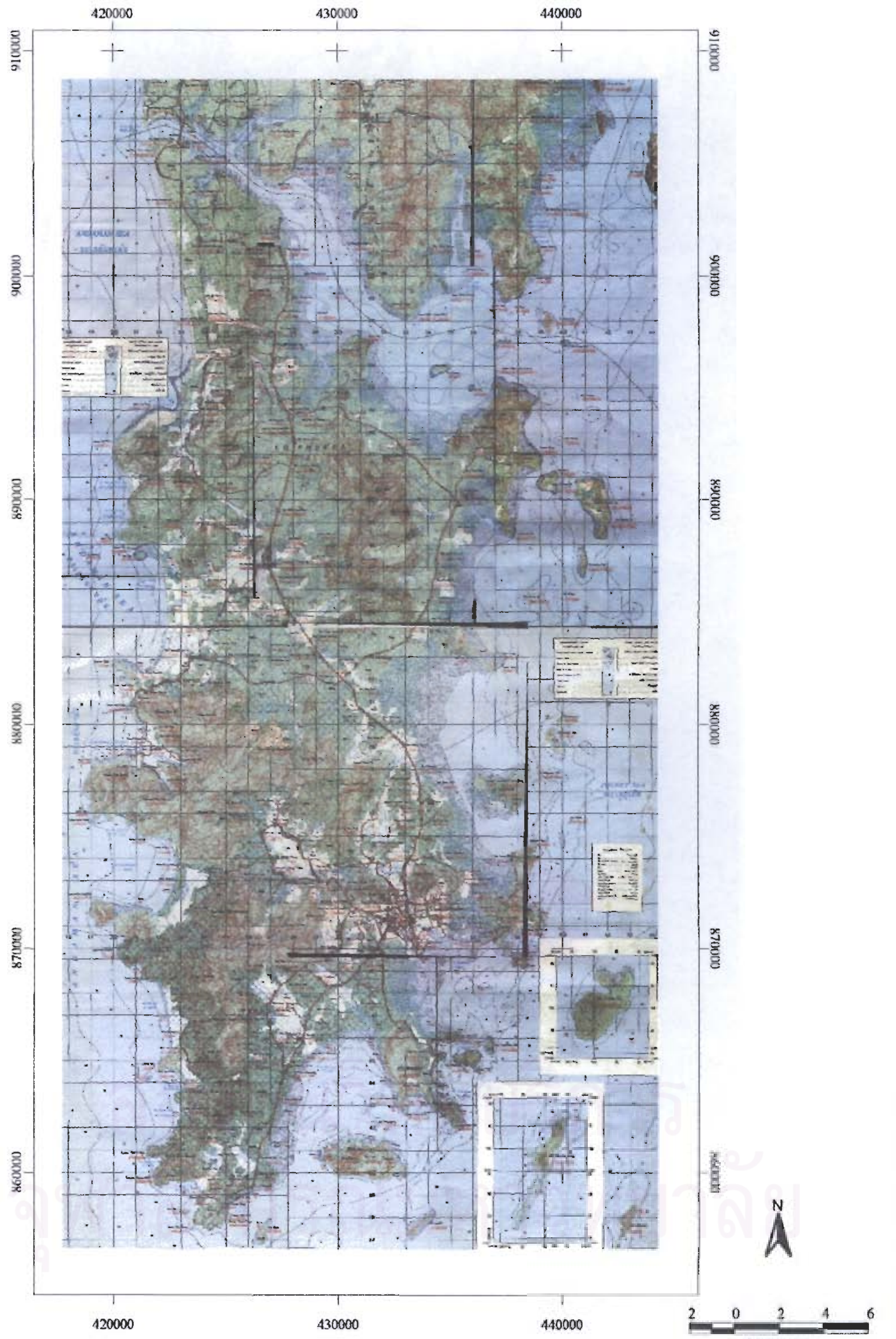
(1) Approximately 50 per cent of the land area of the island is underlain by mountainous and deeply-weathered granites.

(2) The original forest area of granitic terrane has been transferred into tin mines, para-rubber tree plantations, pine-apple plantations, housing and resort development as well as related infrastructure development.

(3) The island is annually under the influence southwest monsoon for at least six months of heavy rainfall 2,363 mm. per annum.

(4) The island has been continuously and extensively developed for tourism, trade and commerce, transportation and communication including "Phuket Cyberport & International City 2000".

For these reasons, potential landslide assessment in this area has been considered necessarily.

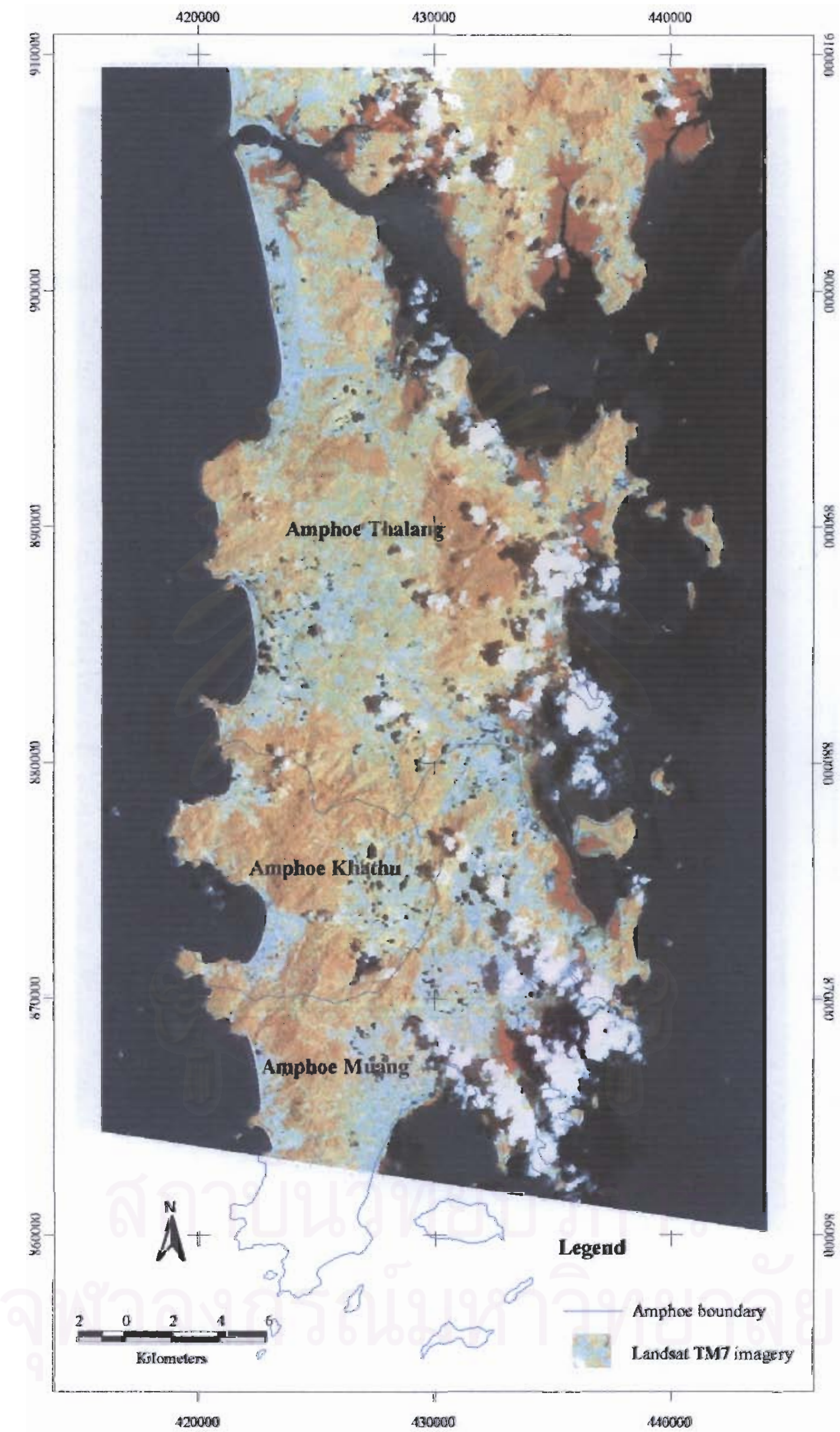


POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Hathaithip Thassanapak
Department of Geology, Faculty of Science
Chulalongkorn University
2001

Figure 1.1 The location map of Changwat Phuket

: A case study area outlined on the topographic map 1:50,000 scale



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Hathaithip Thassanapak
Department of Geology, Faculty of Science
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Figure 1.2 Landsat TM7 Image path/row 130/054, Changwat Phuket subset: Environmental Geology for Reginal Planning, DMR, DGM (March 14, 2000)

(a) False color composite 4/R, 5/G, 7/B

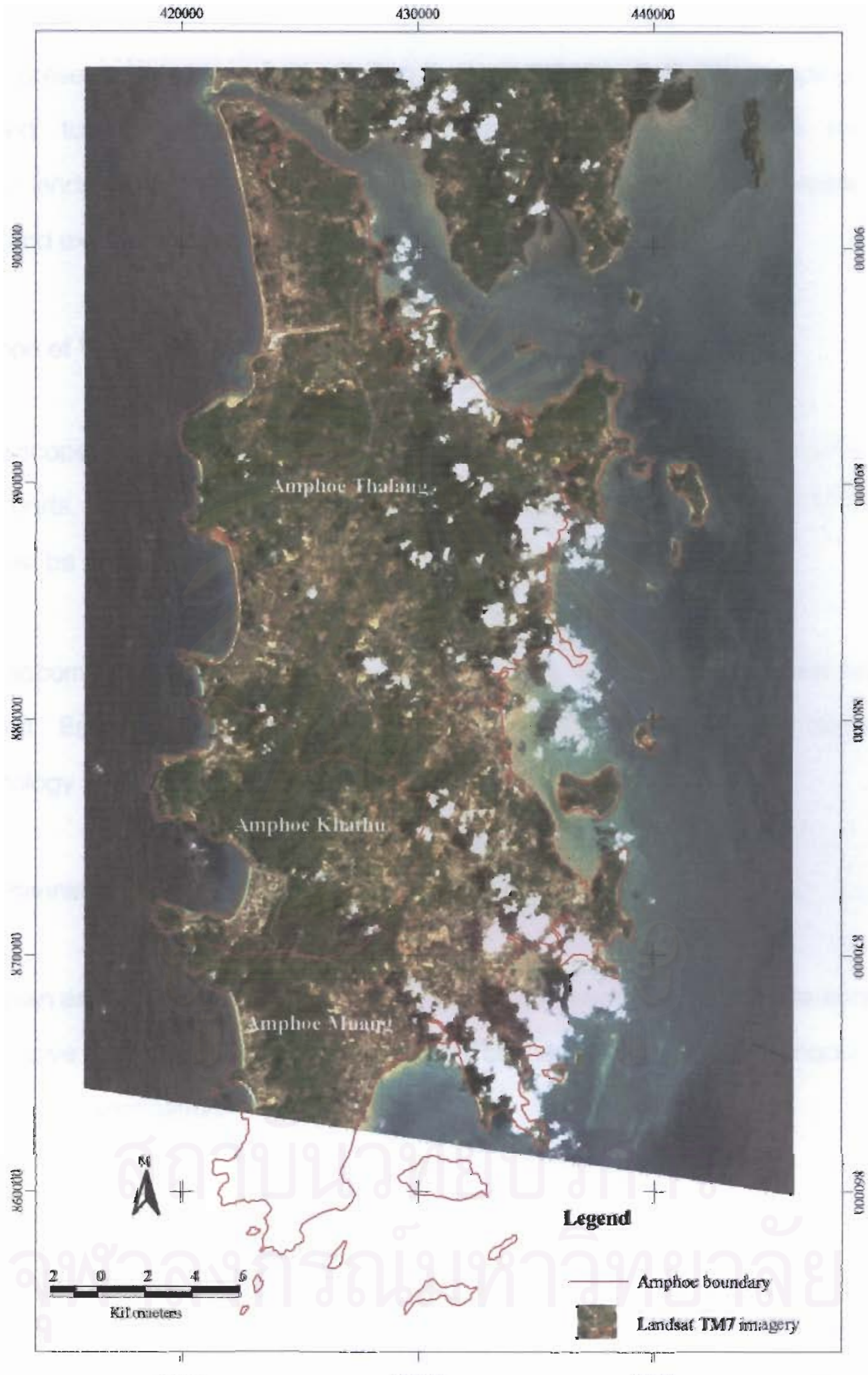

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Figure 1.2 Landsat TM7 Image path/row 130/054, Changwat Phuket subset: Environmental Geology for Reginal Planning, DMR, DGM (March 14, 2000)

(b) Natural color composite 3/R, 2/G, 1/B

1.2 Objective

The present study aims at developing the landslide susceptibility mapping that can be used to predict the different potentials for future landslide movement. Potential landslide assessment in the study area will incorporate both inherent stability factors and external factors into consideration.

1.3 Scope of Work and Study Methodology

The scope of delineating area susceptible to landslides consists of two separate but related parts. Firstly, the influencing factors that are relevant and mappable for the study area must be determined and secondly, these factors must be mapped.

To accomplish the aims of this study, the study involves four sequential steps are designed. Each of which will be described below. The schematic diagram for methodology system is illustrated in Figure 1.3.

(i) Planning and Preparation

To plan and prepare the study include literature review of the basic data acquisition, and intensive comprehension on the framework concept of landslides, methodology and scope of the investigation.

(ii) Reconnaissance Field Observation

The field investigation and direct observation will be carried out on regional and local surveys. The fieldwork involves data gathering of geological features, geomorphology, and existing landuse. The local information obtained from provincial offices, as well as the secondary data. They are the documents and reports about environmental setting and socio-economic background of the study area. The collected data during this phase are used to determine boundaries, potential impacts and data processing.

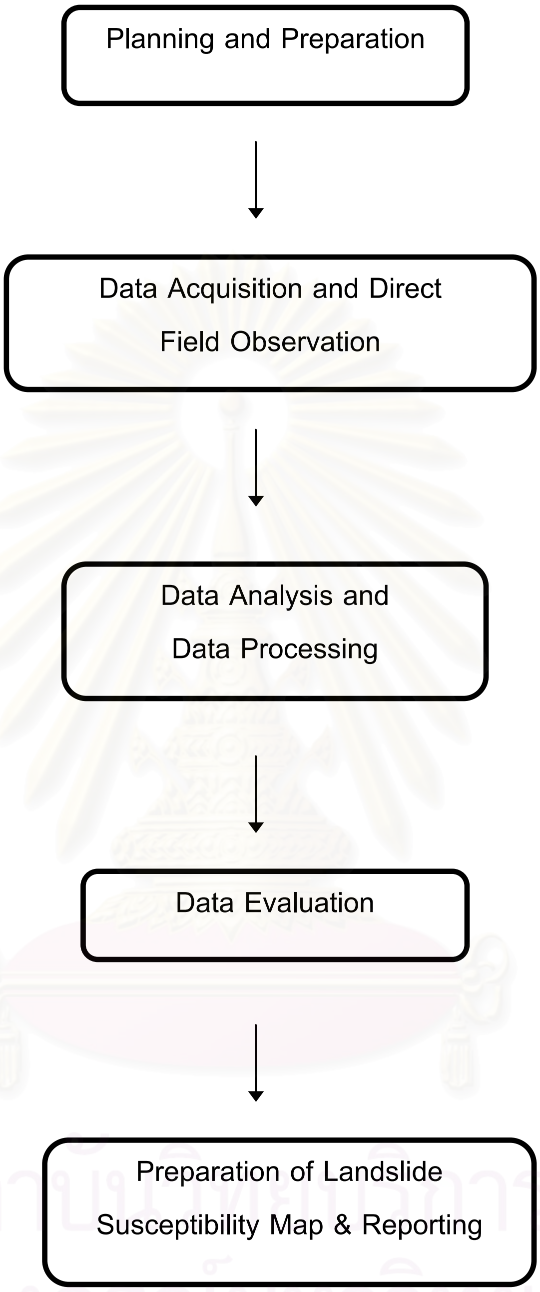


Figure 1.3 The schematic diagram illustrating the methodology system.

(iii) Detailed Data Analysis

In order to define the factors influencing landslides, the rating system has been applied to factors for arriving at a quantitative estimate of landslide susceptibility of each physiographic unit. The data collection step and fieldwork were input into the GIS(Geographic Information System) database formats on the 1:50,000 scale.

(iv) Evaluation and Conclusion

The result of this study is the landslide susceptibility-zoning map, supplemented by the discussion and conclusion. All of these will be incorporated in the final chapter.

During the last field decades, a number of research works on hazard zonation have been undertaken and consequently create the demand on slope instability hazard mapping. The recent development of the Geographic Information System, GIS, has greatly increased the availability of techniques for landslide hazard assessment. In the late 1970s, Newman and others (1978) reported on the feasibility of producing landslide susceptibility map using computer. Carara and others (1978) reported results of multivariate analysis applied on grid cells with a ground resolution of 200 x 200 m using approximately 25 variables. During the 1980s the use of GIS for slope instability mapping increased sharply. Due to the development of commercial GIS system, i.e. ARC/INFO, Intergraph, SPANS, ILWIS and IDRISI. In addition, the used of GIS increased due to the increasing availability of personal computer (PCs). A GIS uses a spatial data base, usually in digital form, to solve geographical problems, such as the relation between distribution and geological units.

Under the present study, the data in digital form are developed to the parameter maps. This data are taken form different sources.

They are as follows :

(1) Geological map is developed to rock type map and lineament map.

(2) Topographic map which contour intervals are used for developed to slope map and hypsometry map.

(3) Surface drainage systems on topographic map are used for developed to surface drainage zone (the distance from the surface drainage).

(4) Soil map of Department of Land Development is developed to soil characteristic map.

(5) Land use map of Department of Land Development is used for the database on land use and land cover map., and

(6) Rainfall data record for the period 1971 to 2000, which the average annual data is used for the database of isohyetal map.

The following GIS produce are used to (Figure 1.4) :

- Classification of each parameter map into a number of relevant classes
- Assignment of weight values to each of the parameter classes (or rating) (e.g. on a scale of 1-5)
- Assignment of weight values to each of the parameter maps
- Calculation of weights for each grid cell and classification in a few hazard classes of potential landslide.

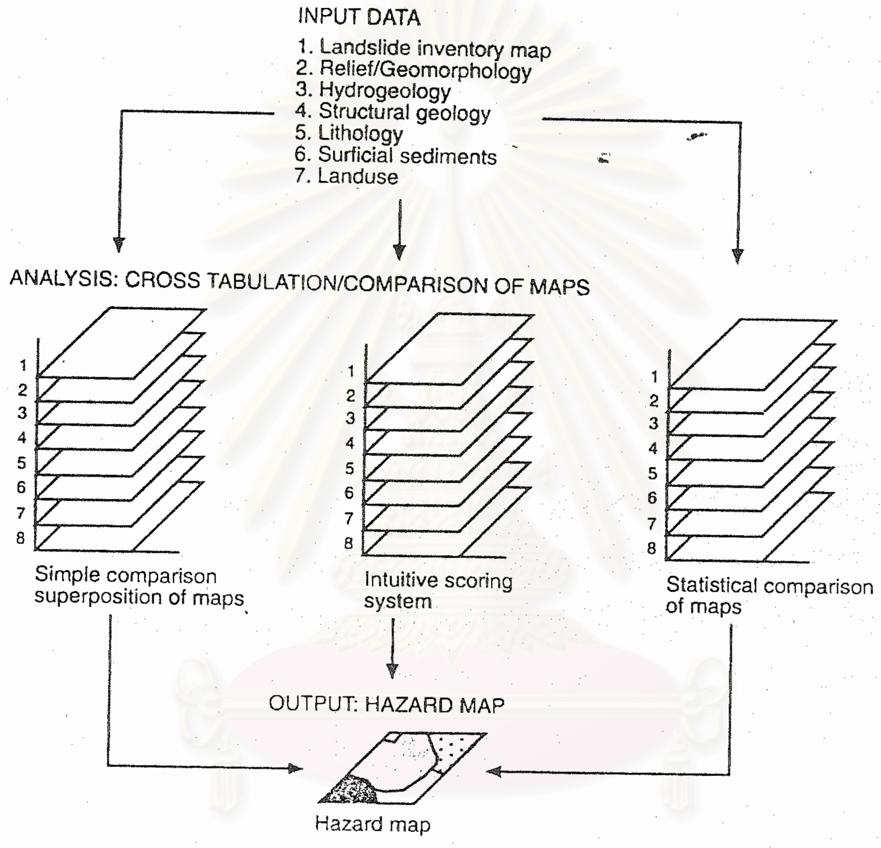


Figure 1.4 Generic model for the production of a mass movement hazard map

(After Bennett and Doyle, 1999)

1.4 Previous Investigations on Landslides in Thailand

The Literatures on the landslide investigation in Thailand are reviewed in chronological order as follows: the first brief investigation on landslide in Thailand was made by Ruenkrairergsa and Chinpongsanond (1980) for the Department of Highways. They reported the incident in northern Thailand. Causes of landslides were due to geological factors especially lineament, water infiltration, and microseismic activities.

Later, Brand (1984) gave a short historical review on the landslide situation from published literatures in Thailand during 1976-1980.

Wannakao and others (1985) studied the engineering properties of rocks causing of slope failures along the Lom Sak-Chum Phae highway between the kms. 18 to 24 where the failures were most intensified. Slope failures at this site can be classified into planar, circular, wedge, and block falls.

Between 19^{th}-23^{rd} November 1988, major storm triggered numerous landslides in Khao Luang Mountain Range, the main mountain range in southern Thailand covering the areas of Nakhon Si Thammarat and Surat Thani. The occurrence of debris flows and other mass movements in the mountains were widespread. Failure of landslide dams caused destructive contributed to severe flooding further downstream areas.

Tingsanchali (1989) conducted a study on 1988 landslides in southern Thailand and proposed that the two principal methods for controlling debris flows were structural control measures and non-structural control measures. The suitability of these two methods or their combinations depends on the size and characteristics of the area considered the socio-economic condition and the financial and political factors.

According to the study on the same event by Aung (1991) most failures took place on slope with gradient between 10 to 30 degrees and extended from the ground surface to the depth of 1 to 3 metres into the residual soil layer. These evidences indicated that those failures were mostly surface erosion or earth flow types. He also constructed the landslide susceptibility map in the area west of Amphoe Phi Pun, Changwat Nakhon Si Thammarat.

DeGraff (1991) concluded that vegetative-cover change on tropical mountain slopes influences debris flows occurrence of the 1988 storm event. The observed differences in number of debris flows between areas under the para-rubber plantation and areas with natural forest cover. The study revealed that the slope stability of the area depends upon the changing pattern of land use and land cover. In addition, the scale of landslides under similar storm condition with different land use pattern was also different.

Zhibin (1991) investigated the characteristics of weathered granites exposed along the flanks and bottom of numerous landslide scars beside the Krathun stream and its tributaries. The study also embraced the effect of typical climatic condition (microclimate), the destruction of natural forest and changing to para-rubber plantation, the importance of subtle landform (depressions) on the landslides. Typical weathering profile of granite terrane was summarized and correlated to the landslides. Landslide types observed, based on field evidences, was mainly erosion, gullying, earth flow, soil slump, debris flow, and rock slide.

Nutalaya (1991) concluded that the followings were the factors of landslides and sheet flooding during the rainstorm event of 20^{th}-23^{rd} November 1988, Khao Luang Mountain Range. They included (1) Deforestation of areas which significant by caused the erosion of steep slopes; (2) steep gradient over 35 per cent and sharp change in gradient which occurs when the mountain streams meet the flat valley floor resulted in the deposition of alluvial fans, and (3) deeply saturated residual sand on the granitic rocks.

Tantiwanit (1992) investigated the characteristics of landslides activities from the November 1988 storm event. The study revealed that the significant factors controlling landslides could be summarised as follows: (1) residual soil from weathered granitic rocks is most susceptibility to landslide; (2) steep gradient over 30 per cent; (3) the change of vegetation cover to para-rubber plantations, and (4) the triggering factor is highly rainfall intensity.

Khantaprab (1993) conducted a study on November 1988 landslides in southern Thailand and proposed the following factors that influencing the landslides. (1) slope gradient greater than 12 degrees; (2) deforestation and changing pattern of land use and land cover to para-rubber plantations; (3) the areas underlain by granitic terrane with residual soils of weathered granite, and (4) high cumulative rainfall intensity the triggering factor.

Nilaweera (1994) studied the effects of root strength properties and root morphological of para-rubber plantations compared with other kinds of forest tree that produced hard deep penetrating root systems in the area of Khao Luang Mountain Range. The replacement of forest trees can cause instability to soil slopes. From the event, the slope, between 10 to 40 degrees in gradient were where the most of landslides occurred.

Pantanahiran (1994) summarised the primary factors that controlled landslides in the Khao Luang Mountain Range during November 1988 storm as followes: (1) fractured limestone and granitic bedrock; (2) shallow sandy soil from the weathering of granitic rock; (3) steep slope of more than 30 per cent; (4) high rainfall in earlier November as well as particular storm in November; (5) the pathway of storm; (6) reduction in natural forest cover; (7) planting of shallow root trees and crops, and (8) recentness of clearing and replanting. He also used GIS and statistical technique to develop a landslide prediction model for Khao Luang Mountain Range. The model uses eight parameters including elevation, aspect of slope, TM 4 (Thematic Mapping Band-4), flow accumulation, brightness, wetness, slope and flow direction. The model is capable of classifying 82 per cent of landslides in the Tha Di stream basin at a 0.4 cutoff probability.

Jworchan (1995) investigated the characteristics of residual soils of November 1988 debris flows in the Khao Luang Mountain Range. The study revealed that the degree of weathering of residual soils are Grade IV to VI for the soil thickness of 1 to 2 metres. with the slope greater than 26 degrees. Moreover, sandy and cohesionless of clayey soil susceptible to surface erosion once saturated.

Harper (1996) determined of the importance of topographic, geologic and geomorphic factors to debris flows susceptibility. The study used both the number of debris flows per square kilometre and the percentage of total land area in each basin, sub-basin, and the Tapi plain foothills as indicators of debris flows susceptibility. It is found that hillslope areas in tropical regions underlain by granite are more susceptible to debris flows than those underlain by clastic sedimentary or metamorphic rocks. The most frequent mode of landuse in which debris flows occurred was rubber tree plantation.

CHAPTER II

BASIC CONCEPTS OF LANDSLIDES

Unstable surficial deposits represent a major hazard in numerous areas throughout the world. For practical purposes, it is useful to distinguish terms employed in the movement of unstable surficial deposits on the slopes.

In strict geological terms, the **mass movement** is the downslope movement of soil, sediment and rock as a result of the pull of gravity (Bennett and Doyle, 1999). Therefore, the mass movement is distinguished from other exogenetic processes by being the outward or downward gravitational movement of earth materials without the aids of running water as a transportational agent. However, it does not deny the importance of water in either its solid or liquid state as a destabilizing factor nor does it excludes subsidence and other movement on flat ground.

The other terms, the **mass wasting**, is synonymous with 'mass movement', but it is really a broader geomorphic concept commonly used in conjunction with the erosion cycle to refer to mass reduction of the interfluves as opposed to the degradation by stream (Crozier, 1986).

Slope instability is another general term, which refers to the pre-deposition of a slope to mass movement. Besides, Varnes (1978) had advocated the term **slope movements** for mass movement restricted to slopes, and this appears to be a suitably neutral, all-embracing term.

The term **landslide** is most common and universally appreciated as the collective term for most slope movements of the mass movement type. However, landslide is an unusual name because it used both for the geomorphic processes, which involved rapid gravity movements, and for the resulting landform that is created by the displaced materials. Landslide, in a strict sense, as characterised by failure of materials at depth and then movement along a rupture zone or slip surface (Grigg and Gillchrist, 1977).

The terminology of features that may indicated catastrophic rotational landslide movement are shown in Figure 2.1.

2.1 Slope Stability

Under natural condition, a slope has the tendency to evolve toward an angle that around the rock or regolith to reach the point where the shear strength or shear resistance is equal to the shear stress. The quantity of rock or regolith from upslope is balanced by the quantity that is moving downslope at that point. Under this situation, such a slope is said to be in a balanced, or steady state, condition.

The main factors that influence slope stability are:

(1) the gravitational force and the gradient of the slope,

(2) the hydrological characteristics of the slope,

(3) the earth materials, and

(4) the occurrence of a triggering event.

The two opposing forces, shear stress and shear strength , determine whether a body of rock or regolith located on a slope will move or remain stationary (Figure 2.2).

The tangential component of gravity acts along and down the slope and caused objects to move downhill. As the slope become steeper, the tangential component increases relative to the perpendicular and the shear stress becomes larger.

The shear strength is the internal resistance of the body of movement and is governed by factors inherent in the body of rock or regolith, such as friction and cohesion between particles, and the binding action of the plant roots.

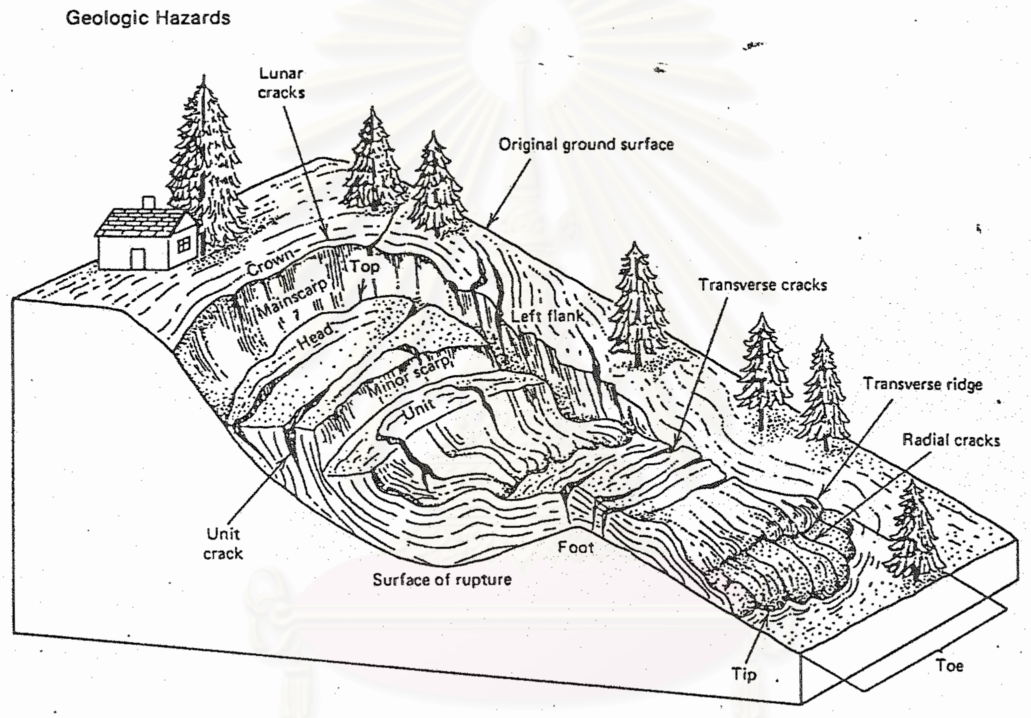


Figure.2.1 Rotational landslide terminology for various parts of the landform

(After Brunsden and Prior,1984)

The relationship between these two opposing forces is expressed in a ratio known as the safety factor (Fs):

$$Fs = \frac{\text{Shear Strength(Resisting Force)}}{\text{Shear Stress (Driving Force)}}$$

When the safety factor is less than 1, slope failure is imminent.

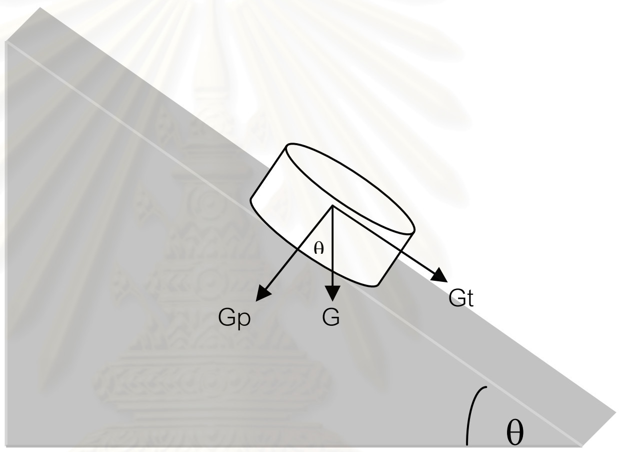


Figure 2.2 Effect of gravity on a rock body or regolith body lying on a hillslope

G : gravity acts vertically

Gp : perpendicular component of gravity

Gt : tangential component of gravity

2.2 Factors influencing landslides

In general, the causes of landslides are diverse and are relatively well understood. However, the search for an individual landslide must be undertaken specifically under the different influencing local conditions. Numerous studies on the causes of landslides have been carried out by many workers.

Sharpe (1938) had grouped the causes of landslides under natural condition into passive and active conditions. The passive or favoring condition includes lithological, structural, topographical, hydrological, and climatological factors, whereas the active condition which initiate the movement include the slope-steepening, earthquake, exceptional heavy rainfall, prolonged wet period, and others.

Terzaghi (1950) had grouped the causes of landslides into three categories; namely, external, internal, and intermediate. The external causes include loading of a slope, steepening of a slope by erosion or excavation, and earthquake shocks, etc; while the internal causes cover the increase water pressure or decrease in cohesion of the slope materials. Besides, there are some other intermediate causes, notably, rapid drawdown, spontaneous liquefaction, and subsurface weathering and erosion.

Zaruba and Mencl (1969) recognized the diversity of factors, which are responsible for the origin of landslides. They are the change of slope gradient, the excess load by embankments, fills and waste dumps, shocks and vibrations, changes in water content, effects of ground water, frost effects, weathering of rocks, and change in the vegetation cover on the slopes.

Griggs and Gilchrist (1977) had outlined factors producing landslides and mass movement into two broad groups, the external factors and internal factors. The external factors embrace; change of slope gradient, excess loading, change in vegetation cover, and shocks and vibration; whereas the internal factors include change in water content, effects of groundwater, and internal properties or weathering of materials.

Howard and Remson (1978) proposed that the ground or slope failures are caused by two principal factors, inherent and superimposed. The inherent factors are the properties and distribution of minerals and other constituents, structural features, moisture content, topography and vegetation, while the superimposed factors include deterioration of materials, increases in moisture content, overloading, removal of underlying or lateral support, earthquakes, and other factors.

Coates (1981) presented the three factors that influence stability of hillslope, they are the internal properties of the earth materials, the geomorphic setting and environment, and independent external factors. For the independent external factors, the term triggering mechanisms have been used because they provide the immediate stress that initiates movements of the mass. These include excessive precipitation, human activities, highway construction, hillside development, dams and reservoirs, mining, lumbering, other man-made landslides, and earthquakes.

Since the shear strength and shear stress are the principal forces affecting the mass movement, Costa and Baker (1981) had outlined factors contributing to increase shear stress and to reduce shear strength. Factors that contribute to increased shear stress are: removal of lateral support, surcharge loading, internal increase in weight of slope material, ground vibrations, undermining, lateral pressure in cracks, and regional tilting while factors that contribute to reduce shear strength are clay properties, gross rock structure, pore pressure effects, freeze-thaw effect, drying, loss of capillary tension, breakdown of soil structure, and deterioration of intergranular cement.

Varnes (1984) identified the causative conditions and processes of landslides. The list of causes that followed is similar to that of Pasek (1974) and of Jahns (1978), who considered first the inherent or basic conditions that affect stability and then, the processes or factors that produce unfavorable changes that may lead to failure. Inherent or basic conditions include geology (lithology, structure), geomorphology, hydrologic conditions and climate, and vegetation; whereas factors producing unfavorable changes in conditions are subdivided into those that change stress conditions and those that change strength of materials. For those that change stress conditions are the removal of lateral support by human activity, uplift from tectonic conditions, gradual erosion/deposition or reflection of groundwater level, and seismic vibrations ; while those that change strength of materials are cover: weathering/physical and chemical actions, increase of water content, increase in pore-water pressure, precipitation, groundwater level change, and vegetation cover change.

Ritter and others (1995) summarised the general controls of slope stability into factors that increase shear stress and factors that reduce shear strength. Factors that increase shear stress are the removal of lateral support, removal of underlying support, surcharge, transitory earth stresses, regional uplift, and lateral pressure; while on the other hand, factors that reduce shear strength cover inherent characteristics of earth materials, weathering and other physiochemical reactions, and water content or pressure in pores and fractures.

Murck and others (1999) identified six types of landslide prone terrain. They include the seismically active regions, mountainous environments, land degradation, areas covered by thick loess sheets, adverse meteorology, and areas subject to rapid development.

2.3 Classifications of Landslides

Prior to the review of various types of classifications of landslides, the most common terms require a brief mention.

(a) Bedrock

This is the unaltered geological substrate, in situ until undergoing some from of movement.

(b) Soil

This is the unconsolidated material above the bedrock. It may include debris, material grain size coarser than 2 mm., and soil, material predominantly finer than 2 mm.

(c) Creep

This is basically defined by its velocity, owing to the slow nature of the movement. There are usually three types of creep:

1. seasonal creep, or movement within the depth of soil affected by seasonal changes in soil moisture and soil temperature;
2. continuous creep, where shear stress exceeds the strength of material;
3. progressive creep, which is associated with slopes reaching the point of failure by other mass movements.

Creep is usually separated from other categories owing to the large area across which it occurs, the slow speed of movement, and the fact that seasonal creep is dependent primarily on changing climatic conditions rather than being gravity dependent.

(d) Falls

These are abrupt free-fall movements of material away from steep slopes such as cliffs. Material is usually described as moving in bulk. This then allows for the omission of small particles detached by weathering.

(e) Slides

This term is usually reserved for movement of material along recognizable shear surfaces. Type of material or type of slide surface is the usual means of subdividing this group, but Hutchinson (1968) uses one or more discrete surfaces and so flows have become a subdivision of slides in some classifications. Two types of slide motion can be singled out. Slump involves a rotational motion whereas a planar or translational slide involves displaced materials that move roughly parallel to the sheared surface.

(f) Flows

These are often looked upon as transitional features since they straddle the two groups of mass movement and mass transport. The material moving behaves like a viscous mass whereby inter-granular movements predominate over shear surface movements.

It must again be obvious according to the classification being used that the different transitional forms can be come different to categorised.

Varnes(1978) moves a step in the right direction by quantifying his statements, for example the definition of debris slab slide is:

"material moving along a planar surface of little disturbed mass of fragmented material having a *D/Lc* ratio of 0.1 or less, containing some water, but none free, and moving at a rate of between 1.5 m./month and 1.5 m/year".

Like other scientific subjects landslide or mass movement classifications seem to pose more problems than other subjects. The combination of earth materials, slope gradients, and agents, responsible from movement produce considerable opportunities for different slope displacements. However numerous classifications already exist in the literature.

The complexity of discriminating factors applied in a selection of nine commonly used classifications each recommended by a different authors (Table 2.1).

The most important discriminating factors can be grouped into three distinct areas, namely, the type of materials and/or the type of movements, morphology of the material moved or the surface of movement, and the geotechnical properties. In this the present study, Varnes' (1978) landslide classification (Table 2.2 and Figure 2.3) has been employed. The reasons are that Varnes' scheme is easier to apply and requires less expertise to use. It is also interesting to noted that whatever system is chosen, the user should not only acknowledge the source of terminology but also realize that the dividing line in most classifications represent and indistinct transition in nature.

Table 2.1 Comparison of classification factors used by nine authors (Hansen,M.J.,1984)

Author	Climate	Material moved	Coherence of material	Size of material	Geology	Type of movement	Speed of movement	Water/air/ice	Triggering mechanism	Morpho Logical Attributes	Complex group
Blong (1973a, b)				O +		O x				X	O P
Coates (1977)		X	+	+		x	+				A
Crozier (1973)						O x				X	A
Hutchinson (1968)				+		x					A
Ladd (1935)					x				+		A
Sharpe (1938)				+		x	+	x			A
Varnes (1978)		X				x	+	+			P
Ward (1945)	+	+				x		+			A
Zaruba and Mencl (1969)		x	x		+	+					A

x : Main factors + : Secondary factors O : Factors used in comparative classifications P : Presence A : Absence ● : Bracketed numbers refer to list of basic discriminating factors

Notes on the above classification:

Blong: Morphological attributes may be used for statistical separation into sub-groups, and this could provide uniformity at this level. This would be preferable to the variety of factors used at present in most works. *Coates*: The design of this classification allows the placement of transitional groups. It does not, however, provide a category for complex phenomena where more than one type of movement is present. ***Crozier***: Measures of tenuity, flowage, dilation and fluidity all show inverse relationships with the depth/length index. The average value of D/L for each type of movement appears to be characteristic, but the standard deviation ranges overlap for adjacent groups. ***Hutchinson***: Also included in the classification are creep, typified by the type, depth and rate of material moved, and frozen ground phenomena. ***Ladd***: This classification is dominated by the use of geology. There is no recognition of shearing surfaces, although structural slides are present. ***Sharpe***: A more complicated classification, but with no allowance for a complex category. ***Varnes***: The later version gives more emphasis to particle size, and uses a new group, lateral spreads. The classification gives clear illustrations as well as providing the complex category. ***Ward***: His various types of movement separate broadly into depth of movement as stated in the text that accompanies his classification. The category of flow is not used, but saturated sands behaving as a heavy liquid are included. ***Zaruba and Mencl***: Here the emphasis is laid on the type of material moved and its coherence rather than the type of movement which results. Surfaces of movement are used as factors of differentiation, but they are not subdivided to their full extent; for example surfaces where shear resistance is exceeded are not divided further according to shape of surface or type of movement occurring on it.

Table 2.2 Classification of landslides suggested by Varnes(1978)

Type of movement		Type of material		
		Bedrock	Engineering Soils	
			Predominantly coarse	Predominantly fine
Falls		Rockfall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slides	rotational/few units	Rock slump	Debris slump	Earth slump
	translational/many units	Rock block slide	Debris block slide	Earth block slide
		Rock slide	Debris slide	Earth slide
Lateral spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
Complex		Combination of two or more principal type of movement		

2.4 Landslide Prevention and Mitigation

It is rather obvious that the best way in preventing damaged from landslide is to avoid building in an area subject to mass movement. Areas that are typically considered unsaved from landslides can be noticed from the following features prior to major landsliding (U.S. Geological Survey, 1997):

- Springs seeps, or saturated ground in areas that have not typically been wet before.
- New cracks or unusual bulges in the ground, street pavements or sidewalks.
- Soil moving away from foundations.
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house.

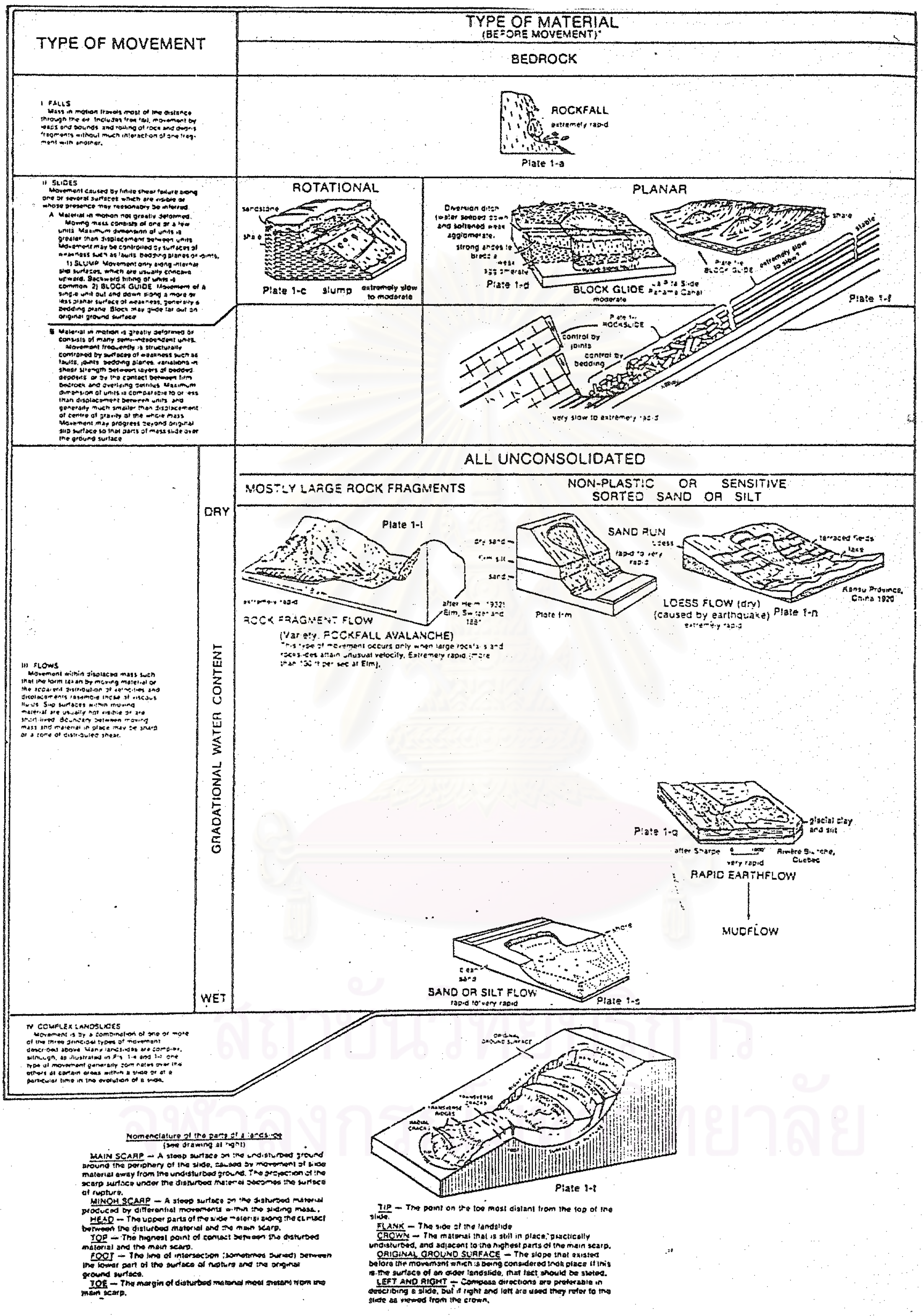
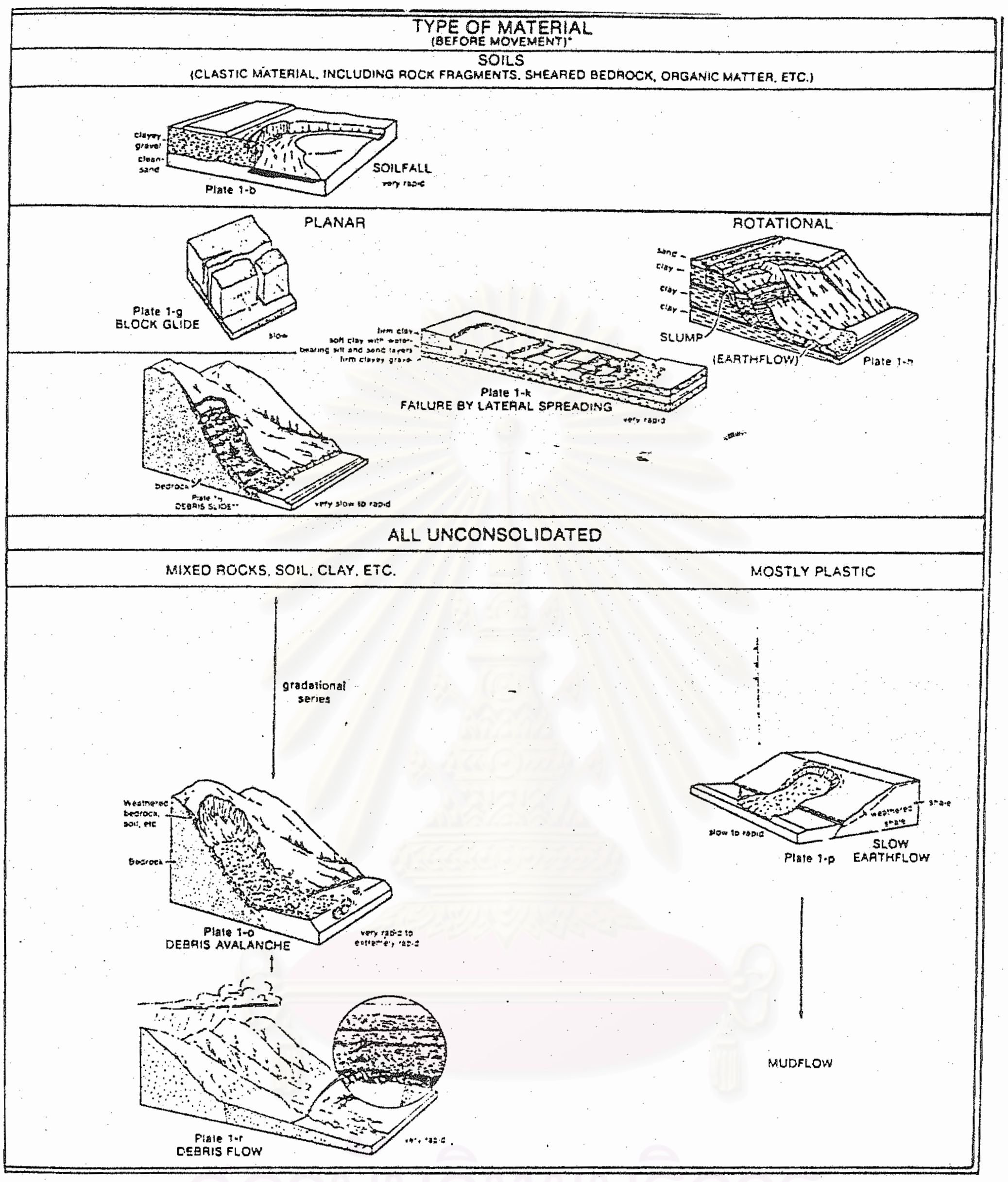


Figure. 2.3. Varnes' Classification of Landslides

(After Brunsden and Prior,1984)



The following definition of a landslide has been adopted for use in this book

Landslide — The term "landslide" denotes downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or combinations thereof.

Landslides move along surfaces of separation by falling, sliding, and by flowing. Parts of a landslide may move upward while other parts move downward. The lower limit of the rate of movement of landslide material is restricted in this book by the economic aspect to that actual or potential rate of movement which provokes correction or maintenance.

* The type of material involved is classified according to its state prior to initial movement or, if the type of movement changes, according to its state at the time of the change in movement. Thus, the Elm slide (Pl. 1-l) began as a rock slide and rock fall in bedrock, but at the time a flowing type of movement started the material was an "unconsolidated" mass of extremely rapidly moving rock fragments.

** By debris is meant natural soil and rock detritus.

Approximate ranges of rates of movement are according to the scale below
Plate 1-u

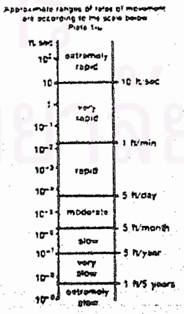


Figure 2.3 (Continued)

- Tilting or cracking of concrete floors and foundations.
- Leaning telephone poles, trees, retaining walls or fences.
- Offset fence lines.
- Sunken or down-dropped road beds.
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels though rain is still falling or just recently stopped.
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.

However, in many cases the construction of railroads, highways, roads, must be carried out traversing hazardous zones between corporate areas. In addition, the expansion of urban area as a result of growing population coupled with limited land resources has motivated the requirement of building on areas having high potential landslide hazards, therefore the methods for landslide mitigation must be taken into consideration. They are:

(a) Slope drainage

The interceptor drains or diversion trenches, perforated or drainage pipes and wells driven into the slopes with installed pumping or siphon are commonly used to reduces the water buildup within slopes.

(b) Slope reduction

Steep slopes can be graded into gentler one, or can be excavated into benches or terraces.

(c) Engineering methods and structures

The slope disintegration can be discouraged using the shotcrete, whereas slopes underlain by sediments or loosely consolidated rocks can be protected using the retaining walls or buttresses. Inclined rock layers can be stabilized with rock bolts.

The slopes subjected to rock falls can be protected by cable nets and wire fences in association with intercept ditches excavation or berms. In addition, rock sheds and tunnel built over highway and railroad segments is designed to around a landslide to pass over the area without disturbing the transportation routes.

2.5 Natural Hazards and Risk Assessment

Natural hazards consist of numerous phenomena, namely avalanches, earthquakes, forest fires of natural origin, typhoons, landslides, flooding, land subsidence, tsunamis, volcanic eruptions, etc. Each hazard has caused a great deal of human suffering and economic loss from the past history to modern world. In recent years, various terms has been used with natural event and their impact on human activities.

Under the present study, the terms are related to hazard and risk earlier proposed in 1984 by the United Nations Organizations of UNDRO (Office of the United Nations Disaster Relief Organisation) and UNESCO have been employed. (Varnes, 1984)

a. **Natural hazard (H)** means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon.
b. **Vulnerability (V)** means the degree of loss to a given elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss).
c. **Specific risk (R_s)** means the expected degree of loss due to a particular natural phenomenon. It may be expressed by the product of H times V.
d. **Elements at risk (E)** means the population, properties, economic activities, including public services, etc., at risk in a given area.
e. **Total risk (R_t)** means the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon, and is therefore the product of specific risk (R_s) and elements at risk (E). Thus :

$$R_t = (E)\ (R_s) = (E)\ (H*V)$$

Risk analysis, or risk assessment, typically is defined as including three related operational elements: risk identification, risk estimation, and risk evaluation.

The risk identification typically focuses on some hazard, some potential risk-producing activity. The identification of a societal risk may target on the description of a “candidate problem,” system side effect, or “impact,” while risk estimation targets on the quantitative description of the population at risk, the identification of the impact-causing events, the specification of the probability that such events will occur, the elucidation of the consequences associated with the various magnitudes of expected events, and the integration of these magnitude/event probability calculations into a quantitative measure of risk.

The output of a risk estimation are in the form of probabilistically derived estimates of the consequences to the population at risk resulting from exposure to the hazard, typically in the form of annual expected, most likely, and maximum probable quantitative estimates. The third operational element is risk analysis is termed “risk evaluation.” Activities performed in the risk evaluation phase of a study are intended to help answering the question, “How safe is safe enough?” Risk evaluation relies heavily on providing the policy maker with referents against which the possible significance of the focal risk may be weighed.

Due to the fact that both activities of external factors and the influence of the inherent factors vary from place to place, and it is possible to identify zones of different degrees of landslide hazard and risk. The identification procedure involve five steps of tasks (Crozier, 1986), they are:

(1) identification of the nature, degree of activity and critical levels of external destabilizing factors;

(2) identification of the physical response of inherent factors to the critical levels of the external factors to the critical levels of activity of the external factors; that is, a determination of terrain sensitivity;

(3) integration of both the frequency of occurrence of critical levels of the external factors and terrain sensitivity to produce a measure of the probability of landslide occurrence;

(4) combination of the probability of landslide occurrence with mass movement characteristics, such as rate ,depth, volume, and zone of influence to produce an assessment of potential landslide hazard. In effect, this is a statement of the frequency/magnitude characteristics of the phenomenon;

(5) combination of potential landslide hazard with the potential human, economic and environmental damage to produce a statement on landslide hazard risk.

It is however noted that there are often insufficient data to carry out all five tasks. Therefore, the map of the probability of occurrence of the potential landslide hazard or a landslide hazard map may be prepared by classifying probability of occurrence units by landslide type. One immediate use for the landslide hazard map is as a basis for assessing risk. Superimposition of the existing land use on the hazard map, combined with knowledge of disaster event damage, can provide a map of current landslide hazard risk.

CHAPTER III

ENVIRONMENTAL SETTING OF CHANGWAT PHUKET

The Phuket Island was originally a part of the landmass of the Thai-Malay Peninsular. The island has been long known as one of the old human settlements for many thousand years. The Phuket Island has also been a famous port of call between China and India in the olden days and well known under the name of "Junkceylon". The name "Phuket" is believed to be derived from the Bahasa Malaysia of "Buket" meaning "mountains" or it is derived from the Thai word of "Phukej" meaning "city of glass".

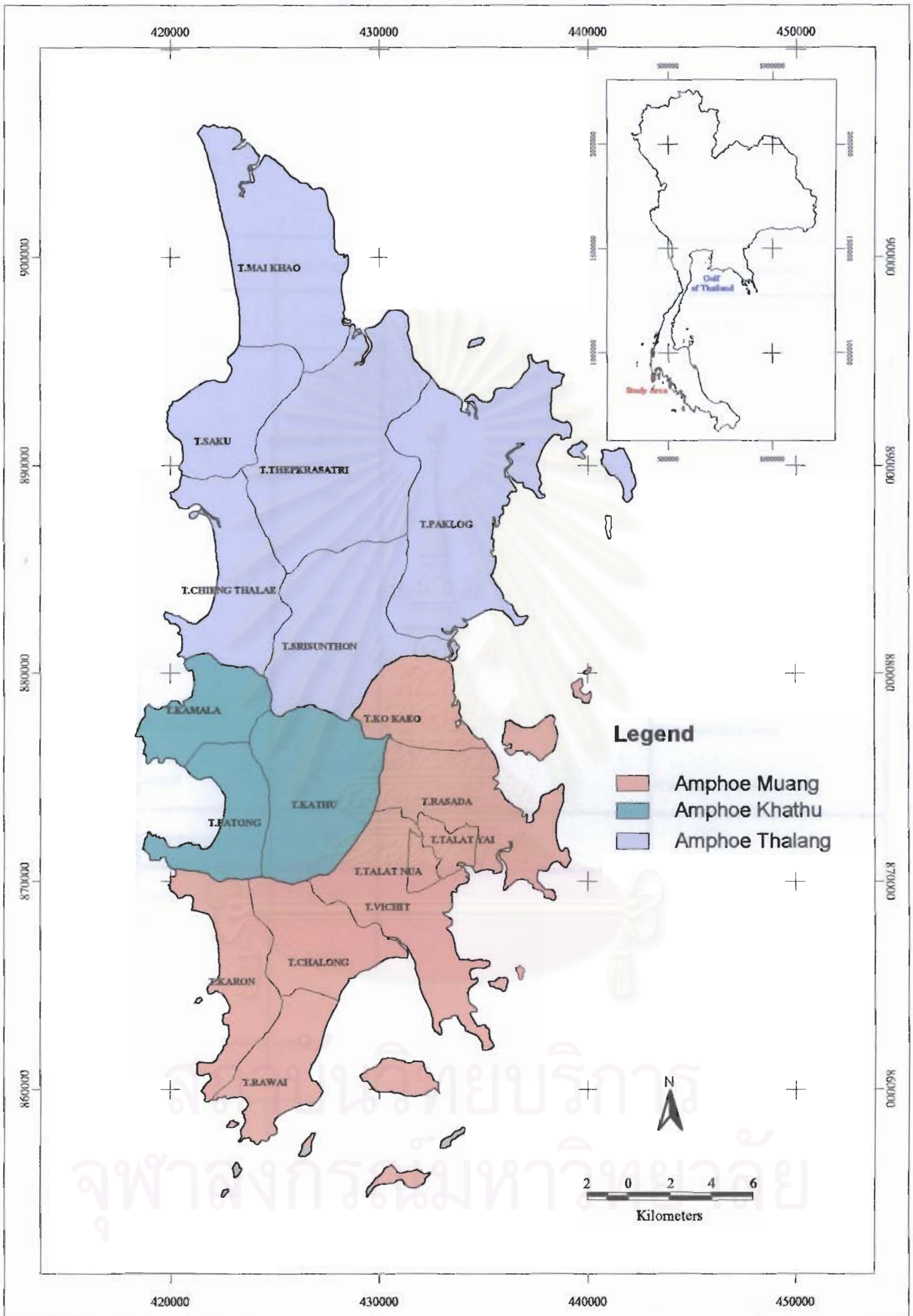
During Ayudhya period, the Phuket Island had been a center of tin trading in the Andaman Sea among the Dutch, French, Portuguese, English, etc. Later on, during Rattanakosin period, the Phuket Island has become most prosperous and important center for tin trading among neighbouring towns, namely, Phang-nga, Krabi, Trang, Ranong, and Satun.

3.1 Socio-Economic Conditions

3.1.1 Administration

The administration of the main island, the Phuket Island, and 32 neighbouring small islands, is divided into 3 Amphoes (district), 17 Tambons (sub-district), and 107 Moobans (village). For Amphoe Muang Phuket, there are 8 Tambons and 44 Moobans; for Amphoe Thalang, there are 6 Tambons and 45 Moobans; and for Amphoe Kathu, there are 3 Tambons and 18 Moobans.

The areas under Amphoe- and Tambon- administration are shown in Figure 3.1 and are summarised in Table 3.1.



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Hathaithip Thassanapak
Department of Geology, Faculty of Science
Chulalongkorn University
2001

Figure 3.1 Amphoe and Tambon administration areas of Changwat Phuket
(Source: Phuket Provincial Statistical Office,2000)

Table 3.1 The areas under Amphoe and Tambon administration of Changwat Phuket

(Source : Phuket Provincial Statistical Office,2000)

Amphoe	Tambon	Area(Sq.km.)	Dist.from amphoe to changwat(km.)	Remarks
Muang Phuket	8 Tambons	224		Municipal Area
	Talat Nua	8.31		
	Talat Yai	3.69		
	Karon	20		Sanitary Area
	Chalong	30		Non-municipal Area
	Rawai	23		Non-municipal Area
	Ratsada	35		Non-municipal Area
	Ko Kaeo	48		Non-municipal Area
	Wichit	56		Non-municipal Area
Kathu	3 Tambons	67.034	9	
	Kathu	31.79		Sanitary Area
	Kamala	18.804		Non-municipal Area
	Patong	16.44		Municipal Area
Thalang	6 Tambons	252	20	
	Thep Krasattri	78.4		Sanitary Area
	Sri sunthon	45.1		Non-municipal Area
	Choeng Thale	37.1		Sanitary Area
	Pa Khlok	51.5		Non-municipal Area
	Mai Khao	29.2		Non-municipal Area
	Sakhu	10.7		Non-municipal Area
Total	17 Tambons	543.034	2 Municipalities and 4 Sanitaries	

3.1.2 Population

The total population of Changwat Phuket was reported to be 241,489 persons in December 31,1999 (Phuket Provincial Statistical Office, 2000). Among these, 118,606 persons were male (49.11 per cent), 122,883 persons were female (50.89 per cent). The average population growth is 2.49 per cent per annum. It is estimated that the total population of Changwat Phuket will reach 359,900 persons until 2017 (Figure 3.2 and Table 3.2). The average population density of Changwat Phuket was approximately 445 persons per square kilometre in 1999. The population density of Amphoe Muang, Amphoe Kathu, and Amphoe Thalang in 1999 were 684,414, and 241 persons per square kilometre, respectively (Figure 3.3).

The population age structure of Changwat Phuket in 1999 is summarised and presented in Figure 3.4 and Table 3.3.

Finally, the population distribution of Tambon levels of Changwat Phuket is presented in Figure 3.5.

3.1.3 Education, Religion, and Health Services

The education services of Changwat Phuket cover from kindergarten level to tertiary education with totally 175 schools and institutions in 1999. The total number of teachers is 2,341, whereas the total number of students is 46,961.

The population of Changwat Phuket can be classified according to religion as follows: Buddhist 75.23 per cent, Muslim 23 per cent, Christian 1.23 per cent, and other 0.54 per cent. There are altogether 31 Buddhist monasteries, 43 Muslim mosques, and 3 Christian churches in Changwat Phuket.

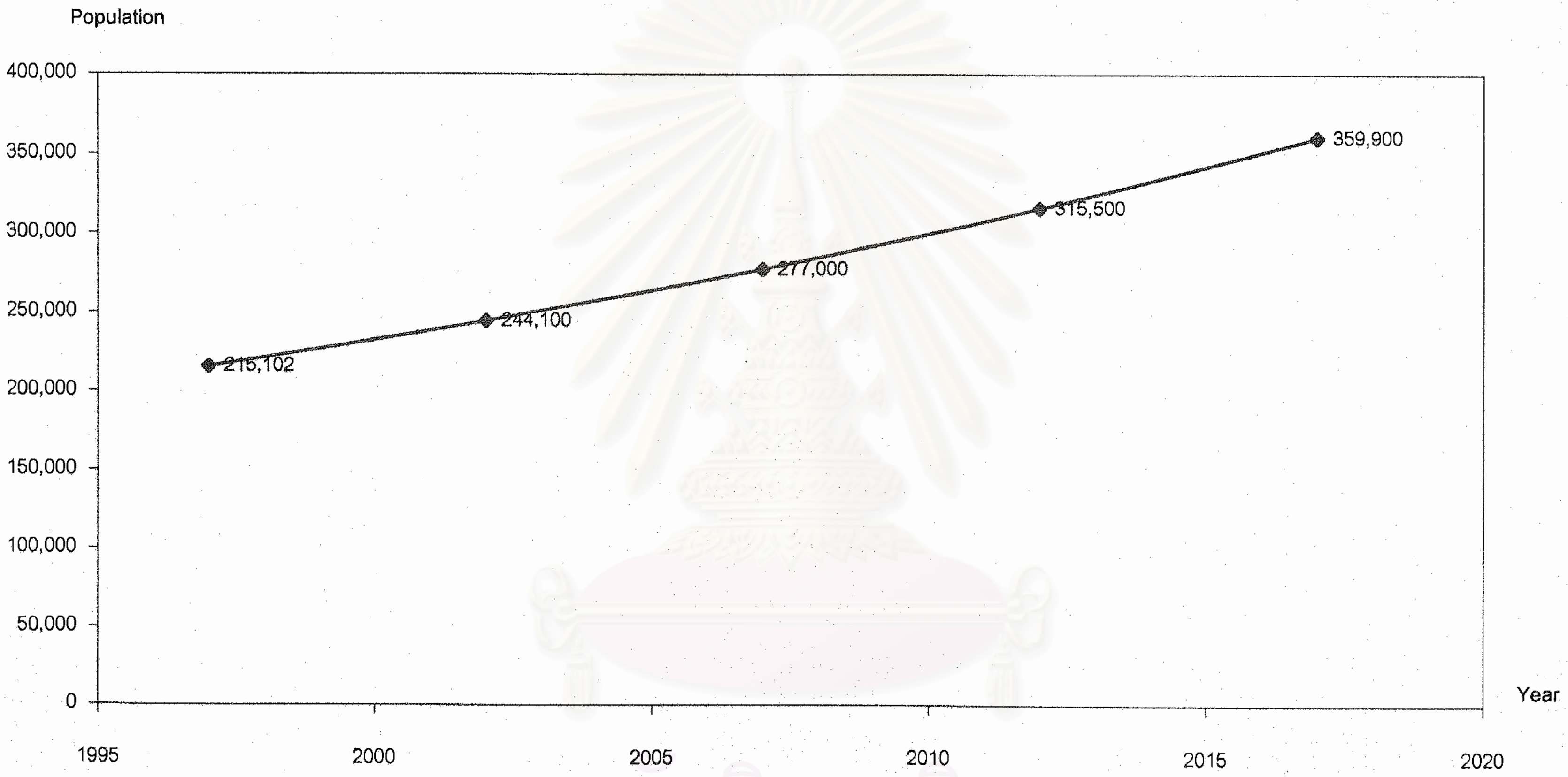


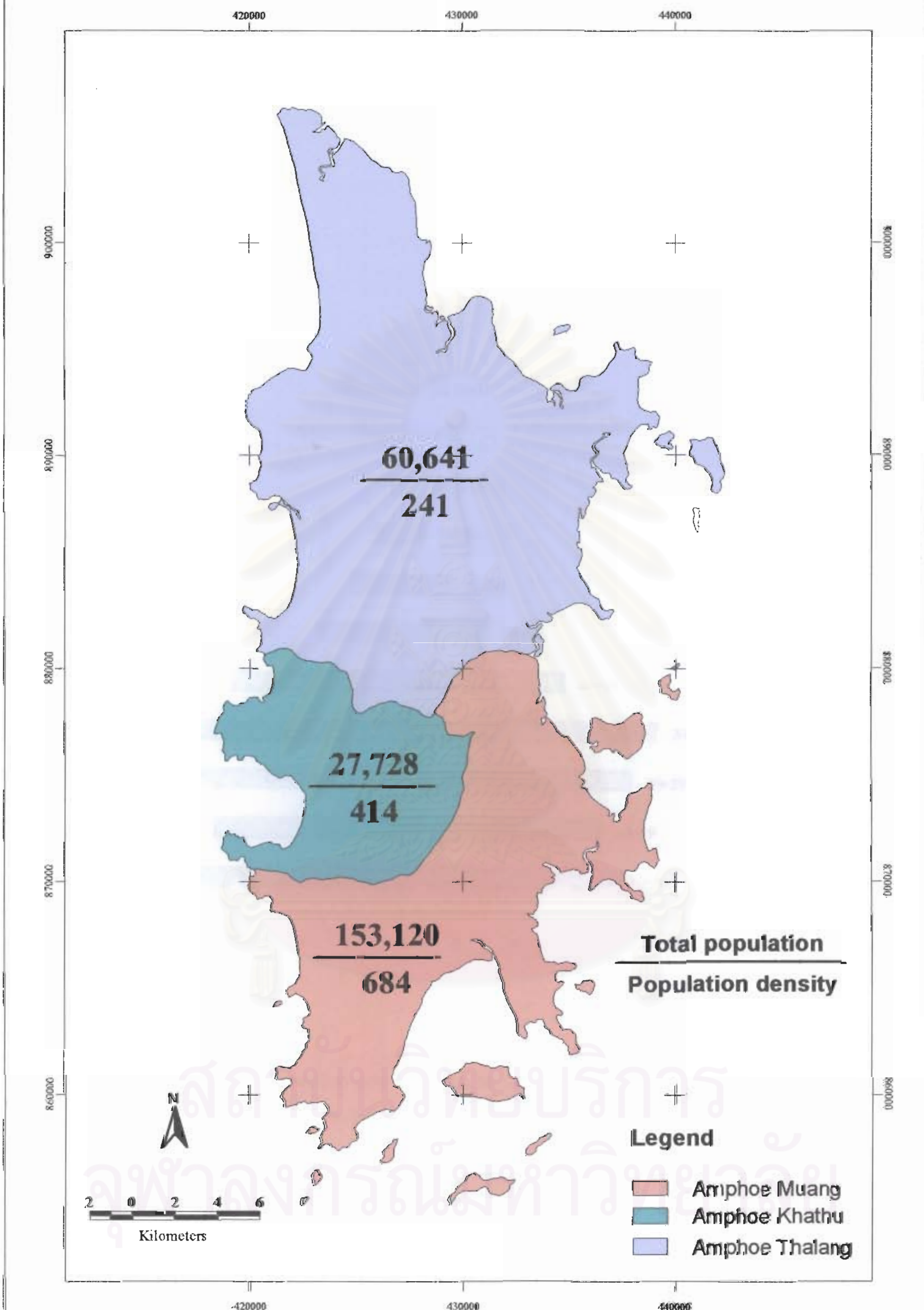
Figure 3.2 The estimation of population growth of changwat Phuket until 2017

(Source: Phuket Provincial Statistical Office,2000)

Table 3.2 The Estimation of Population Growth Of Changwat Phuket until 2017

(Source : Phuket Provincial Statistical Office,2000)

Amphoe	Tambon	Growth Rate	Population Growth				
			1997	2002	2007	2012	2017
Changwat Phuket		2.4896	215,102	244,100	277,000	315,500	359,900
Muang Phuket	8 Tambons	2.163	133,469	153,200	175,700	202,200	233,000
	Talat Nua	2.3537	23,622	26,600	29,900	33,600	37,800
	Talat Yai	1.516	32,323	34,900	37,600	40,600	43,800
	Karon	2.5314	4,897	5,600	6,300	7,200	8,100
	Chalong	2.3416	9,567	10,800	12,100	13,600	15,300
	Rawai	3.4595	10,008	11,900	14,100	16,800	20,000
	Ratsada	3.711	22,011	26,500	31,900	38,400	46,200
	Ko Kaeo	3.3395	7,756	9,200	10,800	12,800	15,100
	Wichit	3.4757	23,285	27,700	33,000	39,200	46,700
Kathu	3 Tambons	2.0436	23,208	25,800	28,700	32,100	36,000
	Kathu	3.339	10,686	12,700	15,000	17,800	21,100
	Kamala	1.1781	3,496	3,700	3,900	4,200	4,400
	Patong	0.7742	9,026	9,400	9,800	10,100	10,500
Thalang	6 Tambons	2.1489	58,425	65,100	72,600	81,200	90,900
	Thep Krasattri	0.9251	15,320	16,000	16,800	17,600	18,400
	Sri sunthon	2.051	10,359	11,500	127,000	14,100	15,600
	Choeng Thale	2.5632	10,646	12,100	13,800	15,600	17,800
	Pa Khlok	2.9697	8,627	10,000	11,600	13,500	15,600
	Mai Khao	2.9835	9,978	11,600	13,400	15,600	18,100
	Sakhu	2.1334	3,495	3,900	4,300	4,800	5,400



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Hathaithip Thassanapak
Department of Geology, Faculty of Science
Chulalongkorn University
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Figure 3.3 Population Density of Changwat Phuket
(Source: Phuket Provincial Statistical Office,2000)

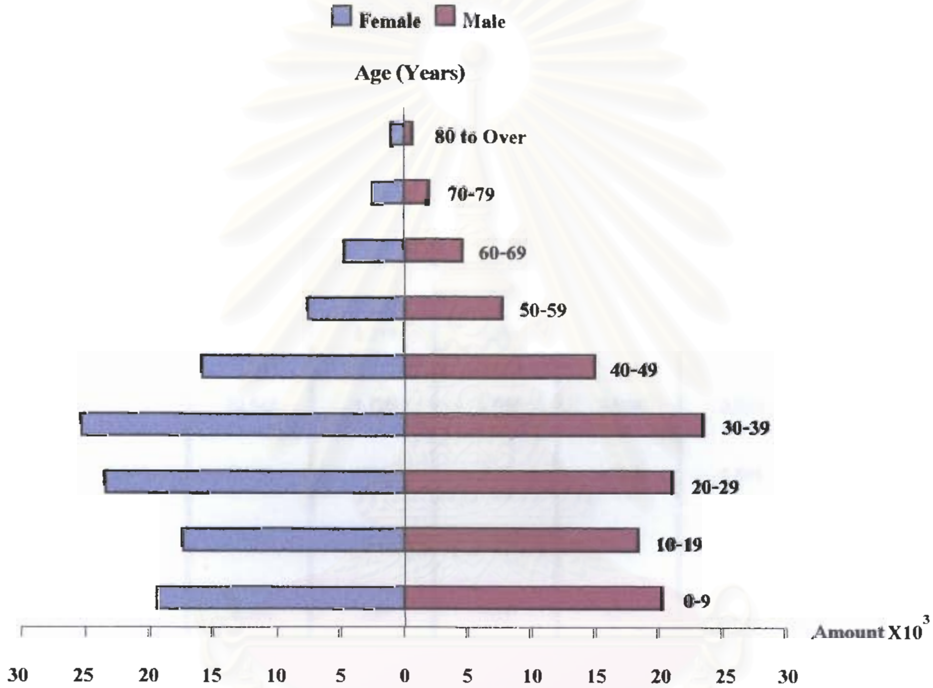


Figure 3.4 Population age structure of Changwat Phuket (1999)

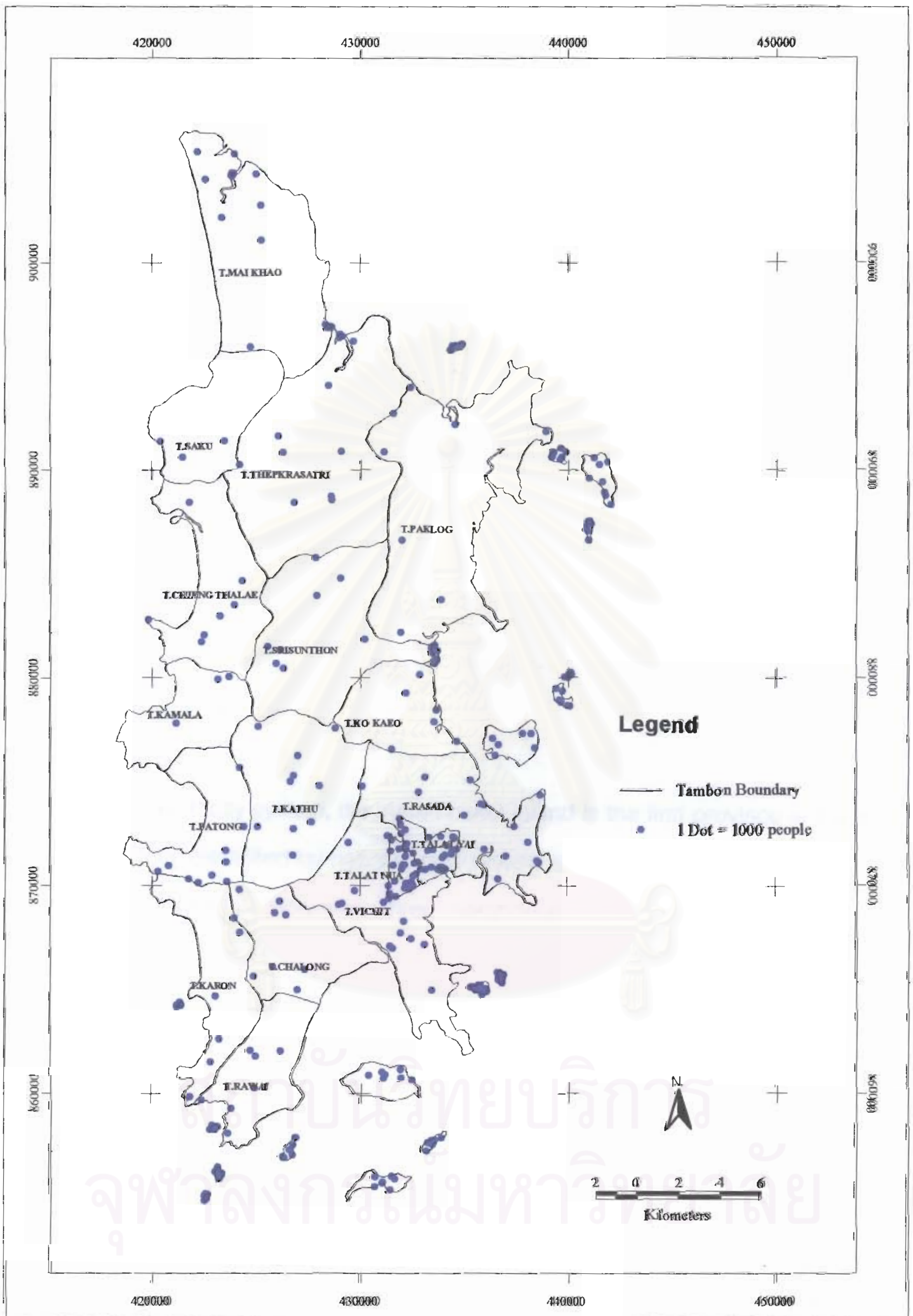
(Source : Phuket Provincial Administration Office,1999)

Table 3.3 The Population Age Structure Of Changwat Phuket in 1999.

(Source : Phuket Provincial Statistical Office,2000)

Age (year)	Muang Phuket		Kathu		Thalang		Total	
	male	female	male	female	male	female	male	female
0 to 9	13,286	12,574	2,193	2,101	4,940	4,666	20,419	19,341
10 to 19	11,760	11,366	1,754	1,774	4,940	4,219	18,454	17,359
20 to 29	12,778	14,389	2,861	3,202	5,602	5,890	21,241	23,481
30 to 39	14,547	16,452	3,211	3,055	5,896	5,821	23,654	25,328
40 to 49	9,651	10,548	1,765	1,780	3,598	3,563	15,014	15,891
50 to 59	5,039	5,054	861	847	1,796	1,684	7,696	7,585
60 to 69	2,936	3,097	527	556	1,072	1,048	4,535	4,701
70 to 79	1,245	1,656	238	305	471	538	1,954	2,499
80 and over	352	678	98	145	186	225	636	1048
Total	71,594	75,814	13,508	13,765	28,501	27,654	113,603	117,233
							230,836	

* Thai Nationality Only and not included Unknown Lunar Calendar



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

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Department of Geology, Faculty of Science
Chulalongkorn University
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Figure 3.5 Population distribution of Tambon levels of Changwat Phuket (1999)
(Source: Phuket Provincial Statistical Office,2000)

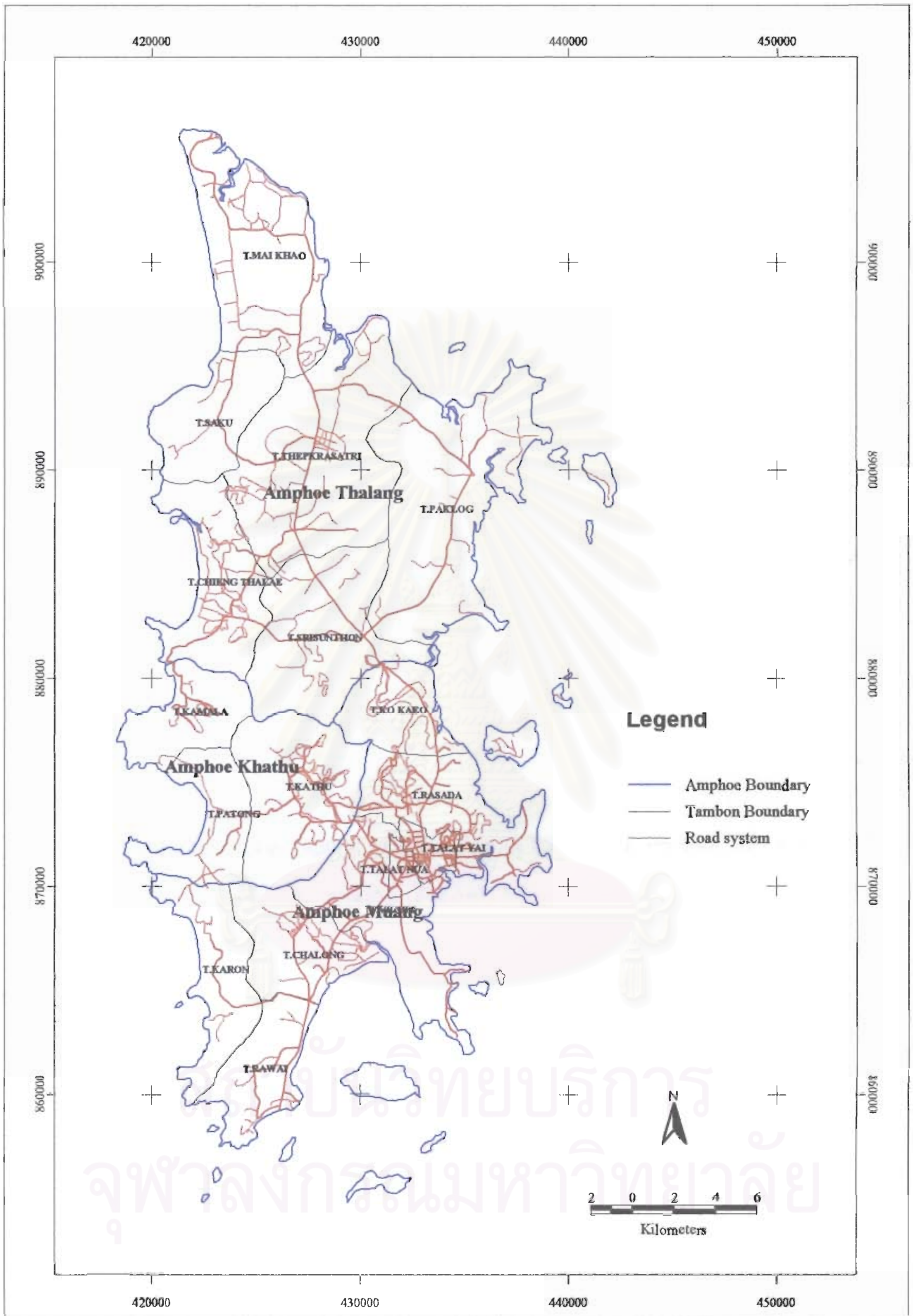
Concerning the medical services in Changwat Phuket, there are 3 government hospitals, 6 private hospitals, 21 health centers, and 122 medical clinics. In 1999, there are totally 117 physicians, 19 dentists, 28 pharmacists, and 387 nurses.

3.1.4 Transportation, Electricity, and Water Supply

The transportation system of Changwat Phuket can be categorised into three groups, namely, on-land road network, international commercial airport, and seaport. Altogether there are asphalt roads with total length of 341 kilometres or 94.7 per cent, and concrete roads with total length of 19 kilometres or 5.3 per cent. For air transportation, there is one international commercial airport with totally 200 domestic and international flights per week. Concerning the sea-going facilities, there are different kinds of port and terminal, namely, one cargoes port, 14 fishing ports, 14 tourists and small fishing ports, and two oil terminals. The road system of Changwat Phuket is presented in Figure 3.6.

For the electricity system, the main Phuket Island is the first province in Thailand that has been fully electrified by national grid system and one local power generator of 10,600-kilowatt capacity. However, three neighbouring small islands, namely, Ko Maphrao, Ko Lon, and Ko Nakha Yai, have been electrified by solar power. The total electricity consumption of Changwat Phuket in 1999 is 752,982,218.23 units.

Altogether there are five water supply stations with total installed capacity of 22,210,800 cubic-metres, whereas the actual water production capacity of 17,182,411 cubic-metres in 1999, namely, Provincial Waterworks Authority Regional Office 4 (Surat Thani), Muang Phuket Municipality Waterworks, Thep Krasattri Municipality Waterworks, Choeng Thale Municipality Waterworks and Ban Sapam Waterworks. There are supplying to 83 villages or 80.6 per cent.



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Hathaithip Thassanapak
Department of Geology, Faculty of Science
Chulalongkorn University
2001

Figure 3.6 Road system of Changwat Phuket
(Source: Phuket Provincial Statistical Office,2000)

3.1.5 Economy

The Gross Provincial Product, GPP, of Changwat Phuket is the highest in southern Thailand or the sixth rank of the country with the figure of 33,567,021 Baht in 1997. The Per Capita Income is 173,206 Baht per annum in 1997. The service industry contributes approximately 30 per cent of the GPP, whereas the agriculture, trades, industry, and others contribute approximate 15,13,11, 31 per cent, respectively. The average economic growth of Changwat Phuket in 1997 was 10.07 per cent.

3.1.6 Recreation and Tourist Attractions

The Phuket Island has been long known as the "Pearl of the Andaman" and it is Thailand most popular beach destination for domestic and overseas tourists. The number of overseas visitors, tourists and excursionists as well as the Thai tourists coming to Changwat Phuket from 1997 to 1999 are summarised and presented in Table 3.4.

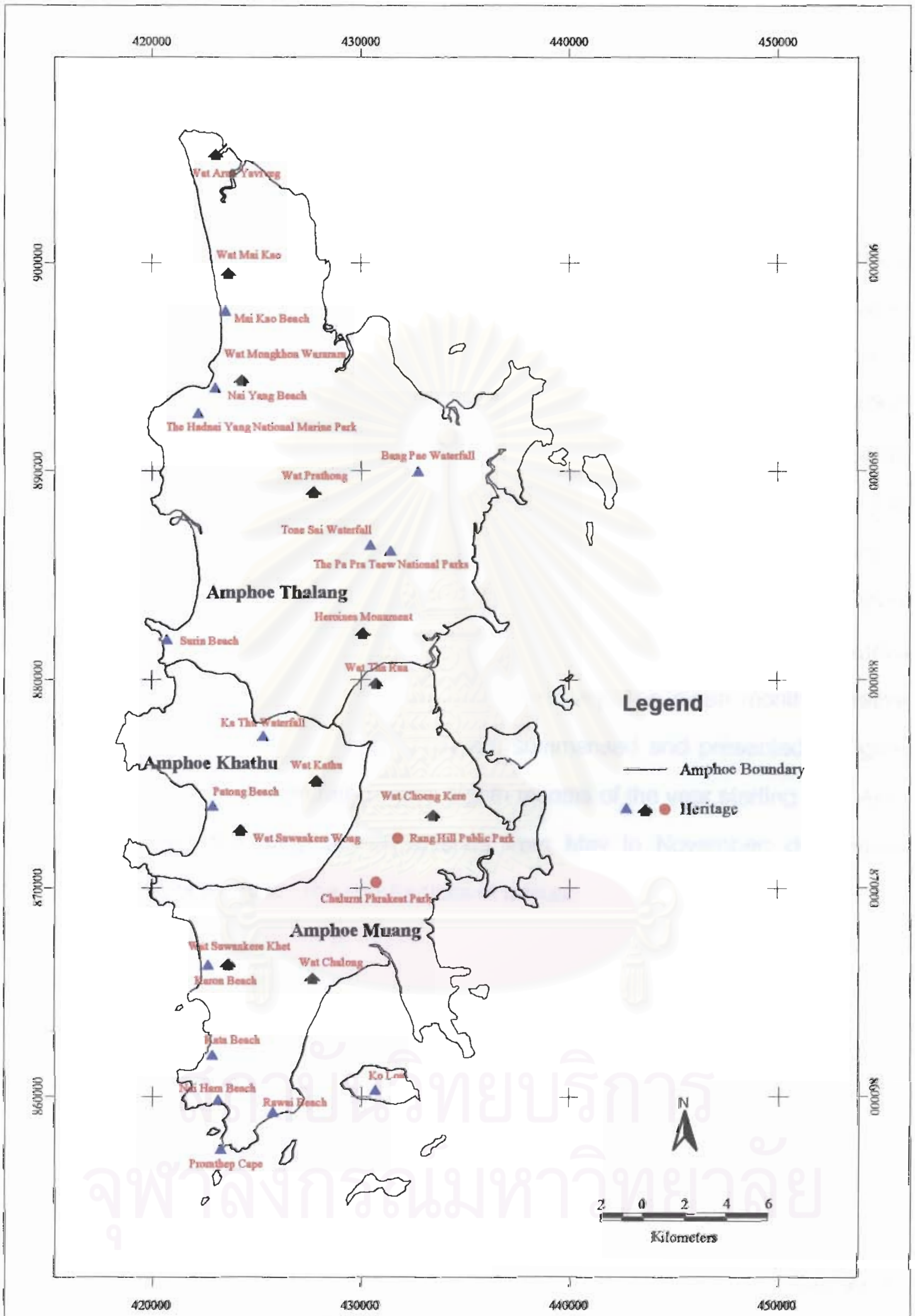
There are numerous places of attraction in Changwat Phuket and surrounding area including small islands around Phuket Island. With respect to the natural attractions, they include beaches and small islands, marine life, national parks, capes, etc, For cultural attractions, heroines monument, old building Shino-Portuguese architecture, Buddhist monasteries, Thalang National Museum, vegetarian festival, tin mines, etc. In addition, there are facilities and infrastructures for tourism and recreation, namely, hotel accommodation, restaurants, entertainment, sport activities etc.

Natural beauties and tourist attractions of the Phuket Island are presented in Figure 3.7.

Table 3.4 Number of Hotels and Visistors(1997-1999)

(Source : Phuket Provincial Statistical Office,2000)

Item	1997	1998	1999
Number of hotels	293	293	303
Number of rooms in hotels	18,590	17,952	20,150
Number of visistors	**2,401,631**	**2,660,420**	**3,083,208**
Thai	747,718	779,167	915,406
Foreigner	1,653,913	1,881,253	2,167,802
Number of tourists	**2,369,021**	**2,626,938**	**2,964,327**
Thai	717,846	750,922	846,463
Foreigner	1,651,175	1,879,016	2,117,864
Number of excurtionists	**32,610**	**30,482**	**118,881**
Thai	29,872	28,245	68,943
Foreigner	2,738	2,237	49,938



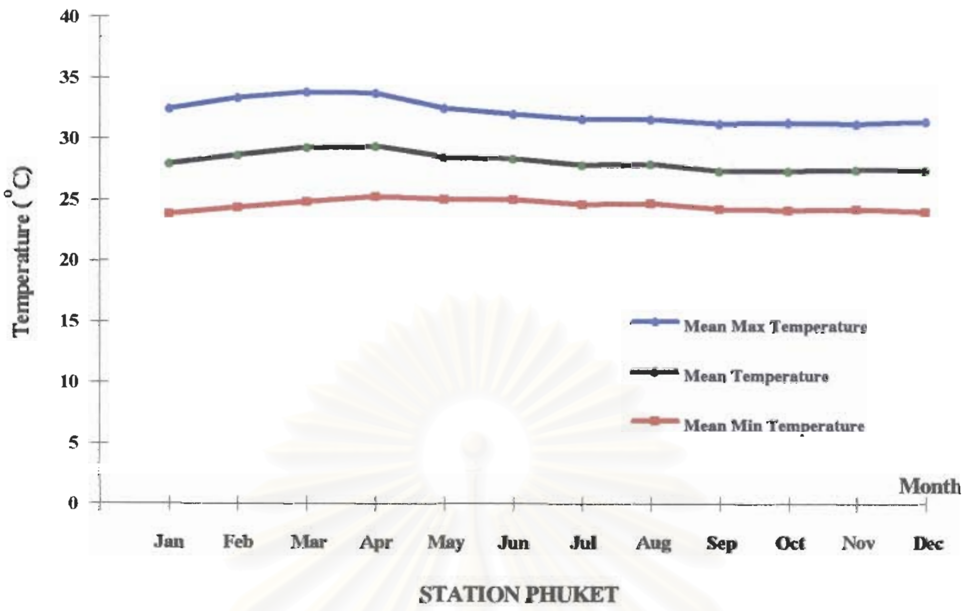
POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET	Figure 3.7 Natural beauties and tourist attraction of Changwat Phuket (Source: Phuket Provincial Statistical Office,2000)
Hathaithip Thassanapak Department of Geology, Faculty of Science Chulalongkorn University 2001	

3.2 Physical Environment

3.2.1 Climate

The climate of the province is classified as "Tropical Monsoon Climate" according to the Koppen Classification. The past 30-year (1971-2000) mean annual temperature is 28.1 degree Celsius and the mean monthly temperature varies between 24.1 to 31.8 degree Celsius (Figure 3.8). The mean annual rainfall of the same period is 2,363 millimetres and the mean monthly annual rainfall varies between 26.6 to 406.6 millimetres. (Figure 3.9). The pattern of relationship between average monthly temperature and average monthly rainfall are summarised as hythergraph in Figure 3.10. The mean annual humidity is 81.3 per cent and the mean monthly humidity is between 86.4 per cent in October and 75.1 per cent in February. The mean annual number of rainy days is 182.7 days and the mean monthly numbers of rainy days varies between 23.2 days in October and 4.4 days in February. The mean monthly relative humidity, rainfall, temperature and rainy day are summarised and presented in Figure 3.11. Rainfall is usually concentrated within eighth months of the year starting from April to November while the rainy season extends from May to November; dry season occupies the rest of the year. The distributions of annual rainfall in Changwat Phuket are presented as the isohyetal map in Figure 3.12. The area of Changwat Phuket is under the influence of the Southwest Monsoon between May to September. This monsoon brings the rain from the Indian Ocean. During October to April, the area is under the influence of the Northeast Monsoon, which brings the cold climate from China. The average monthly wind speed and direction of Changwat Phuket are summarised as the wind rose diagram in Figure 3.13 (Meteorological Department, 2001).

In addition, the historical records of tropical cyclone during November to December are presented in Figure 3.14. The climatological data of Changwat Phuket for the period 1971-2000 is presented in Table 3.5.



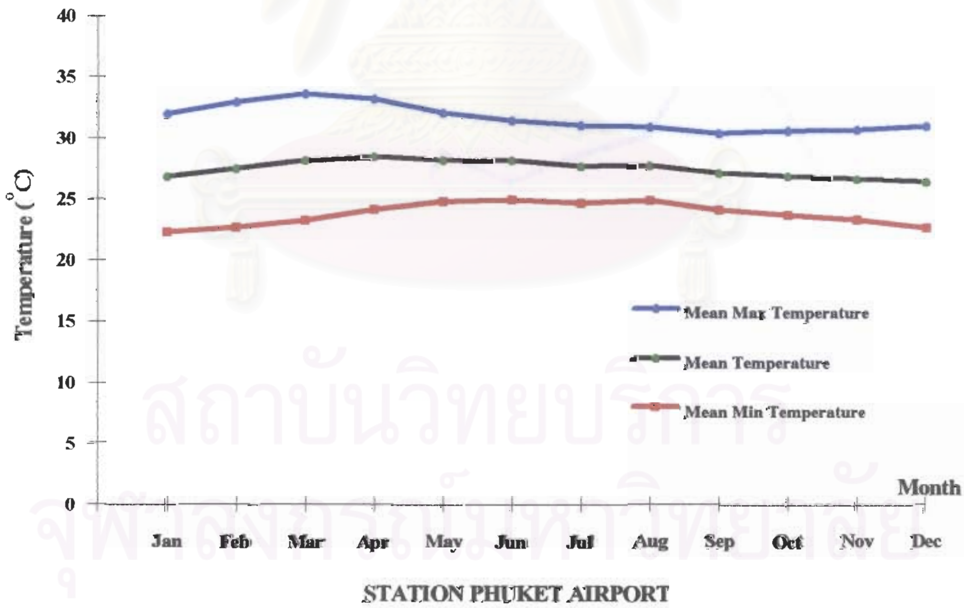
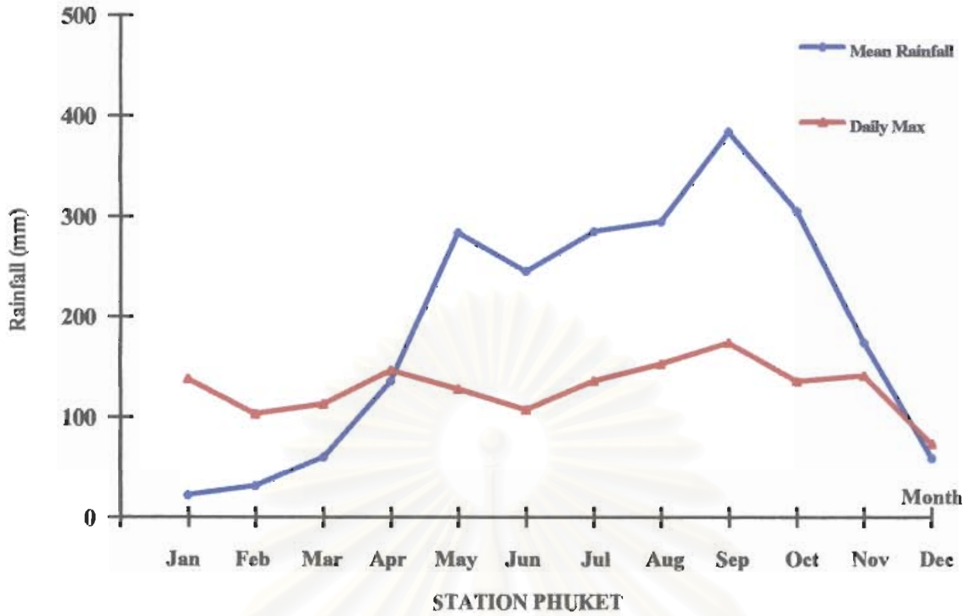


Figure 3.8 Mean monthly temperature of Changwat Phuket (1971-2000)

(Source: Meteorological Department,2001)



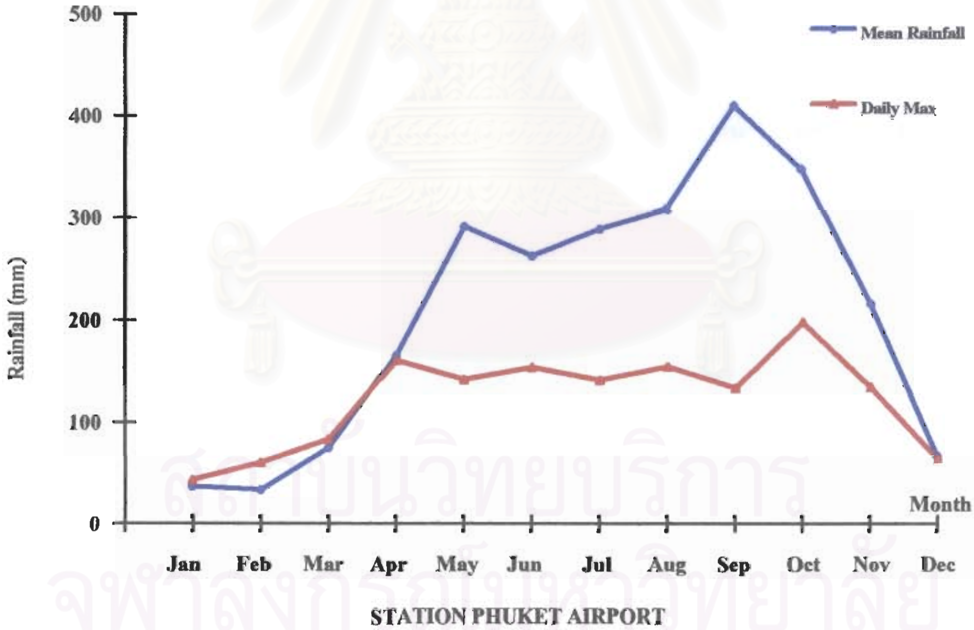


Figure 3.9 Mean monthly Rainfall of Changwat Phuket (1971-2000)

(Source: Meteorological Department,2001)

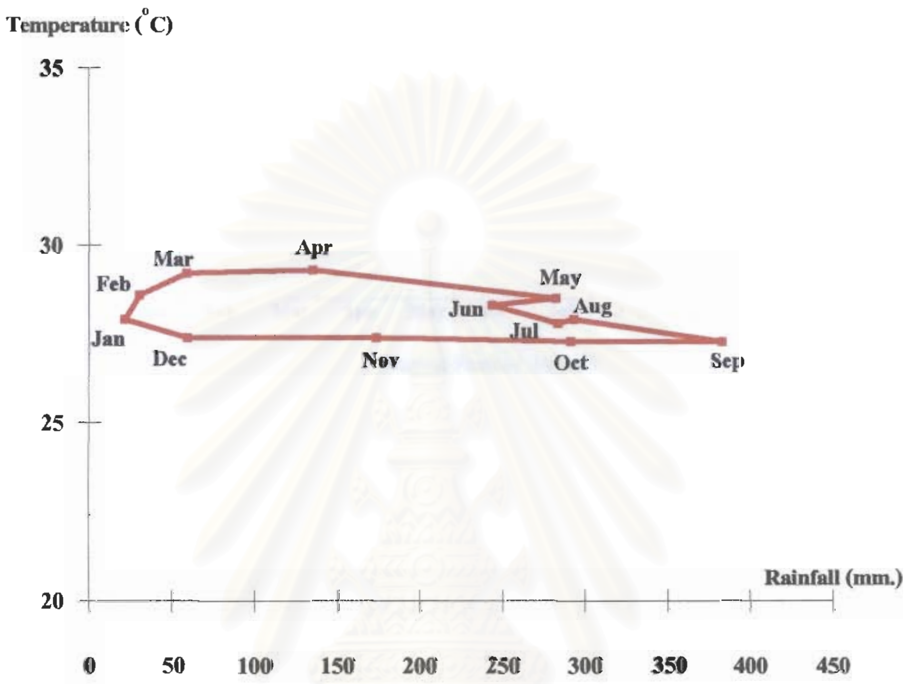
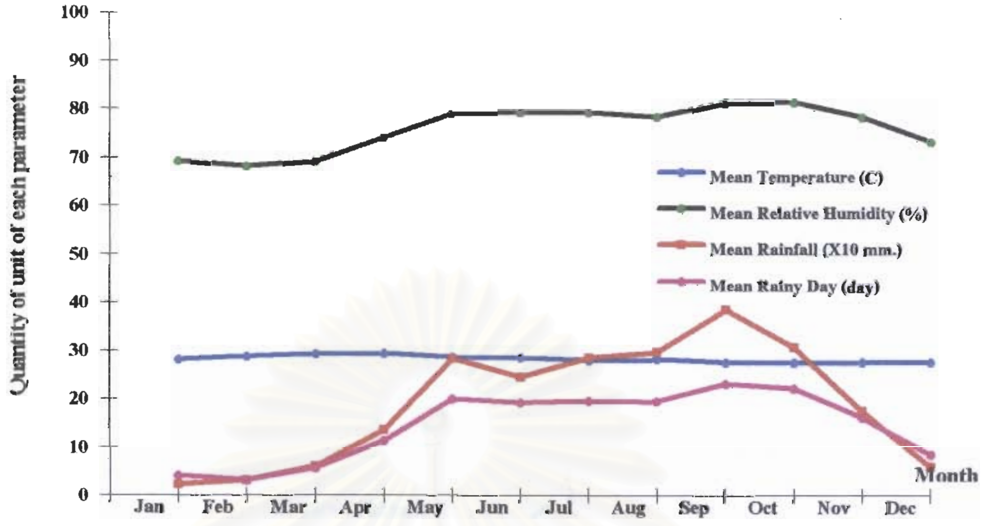
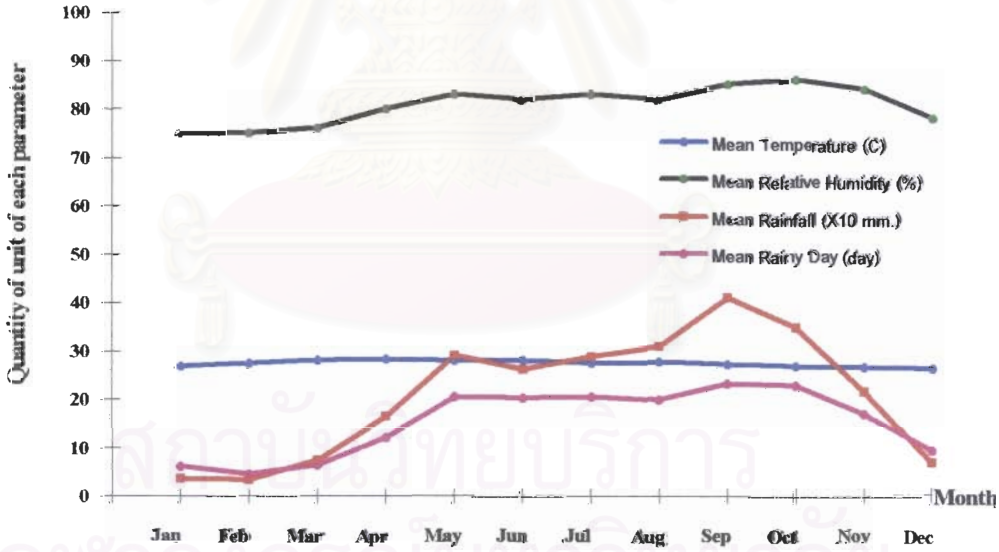


Figure 3.10 Hythergraph of Changwat Phuket (1971-2000)

(Source: Meteorological Department,2001)



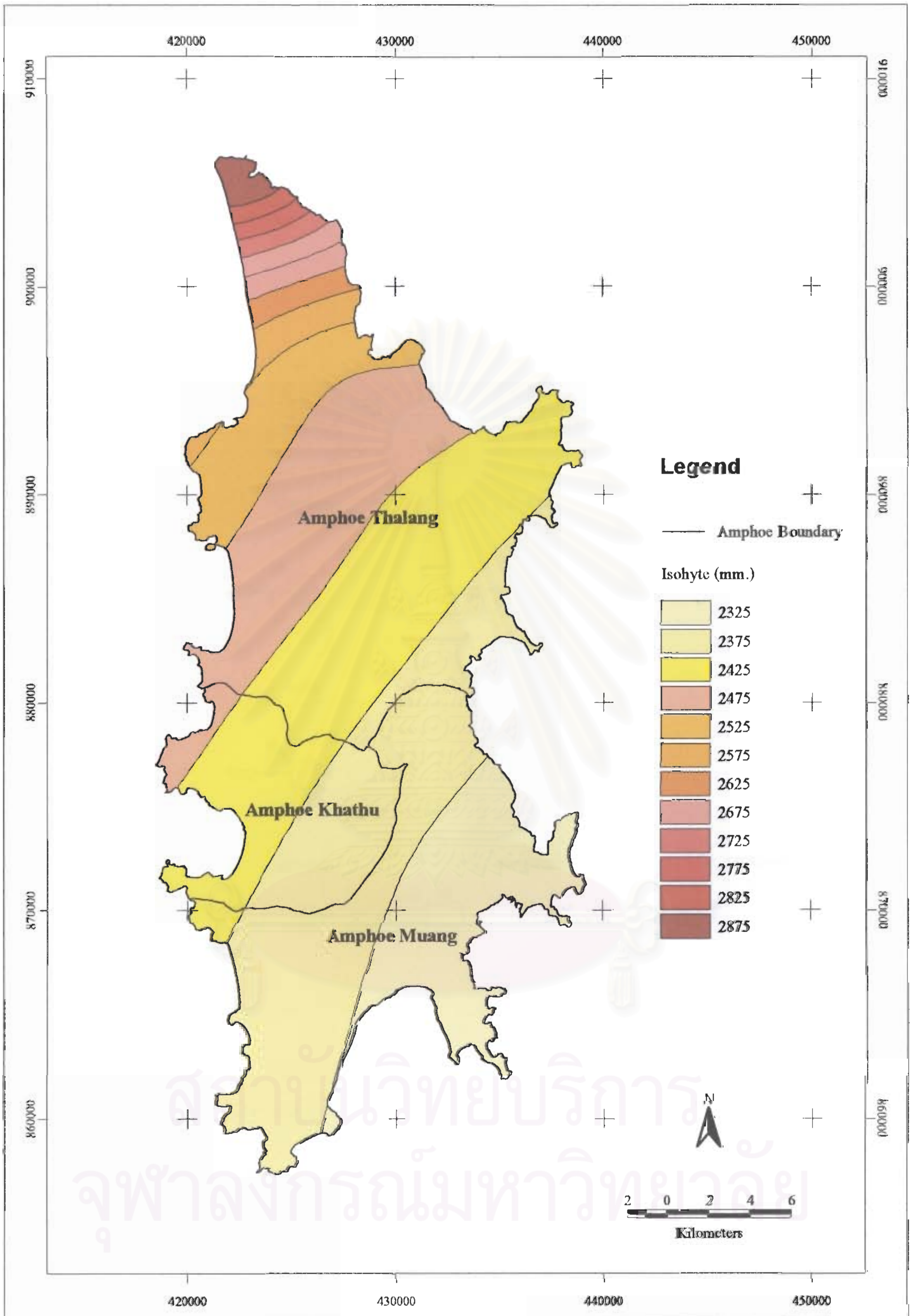
Station Phuket Airport



Station Phuket

Figure 3.11 Mean monthly relative humidity, rainfall, temperature and rainy day of Changwat Phuket (1971-2000)

(Source: Meteorological Department, 2001)



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET	
Hathaithip Thassanapak Department of Geology, Faculty of Science Chulalongkorn University 2001	Figure 3.12 Isohyetal map of Changwat Phuket (Source: Meteorological Department, 2001)

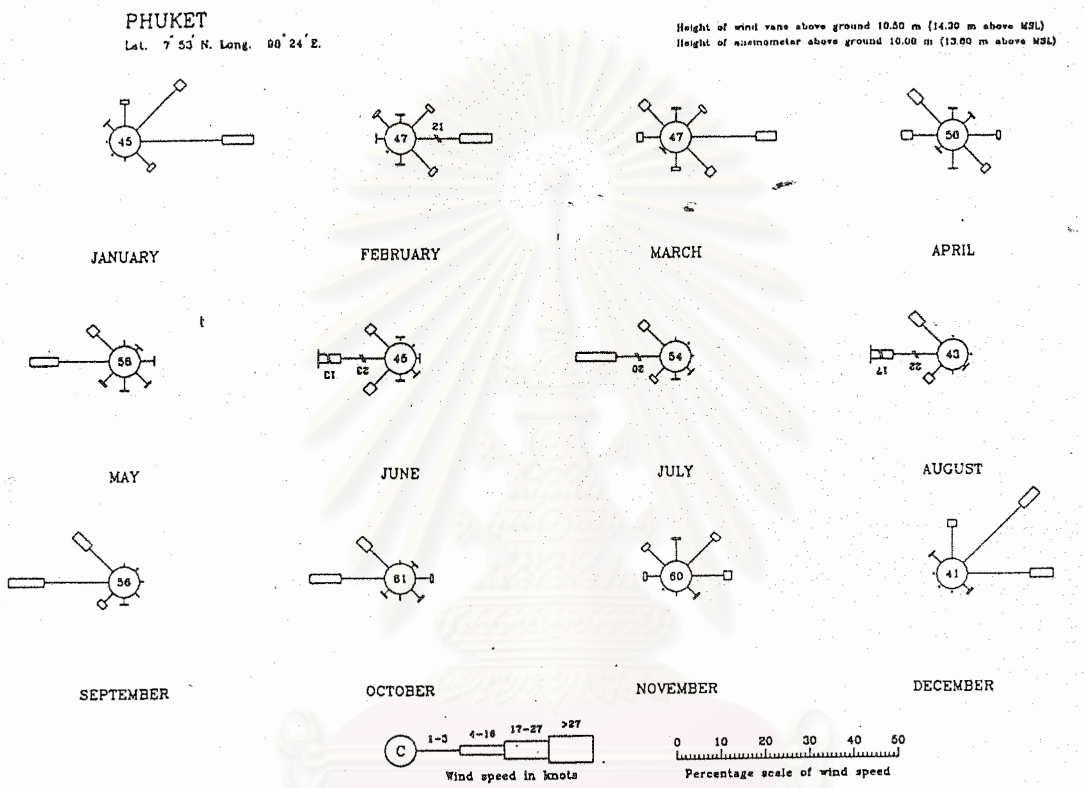
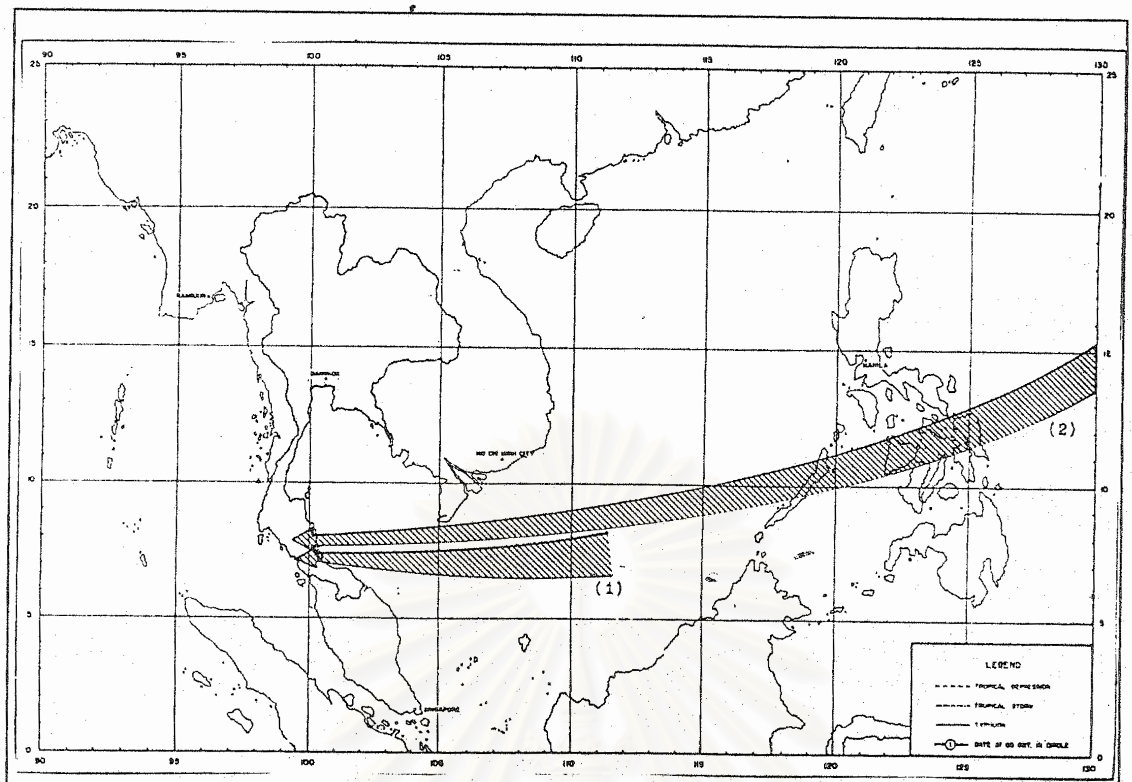
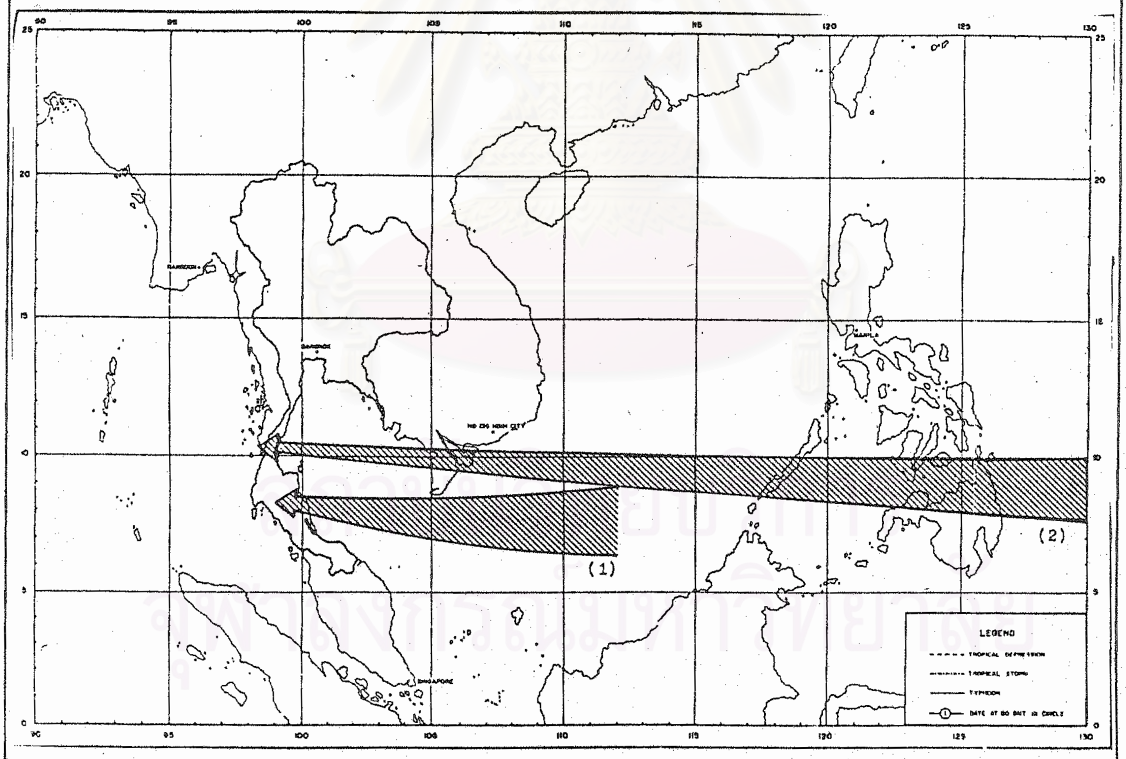


Figure. 3.13. Wind rose diagram of Changwat Phuket.

(Source: Meteorological Department,2001)



November



December

Figure. 3.14. The historical record of tropical cyclone during November to December of Changwat Phuket

(Source: Meteorological Department,2001)

Table 3.5 Climatological Data for the period 1971-2000 (Source:Meteorological Department,2001)

Station PHUKET	Elavation of station above MSL	2	Meters
Index station 48564	Height of barometer above MSL.	3	Meters
Latitude 07 53 N	Height of thermometer above ground	1.22	Meters
Longitude 98 24 E	Height of wind vane above ground	10.50	Meters
	Height of raingauge	0.78	Meters

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pressure (Hectopascal)													
Mean	1010.75	1010.32	1009.67	1008.66	1008.29	1008.35	1008.53	1008.87	1009.36	1009.66	1009.87	1010.74	1009.42
Ext. max.	1016.60	1017.77	1016.72	1015.79	1013.82	1013.79	1013.83	1014.73	1015.89	1015.41	1015.89	1016.23	1017.77
Ext. min.	1004.11	1003.06	102.61	1003.31	1002.69	1003.20	1003.12	1003.28	1003.39	1004.45	1003.87	1004.10	1002.61
Mean diary range	4.12	4.23	4.31	3.97	3.34	2.80	2.78	2.96	3.47	3.83	3.89	3.91	3.63
Temperature (celsius)													
Mean	27.9	28.6	29.2	29.3	28.5	28.3	27.8	27.9	27.3	27.3	27.4	27.4	28.1
Mean max.	32.4	33.3	33.8	33.7	32.5	32.0	31.6	31.6	31.2	31.3	31.2	31.4	32.2
Mean min.	23.8	24.3	24.8	25.2	25.0	25.0	24.6	24.7	24.2	24.1	24.2	24.0	24
Ext. max.	36.3	36.7	37.7	37.8	37.8	35.1	35.0	34.7	34.8	34.4	34.3	34.2	37
Ext. min.	18.3	18.6	20.0	20.5	21.1	21.0	20.5	21.0	21.1	20.5	19.7	18.4	18
Relative Humidity (%)													
Mean	69	68	69	74	79	79	79	78	81	81	78	73	76
Mean max.	84	84	85	90	92	91	91	90	93	93	90	86	89
Mean min.	53	51	52	57	65	65	66	65	68	67	64	59	61
Ext. min.	30	33	30	28	42	46	46	40	48	43	39	37	28
Dew Point (celsius)													
Mean	21.4	21.7	22.6	23.8	24.3	24.0	23.7	23.5	23.6	23.6	23.1	21.9	23.1

Table 3.5 continued

Evapolation (mm.)													
Mean-pan	154.4	151.8	168.6	146.3	121.7	111.6	111.2	111.5	102.4	106.6	110.0	133.3	1529.4
Cloudiness (0-10)													
Mean	4.0	4.0	4.6	5.8	7.2	7.5	7.6	7.6	7.8	7.6	6.8	5.2	6.3
Sunshine Duration (hr.)													
							NO OBSERVATION						
Visibility(km.)													
0700 L.S.T	9.0	8.3	7.6	7.7	8.7	9.0	8.8	8.9	8.5	8.8	9.1	9.1	8.6
Mean	9.6	9.0	8.0	8.2	9.2	9.5	9.3	9.4	9.1	9.3	9.6	9.7	9.2
Wind (knots)													
Mean wind speed	2.9	2.7	2.5	2.0	2.1	2.6	2.6	3.4	2.6	2.0	2.3	3.3	-
Prevailing wind	E	E	E	E	W	W	W	W	W	W	NE	NE	NE
Max. wind speed	20	22	22	32	27	40	32	30	28	30	27	22	40
Rainfall (mm.)													
Mean	21.7	30.3	59.2	135.4	282.6	244.0	283.5	293.5	382.8	205	173.8	59.4	2271.2
Rainfall (mm.)													
Mean rainy day	4.0	3.1	5.6	11.2	19.9	19.1	19.5	19.2	22.9	22.0	16.0	8.5	171.0
Daily maximum	36.6	102.3	111.9	145.7	127.0	106.4	135.3	151.7	172.8	135.3	141.0	73.4	172.8
Number of days with													
Haze	10.2	12.5	20.2	14.8	2.3	1.8	3.4	3.4	1.4	2.5	2.8	7.0	82.3
Fog	0.0	0.0	0.0	0.4	0.3	0.0	0.0	0.1	0.2	0.1	0.0	0.0	0.1
Hail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thundersorm	0.9	1.2	3.9	8.0	9.6	3.9	3.8	2.4	2.8	5.3	5.3	2.1	49.2
Squall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.5 continued

Station PHUKET AIRPORT	Elavation of station above MSL	6	Meters
Index station 48565	Height of barometer above MSL	10	Meters
Latitude 08 07 N	Height of thermometer above ground	1.20	Meters
Longitude 98 19 E	Height of wind vane above ground	10.50	Meters
	Height of raingauge	0.75	Meters

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pressure (Hectopascal)													
Mean	1010.96	1010.57	1009.94	108.96	1008.56	1008.64	1008.82	1009.21	1009.70	1009.94	1010.08	1010.93	1009.69
Ext. max.	1016.30	1016.53	1016.30	1015.98	1014.10	1014.42	1013.83	1015.07	1015.75	1005.84	1015.38	1016.42	1016.53
Ext. min.	1003.89	1003.38	1002.68	1003.40	1002.98	1003.72	1003.29	1003.52	1004.02	1004.50	1004.05	1004.29	1002.68
Mean diary range	3.79	3.82	3.91	9.67	3.15	2.68	2.6	2.79	3.28	3.62	3.69	3.65	3.39
Temperature (celsius)													
Mean	26.7	27.4	28.1	28.4	28.1	28.1	27.6	27.7	27.1	26.8	26.6	26.4	27.4
Mean max.	31.9	32.9	33.6	33.2	32.0	31.4	31.0	30.9	30.4	30.6	30.7	31.0	31.6
Mean min.	22.2	22.6	23.2	24.1	24.7	24.9	24.6	24.9	24.1	23.7	23.3	22.7	23.8
Ext. max.	35.5	36.2	37.5	37.6	37.2	35.0	34.2	34.8	34.4	33.9	36.1	33.5	37.6
Ext. min.	17.8	17.1	18.5	21.1	21.4	20.5	21.0	20.7	21.2	21.0	19.8	17.2	17.1
Relative Humidity (%)													
Mean	75	75	76	80	83	82	83	82	85	86	84	78	81
Mean max.	92	92	94	95	95	92	93	91	95	96	95	91	93
Relative Humidity (%)													
Mean min.	55	53	55	62	69	71	71	71	74	72	68	61	65
Ext. min.	33	33	27	29	45	46	54	43	55	52	46	40	27
Dew Point (celsius)													

Table 3.5 continued

Mean	21.6	22.1	23.0	24.2	24.7	21.6	24.2	24.2	24.2	24.1	23.4	22.1	23.5
Evapolation (mm.)													
Mean-pan	160.2	157.3	188.4	160.9	138.3	128.2	133.4	136.9	118.9	117.6	118.8	137.9	1696.8
Cloudiness (0-10)													
Mean	5.2	5.0	5.5	6.6	7.6	7.8	7.9	8.0	8.1	7.9	7.2	5.9	6.9
Sunshine Duration (hr.)													
Mean	272.0	254.3	266.7	231.3	182.9	124.0	158.3	160.1	131.1	158.1	176.0	222.8	2337.6
Visibility(km.)													
0700 L.S.T	9.4	8.7	8.1	8.4	9.1	9.3	9.3	9.1	9.0	9.2	9.6	9.5	9.1
Mean	10	9.4	8.7	8.8	9.4	9.6	9.6	9.6	9.4	9.5	9.8	9.9	9.5
Wind (knots)													
Mean wind speed	4.3	4.2	4.1	3.6	4.2	5.7	5.4	6.4	5.3	3.7	3.1	4.2	-
Prevailing wind	E	E	E	NW	W	W	W	W	W	W	W	E	E
Max. wind speed	30	30	30	32	48	42	44	42	50	46	37	99	99
Rainfall (mm.)													
Mean	35.9	32.6	74.0	165.0	291.4	262.4	288.9	308.3	408.9	47.5	216.0	65.9	2496.8
Rainfall (mm.)													
Mean rainy day	6.1	4.5	6.3	12.2	20.7	20.4	20.6	19.9	23.2	22.8	16.9	9.2	182.8
Daily maximum	42.0	59.0	82.0	160.3	141.4	153.0	140.9	154.1	133.0	97.6	134.7	63.2	197.6
Number of days with													
Haze	8.5	11.3	15.5	9.1	1.1	1.3	0.9	1.0	1.2	0.8	1.7	6.2	58.6
Fog	0.0	0.0	0.1	0.4	0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Hail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thundersorm	1.9	2.7	5.8	11.6	11.5	4.9	4.9	2.9	4.0	8.1	7.4	2.9	68.6
Squall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3.2.2 Topography and Landform

The topography of Phuket Island is mainly dominated by the part of Ta-nao Sri Mountain Range the part of Ta-nao Sri Range extended southwardly within the Phuket Island, the high mountainous area with maximum elevation of 529 metres (MSL) at Khao Mai Thao Sip Song in Amphoe Kathu occupies the western part of the island. The flat plain of the island, namely, coastal plain and floodplain are situated very closed to the MSL. Therefore, the maximum relief of the island is slightly over 520 metres. The elevation of Phuket Island is summarised as hypsometry map in Figure 3.15.

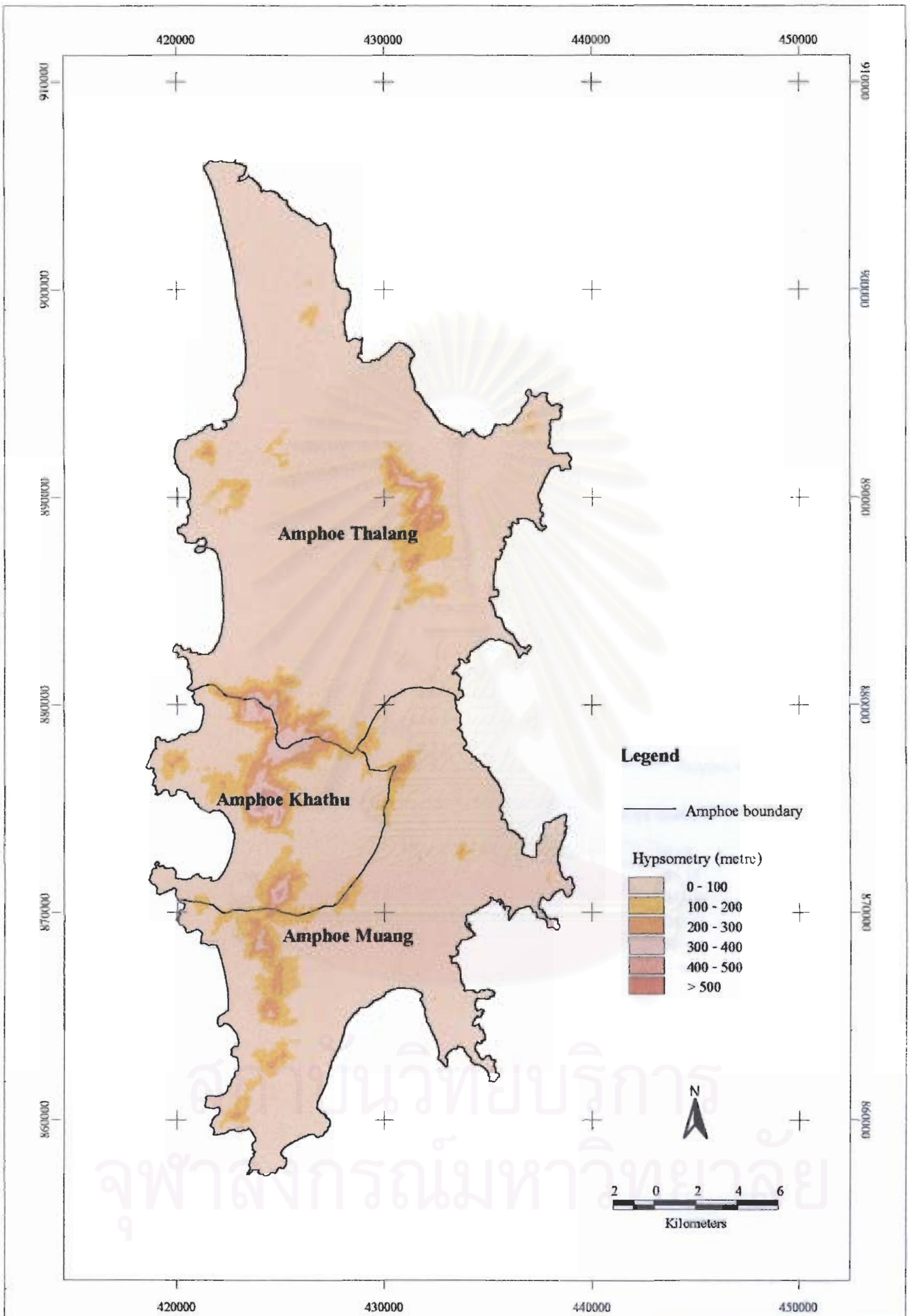
Generally, the landform of Phuket Island can be subdivided into 3 main types, notably, mountainous area, rolling or undulating area, and flat plain. The mountainous area occupies approximately 40 per cent of the total area of Phuket Island mainly in the western part. The rolling or undulating area occupies approximately 20 per cent of the total area of Phuket Island particularly between the mountainous area and flat plain. The flat plain of both coastal plain and floodplain occupies approximately 40 per cent of the total area of Phuket Island and mainly occupies the eastern part of the island. The slope and landform map of Phuket Island is presented in Figure 3.16.

3.2.3 Geology of Phuket Island

Various types of rock units ranging from unconsolidated sediments, sedimentary rocks, meta-sediments, and igneous rocks are present in the Phuket Island.

The oldest rocks of the island are sedimentary rocks of Kaeng Krachan Group covering less than one third of the area as narrow strips along the east coast and on a number of adjacent small islands.

The igneous rocks of Phuket Island are granitic rocks. The granitic rocks of Cretaceous Era (140-64 million years) cover more than two third of the island mostly in the western and east -central part.



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

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Department of Geology, Faculty of Science
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Figure 3.15 Hypsometry map of Changwat Phuket

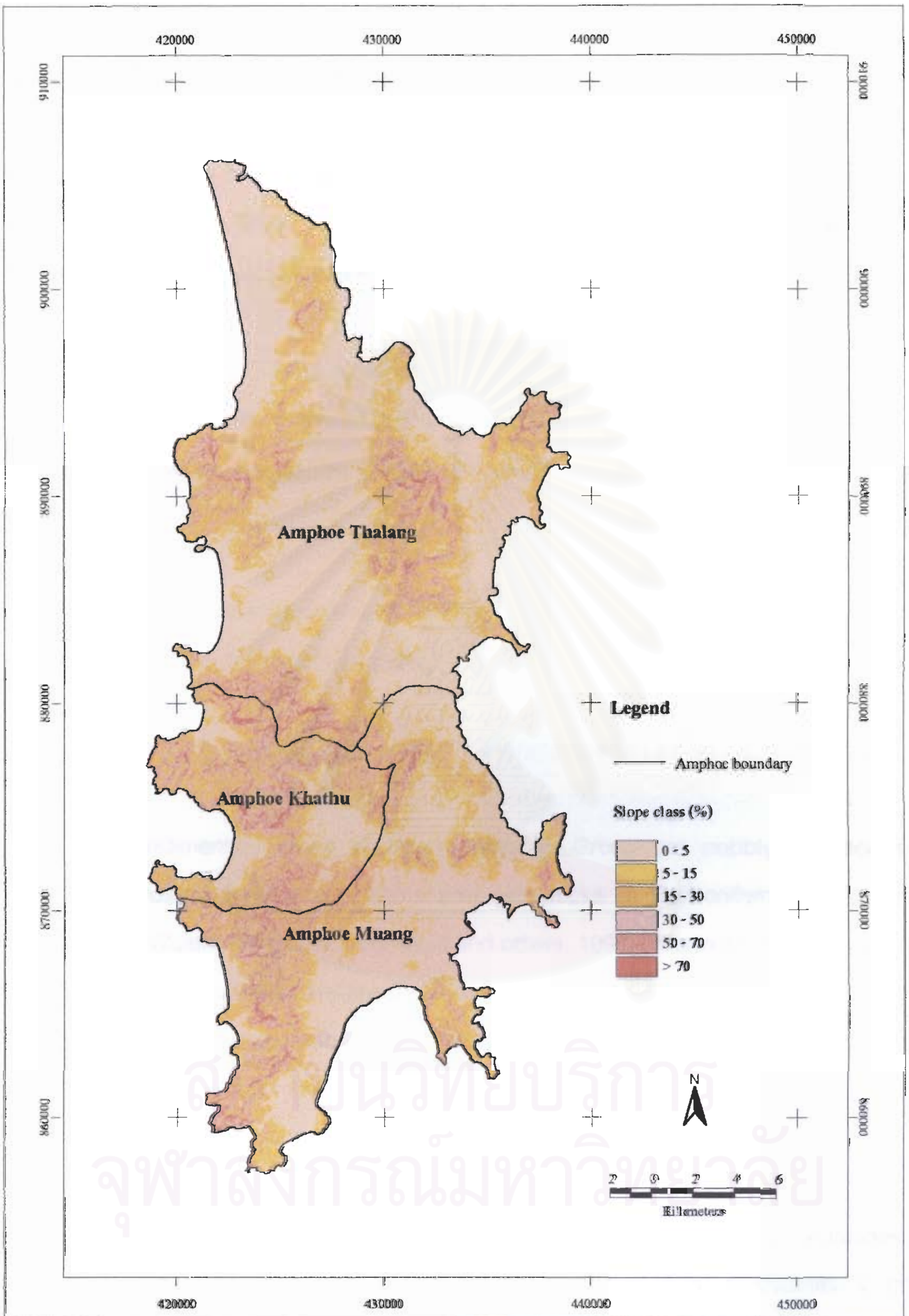

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Figure 3.16 Slope map of Changwat Phuket

There are numerous varieties of late megmatic derivations in this area. They are aplite and dikes and sills of pegmatitre, quartz, and felsic which are found cross-cutting into Kaeng Krachan Group and the main granite rocks. Predominantly, these late tabular plutons trend in the NE-SW which some of them carry tin and tungsten minerals in volume large enough to be the prime source for the economic ore deposits. Many tin mines have been worked in these minor intrusives (Charusiri and Pongsapich, 1982).

Some rocks of Kaeng Krachan Group show evidence of low-grade contact metamorphism. Besides, extensive contact metamorphosed sedimentary rocks of the Phuket Island occur around the granite plutons and as roof pendants (Putthapiban, 1984).

The unconsolidated sediments of Quaternary age are colluvial deposits, flood plain deposits and coastal plain deposits.

3.2.3.1 Sedimentary Rocks

The sedimentary rocks of Kaeng Krachan Group are pebbly mudstones, laminated mudstones, siltstones, shale and graywacks of Carboniferous to Lower Permian Age (Waterhouse, 1982; Archibold and others, 1984). The rocks exposed along the East Coast of Phuket Island are those of the lower part of Kaeng Krachan Group having a thickness of approximately 520 metres. They occure as N-S moutain range parallel to the coast and cover about 30 per cent of total area (Chaimanee and Teerarungsikul, 1993)

Rocks of Kaeng Krachan Group on Phuket Island are mainly pebbly mudstones, graywacks, laminated mudstones, and turbidites. The pebbly mudstones (or diamictites) are poorly sorted and contain abundant clasts of carbonate rocks, slate, quartzitic sanstone and granite. These clasts vary from pebbles to boulders in size and their shapes are mainly angular to subangular with fewer subrounded to well-rounded

3.2.3.2 Granitic Rocks

The granites of Phuket Island are felsic types with compositions ranging from granite to Leucomonzonite (adamellite) quartz monzodiorite is presented in small amounts along the margins of some plutons. The granites form the elongate bodies aligned in a north-south direction parallel to regional structural features. In general, they form two separate mountain ranges, the western range (Khao Mai Tao Sip Song) and the relatively shorter eastern range (Khao Prathiu). However, a number of granites bodies are found as low hills in the eastern part and as small islands to the south of Phuket. These granites intrude sedimentary rocks of Kaeng Krachan Group (Permo-Carboniferous). Contact metamorphic aureoles are poorly defined. The observed contacts between granite and country rocks are relatively gently dipping. Therefore the true width of contact aureoles is much less than the apparent width and is considered to be approximately one kilometre (Putthapiban, 1984).

The one common structural feature is well developed jointing with a moderate to steep dip (50 to 80 degrees); horizontal joints are less common. There are two dominant joint systems, one trending north-east, the other trending north-west. Joint analyses indicate similarities between the joint pattern of the eastern and western granite bodies, but in the eastern granites, the northeast joints are more prominent. The joint systems have similar orientations to the major fault system (Putthapiban, 1984)

Putthapiban (1984) has been grouped the granitic rocks into 4 suite based on the detailed mapping, petrography, geochemistry, rubidium-strontium isochron age determination and potassium-argon dating.

They are :

G1-suite : Khao Pratiu suite (82±4 my.)

G2-suite : Kata Beach suite (98±7 my.)

G3-suite : Naithon Beach suite (100±6 my.)

G4-suite : Khao To Sae suite (78±4 my.)

Recently, Chaimanee and Teerarungsikul (1993) have been grouped the granitic into 5 suite, which, are divided the Khao Rang granitic from Khao Tosae suite, as following :

1. **Khao Prathiu suite-G1** (Porphyritic-biotite granite) show coarse to very coarse texture. The main accessory minerals are hornblend, allannite, sphene and apatite. Rb/Sr feldspar age of this granite revealed with 82±4 my. This suite is found as Khao Prathiu and Khao Para in eastern part of Amphoe Thalang cover the area approximately 25 square kilometres.
2. **Kata Beach suite-G2** (Biotite-hornblend granite) show fine grain texture. Feldspar megacrysts align with contact trend of the phuton. The main accessory minerals composed of sphene, magnetite and apatite. The Rb/Sr age gave about 98±7 my. The distribution is found as Khao Sai Kru, Khao Promthep, Khao Tut, Khao Sai Mean, Laem Khang, Khao Get Ni, Khao Ta Giang and Kanim Waterfalls.
3. **Naithon Beach suite-G3** (Porphyritic muscovite-biotite granite) show coarse texture. The main accessory minerals are zircon, monzonite and apatite. This granite is very similar with the G1 granite but it contains highly muscovite. The Rb/Sr age gave about 100±6 my. The rock suite is found as Khao Sai Kru, Khao Muang, Laem Son and Laem To which cover the area about 6 square kilometres.
4. **Khao To Sae suite-G4** (Biotite-muscovite granite) show fine to medium texture. Cassiterite, scheete and monazite are the main accessory minerals. The Rb/Sr age gave about 78±4 my. This suite is distribute in Khao Tosae, Khao Mapraw, Khao Panturat, Khao Ko En and Khao Ban Bang Duk. These areas always found as tin source.
5. **Khao Rang suite-G5** (Tourmarine granite) show granular texture with medium to coarse grained. The Rb/Sr age is equivalent to Khao Tosae but they are different in mineral composition, physical characteristics and petrographic characteristics. The distribution is

found as the northern part of Amphoe Muang Phuket, only at Khao Rang. (Chaimanee and Teerarungsikul, 1993)

3.2.3.3 Metamorphic Rocks

The metamorphic rocks of Phuket Island are sedimentary rocks of Kaeng Krachan Group adjacent to granites and have undergone contact metamorphism with different mineralogical variation. These meta-sedimentary rocks are andalusite schist, tourmaline schist, hornfelsic and quartzite. The very low-grade metamorphic rocks of originally sedimentary rocks are exposed along the east coast of Phuket Island at Ko Sire, Ban Chao Lae, and Ban Sam Laem. For the contact metamorphic aureole rocks of originally sedimentary rocks adjacent to granites, pegmatites, and aplite dykes, they are located in the vicinity of Khao To Sae-Khao Rang, Khao Prathiu, and the Kathu-Ta Rau old mining district (Putthapiban, 1984).

3.2.3.4 Structural Geology

The regional tectonic elements of southern Peninsular Thailand including Phuket Island are oriented approximately in the north-south direction (Putthapiban, 1984).

The major structural features are folds and faults, which share a more or less similar north-south attitude. The antiforms tend to be restricted to sediments peripheral to the granite batholiths and may possibly be the result of granite emplacement. Most of the sedimentary rocks on the east coast of Phuket Island dip gently eastward at about 20 to 30 degrees. Beds with a westwardly dip are confined to fault zones and small open folds such as those found at Laem Phap Pha and Ao MaKham. The axes of these folds trend north-south (Laem Phap Pha) and north-northeast (Ao Makham) with plunge angles of 15 degrees (Putthapiban, 1984). Garson and others (1975) suggested that the major folding event took place in the late Triassic.

The most prominent structural features of Phuket Island are mostly north-northeast trending transcurrent faults, the Khlong Marui Fault on the east and the Ranong Fault on the west (Puttapiban, 1984, Figure 3.17).

Rock type map and lineament map of Changwat Phuket are presented in Figure 3.18 and 3.19, respectively.

3.2.4 Water Resources

3.2.4.1 Surface Water

There is no major river in Phuket Island; however, there are a few small and short streams. They are:

(a) **Klong Bang Yai,** originates from mountainous area in the western part of Amphoe Kathu, flowing through Amphoe Kathu and Amphoe Muang and eventually drains into the sea on the eastern part of the island at the upper part of Chalong Bay.

(b) **Klong Thalang,** originates from mountainous area in the northeastern part of Amphoe Thalang, flowing through Amphoe Thalang westwardly and eventually join Klong Kala and flowing to the sea on the western part of the island in the vicinity of Ko Tha.

(c) **Klong Kata,** originates from mountainous area in the western part of Amphoe Muang, flowing easwardly into the sea on the eastern part of the island at the lower part of Chalong Bay.

(d) **Klong Chalong,** originates from mountainous area in the western part of Amphoe Muang, flowing eastwardly into the sea on the eastern part of the island at the lower part of the Chalong Bay.

In addition, to the natural streams, numerous old tin-mine pits widely distributed throughout the island are becoming reservoir for surface water resources. The surface water resources of Phuket Island are summarised and presented in Figure 3.20.

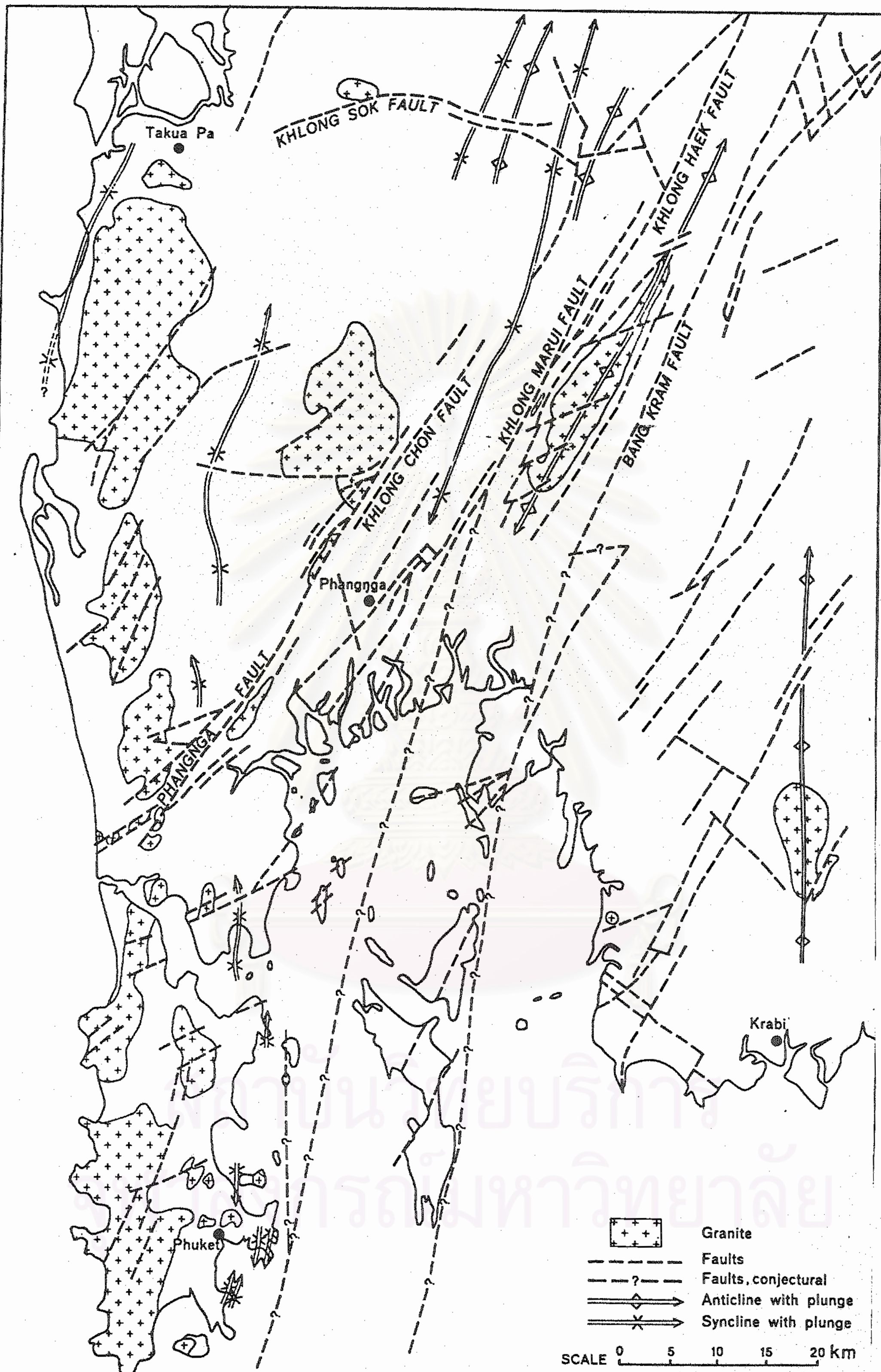
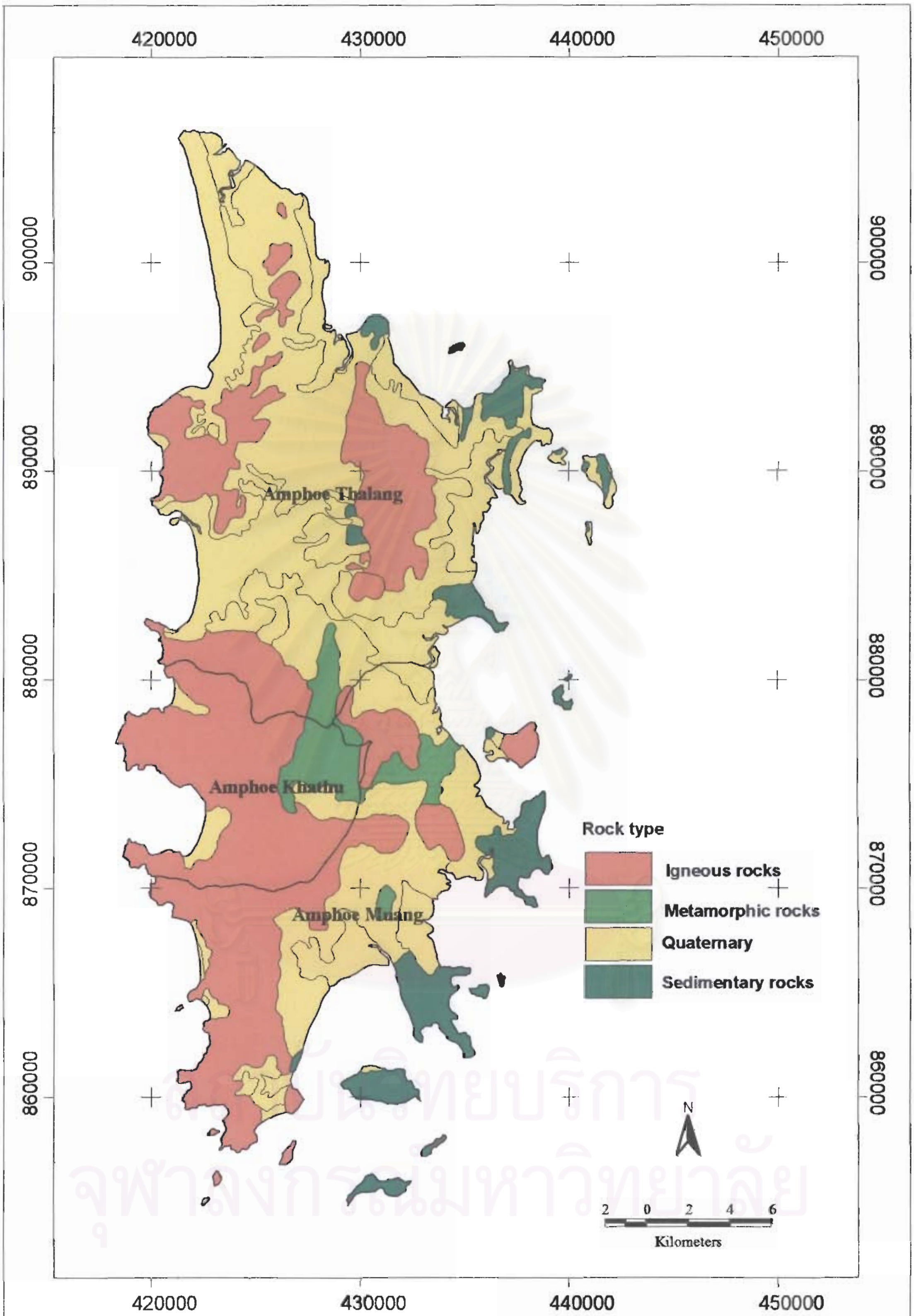
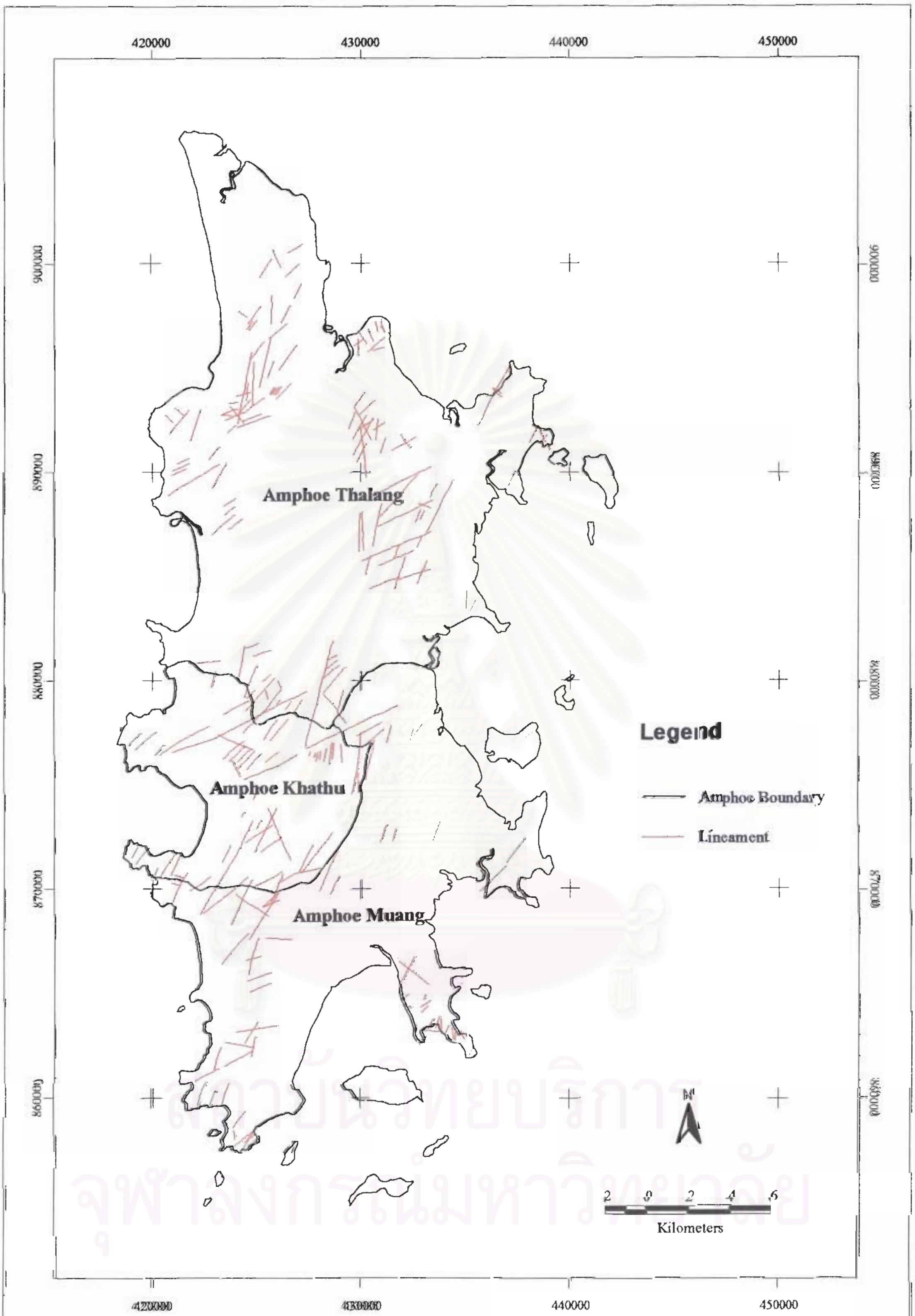


Figure 3.17 Main structural features of the area around Phuket, Krabi and Takua Pa

(After Garson and others,1975)



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET	Figure 3.18 Rock type map of Changwat Phuket (Source:Chaimanee and Teerarungsikul,1990)
Hathaithip Thassanapak Department of Geology, Faculty of Science Chulalongkorn University 2001	



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Figure 3.19 Lineament map of Changwat Phuket

(Source:Chaimanee and Teerarungsikul,1990)

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3.2.4.2 Subsurface Water

There are many localities in Phuket Island where shallow groundwater is available in shallow dug-wells within the depth range between 2 to 4 metres below the ground surface. The groundwater from these wells is generally available all year round, especially in the area of Chalong Bay, Rawai Beach, Kata Beach, Karon Beach, Patong Beach, Kamala Beach, and Mai Khao Beach.

The overall water resources of Phuket Island is inadequate to meet the ever-increasing demand due to limited natural water resources from streams and old tin-mine pits. At present, the raw-water for water supply of Phuket Island is obtained from the Bang Wad reservoir in Amphoe Kathu with the installed capacity of 8.44 million cubic metres. The Royal Irrigation Department has conducted the study on potential sites for reservoir as follows:

(a) **Ban Tho Sung Reservoir,** Tambon Kathu, Amphoe Kathu, installed capacity of 4.2 million cubic metres.

(b) **Che Tra Reservoir,** Tambon Sri sunthon, Amphoe Thalang, installed capacity of 4 million cubic metres.

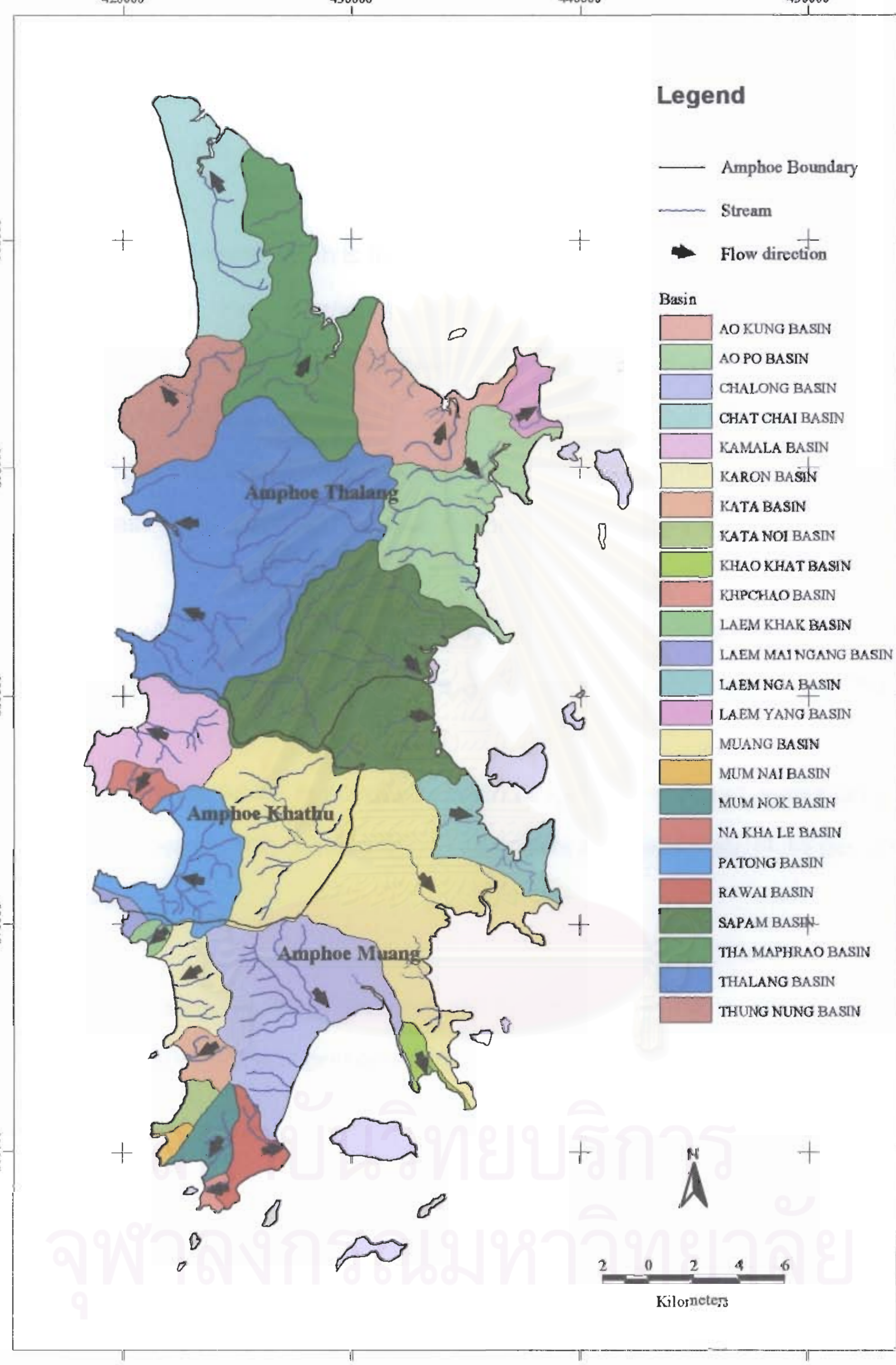
(c) **Klong Bang Nieo Dam Reservoir,** Tambon Sri sunthon, Amphoe Thalang, installed capacity 1.5 million cubic metres.

(d) **Klong Yon Reservoir,** Tambon Wichit, Amphoe Muang, installed capacity 1.5 million cubic metres.

(e) **Klong Kra-ta Reservoir,** Tambon Chalong, Amphoe Muang, installed capacity 4.7 million cubic metres.

(f) **Pak Bang Reservoir,** Tambon Kamala, Amphoe Kathu, installed capacity 2.6 million cubic metres.

(g) **Bang La Reservoir,** Tambon Karon, Amphoe Muang, and installed capacity 2 million cubic metres.



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

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Figure 3.20 Surface water resource of Changwat Phuket (Source: Department of Environmental Quality Promotion,2000)

3.2.5 Existing Land use and Land cover

From the basic data and information obtained from the Department of Land Development (1987), the land use pattern of Changwat Phuket can be classified into four groups as follows:

(a) **Urban and built up area**: which is further subdivided into residential, commercial and services, industrial, transportation and communication, and institutional lands. This category of land use covers approximately 6.22 per cent of the total area.

(b) **Agriculture area**: which covers the paddy fields, para-rubber plantations, coconut and pineapple plantations, mixed orchards, catchews, crops and coastal aqua cultural areas. This group of land use covers approximately 49.75 per cent of the total area.

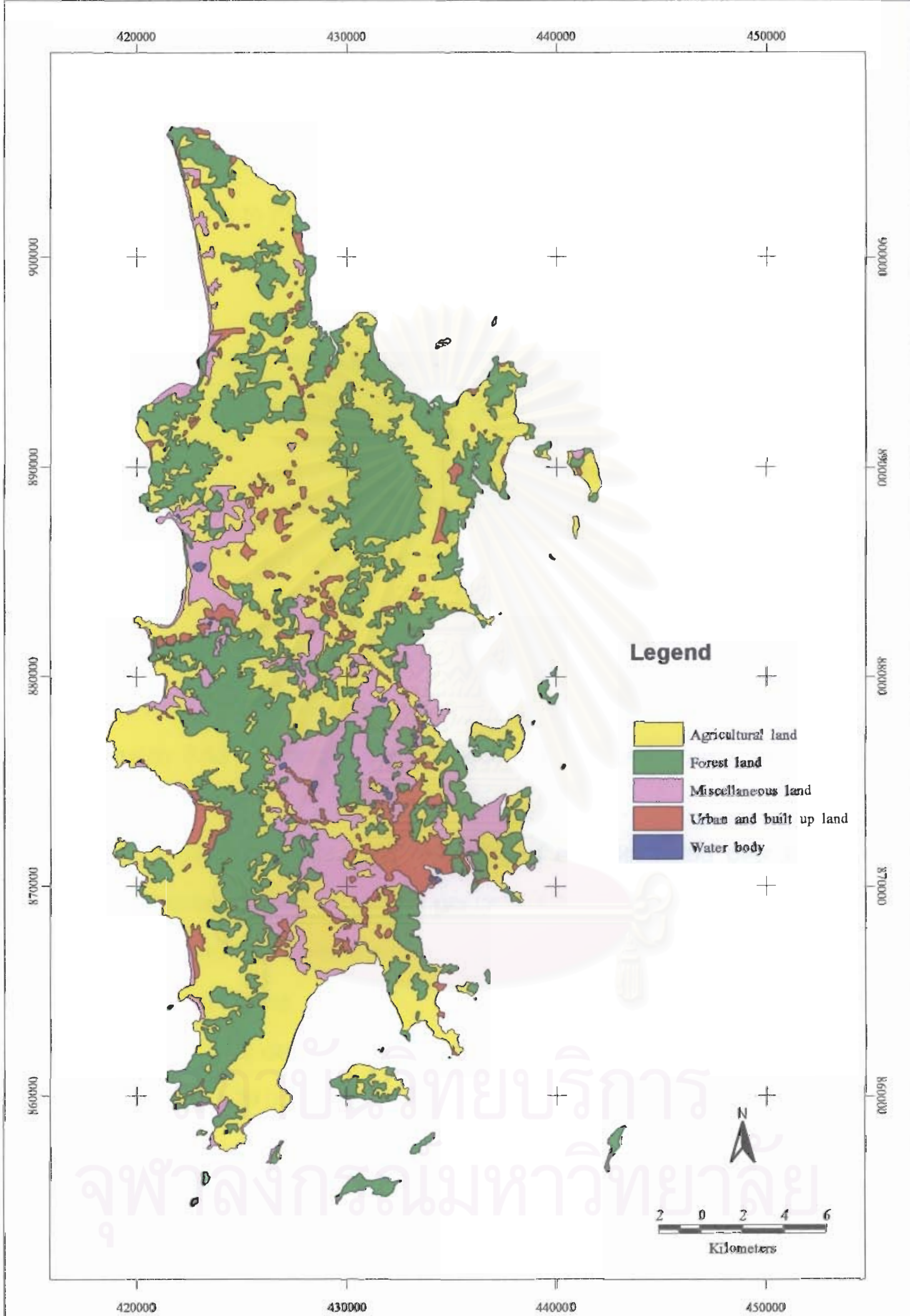
(c) **Forest area**: which is subdivided into beach forest, mangrove forest and topical forest. This category of land use covers approximately 29.89 per cent of the total area.

(d) **Miscellaneous area**: which is subdivided into rangeland, wet land, water body, old tin-mines and beach. This group of land use covers approximately 14.14 per cent of the total area.

The details of various types of land use are summarised in Table 3.4, and the land use map of Changwat Phuket is presented in Figure 3.21.

Table 3.4 Existing land use of Changwat Phuket (1987)
(Source: Department of Land Development, 1987)

Type of land use	Area	
	Rai	Per cent (%)
1. Urban and build-up land	**21,095**	**6.22**
- City, Town, Commercial and Service	5,272	1.55
- Village, Institutional land, Transportation, Communication and utility, Industrial land	15,823	4.67
2. Agriculture land	**168,885**	**49.75**
- Paddy field	18,864	5.56
- Para rubber	127,151	37.46
- Coconut	21,538	6.35
- Orchard (mixed, rambutan)	646	0.19
- Cashew	476	0.14
- Field crop (corn, pineapple)	90	0.02
- Aquacultural land	120	0.03
3. Forest land	**101,423**	**29.89**
- Evergreen forest	80,417	23.70
- Disturbed evergreen forest	2,141	0.63
- Mangrove forest	17,902	5.28
- Disturbed mangrove forest	241	0.07
- Beach forest	541	0.16
- Forest plantation	181	0.05
4. Miscellaneous land	**47,993**	**14.14**
- Rangeland	862	0.25
- Abandoned mine	42,740	12.59
- Natural water body	662	0.20
- Wetland	361	0.11
- Beach	3,368	0.99
Total	339,396	100.00



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

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2001

Figure 3.21 Land use and land cover of Changwat Phuket (Source:Department of Land Development,1987)

3.2.6 Soil Characteristics

In Changwat Phuket, the types of soil and landforms they occupy are usually well related (Department of Land Development, 1980). The various mapped units of soil are grouped according to the general physiographic characteristics and their patterns as follows :

(1) **Very thick loamy sand,** very well drained and occupies about 3.14 per cent of the total area. Most of these areas are in the western coastal plain of Changwat Phuket (Phuket Island).

(2) **Moderately thick loamy sand**, very well drained and covers the western coastal area. These soils are classified as spodosols and occupy about 1.28 per cent of the total area of Changwat Phuket.

(3) **Estuarine complex deposits**, very poorly drained, saline and saturated with water all the time. Most of these areas are covered with mangrove forest occupying approximately 8.63 per cent of the total area in the eastern coastal plain of Phuket Island.

(4) **Very thick sandy clay loam**, well drained and are distributed over the area of Changwat Phuket covering about 5.87 per cent of the total area.

(5) **Thick clayey loam**, well drained and are distributed about 2.03 per cent of the total area of Changwat Phuket.

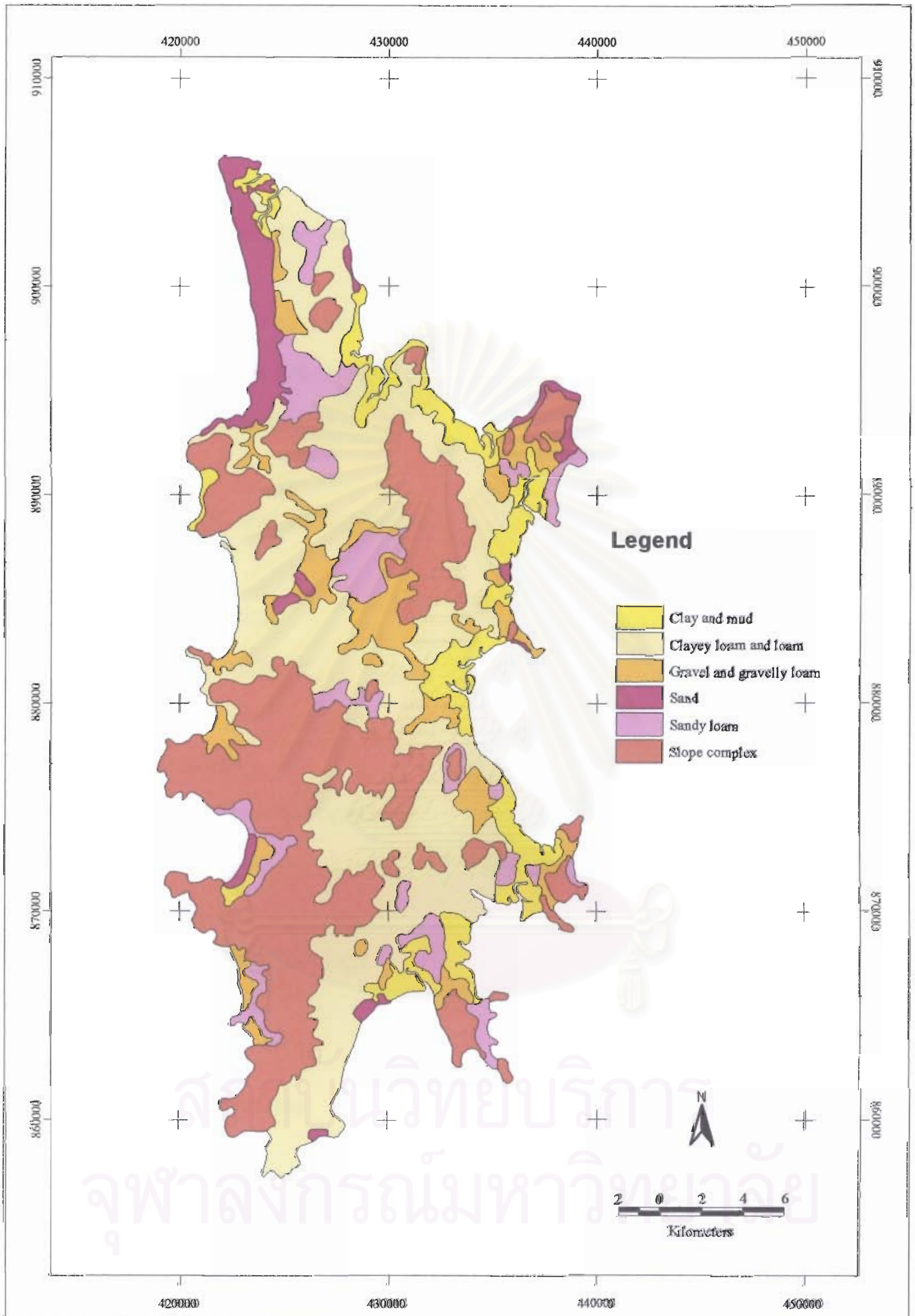
(6) **Very thick loam**, well drained, and distributed over the area of Changwat Phuket. They occupy about 29.05 per cent of the total area of Changwat Phuket.

(7) **Clayey loam or sandy clay loam with gravel or lateritic layer**, present at the depth of 50-100 centimetres below the surface. They are well drained. Most of them are distributed over the area covering approximately 6.09 per cent of the total area of Changwat Phuket.

(8) **Clayey loam or sandy-clay loam with lateritic layer**, present at the depth of 15-50 centimetres below surface (shallow depth). They are well drained. Most of them cover the small areas in the central and the eastern parts of Changwat Phuket. They occupy approximately 1.89 per cent of the total area of Changwat Phuket.

(9) **Others include hills and mountains**, old tin-mine land and water bodies, they occupy about 41.75 per cent of the total area of Changwat Phuket.

The map showing soil characteristic of soils in Changwat Phuket is presented in Figure 3.22.



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET

Hathaithip Thassanapak
Department of Geology, Faculty of Science
Chulalongkorn University
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Figure 3.22 Soil characteristics map of Changwat Phuket (Source: Department of Land Development, 1980)

CHAPTER IV

THE ANALYSIS OF LANDSLIDE POTENTIAL IN CHANGWAT PHUKET

4.1 Parameters Influencing the Landslide

In general, most of the landslide hazard evaluation techniques, which have been developed up to the present time, have used a combination of the following parameters:

1) Landslide distribution
2) Geology:
   i) Lithology, and Stratrigraphy
   ii) Structure
   iii) Neotectonics
3) Geomorphology:
   i) Relief
   ii) Landforms
4) Hydrology and Hydrogeology
5) Seismicity
6) Climate
7) Vegetation and Pedology
8) Land use
9) Time
10) Geotechnical Data

However, data can usually be collected at a various of levels depending on many constraints. The list is extensive, and only in an ideal case will all types of data be available. Parameter can also be either qualitative, or quantitative.

Under the present study, the inherent factors, namely; slope, elevation, geology, land use and land cover; and the triggering factors of rainfall intensity are employed in the evaluation.

There are several reasons, which have been taken into consideration in determining and selecting these parameters. With respect to the geological conditions of the area, the nature of lithology and its weathering characteristics as well as the geological structures especially weak zones of fault and joint or lineament zones are among the most important controlling factor for landslide. Besides, the landform parameters particularly regarding the slope and elevation are obviously critical for the analysis of landslide. The importance of surface water characteristics in terms of surface drainage zone in particular is also taken as important factors in supplying of water into the soil/rock mass underneath. The water has two functions, namely, increase of weight and increase the lubricant factor of soil/rock mass. The distribution and characteristics of surficial deposits of the area is indeed very important factor in determining the landslide potential. The stability of the mass of these surficial deposits depending upon the characteristics of these masses. The changing of land use and land cover from natural to man-made patterns generally increases the weathering and erosion, removal of support by human's activities, and deforestation will decrease the stability of the ground and surficial materials.

Considering the triggering mechanism for landslide potential in the study area, attention is focusing upon the rainfall especially the amount of rainfall, duration of rainfall and distribution of rainfall.

4.2 Reconnaissance Field Observation

The physiographic setting of Phuket Island has been underlying mostly the granitic mountain range approximately 40 per cent of the total area, especially the western of the island.

The highest elevation of the hillslope is 529 m MSL at Khao Mai Tao Sip Song on the western part of the area and slope steepness more than 30 degrees.

They are numerous road cuts across these granite hillslope (Figure 4.1a and b). Hillside cuts required for highway construction often become to destabilize of slope gradient of the hillslope. Most of these failure tends to be earth flow or earth slump (Figure 4.2). The slope failure revealed that the earth materials were the weathered granitic rock (Figure 4.3a and b). An attempts to remedy and control these failures problem show along the Highway no. 4233, especially route between Kamala beach and Patong beach and along distance Patong beach to Karon beach (Figure 4.4).

The increased pressure from expanding population and economic for construction on hillslopes, such as hotel and entertainment buildings can be seen along the distance of Patong beach (Figure 4.5a and b).

Beside that, the local communities of Patong have been cultivated on hillslopes, especially mixed orchards (Figure 4.6).

The literature review show that the likelihood of landslide is increased whenever hillslopes are steepened such as occurs which highway construction and emplacement of building on sloping terrain.

4.3 The Proposed Weighting-Rating System of Parameter

Landslide hazard is commonly shown as maps, 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). Landslide hazard zonation requires a detailed knowledge of the processes that are or have been active in an area, and of the factors leading to the occurrence of the potentially damaging phenomenon.

A summary of the various trends in the development of techniques is given in Table 4.1.

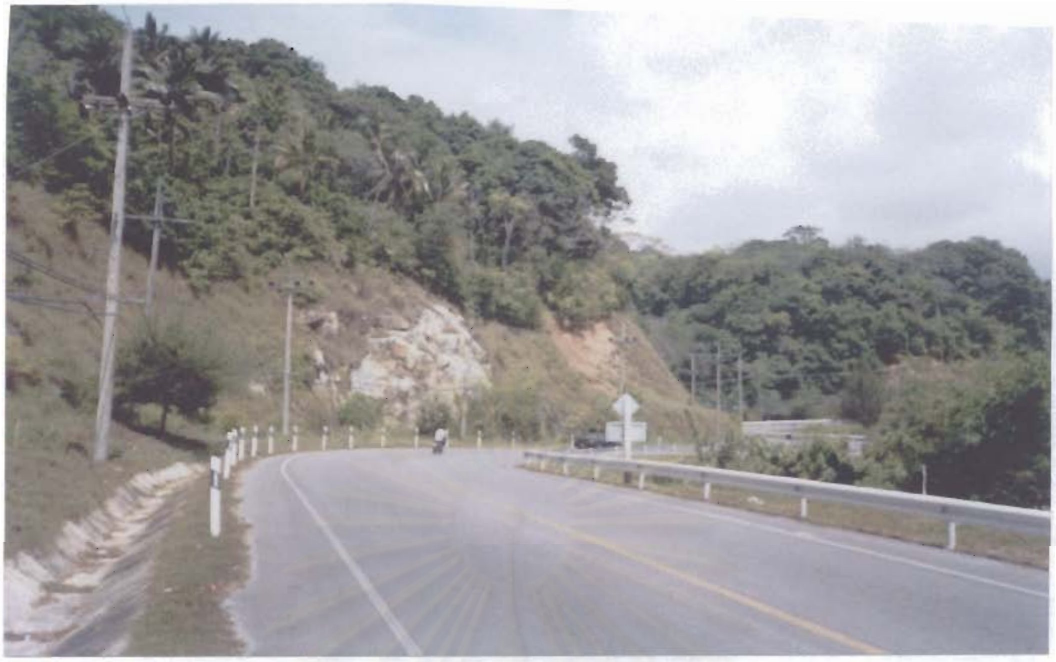


Figure 4.1a Road cuts along Highway number 4233, Grid Ref. 200E 685N.

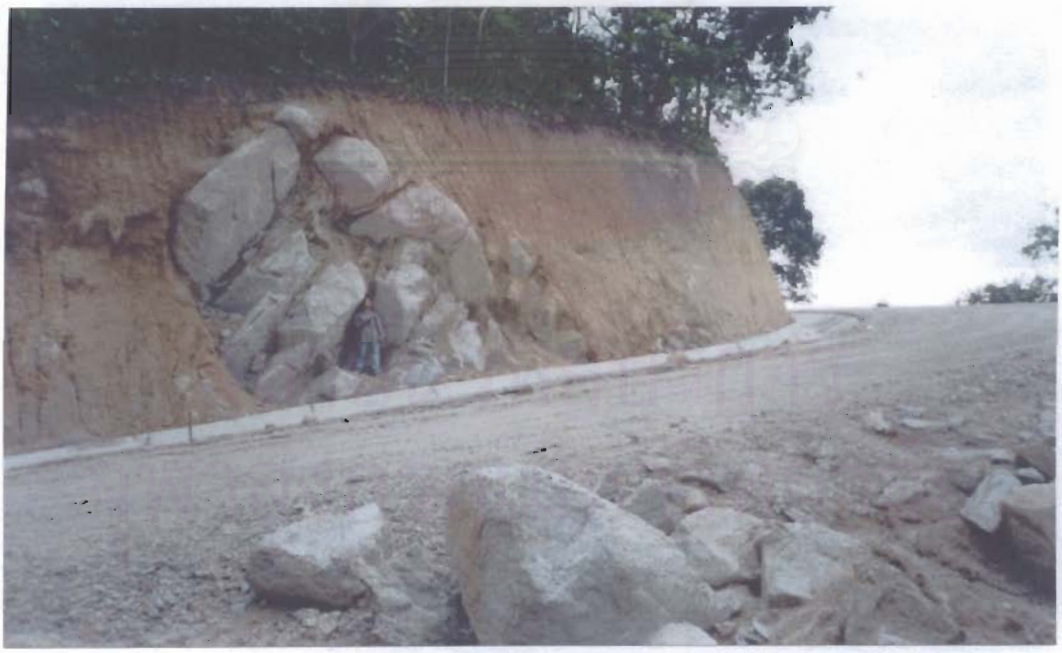


Figure 4.1b Road cuts along Highway number 4233, Grid Ref. 196E 781N.

Figure 4.2 Earth slump affected by the highway construction along Highway number 4233 between Kamala beach-Patong beach, Grid Ref. 232E 754N.

Figure 4.3a Residual soils and weathered granitic rock along Highway number 4233, Grid Ref. 196E 781N.

Figure 4.3b Residual soils and weathered granitic rock along Highway number4233, Grid Ref. 196E 781N.

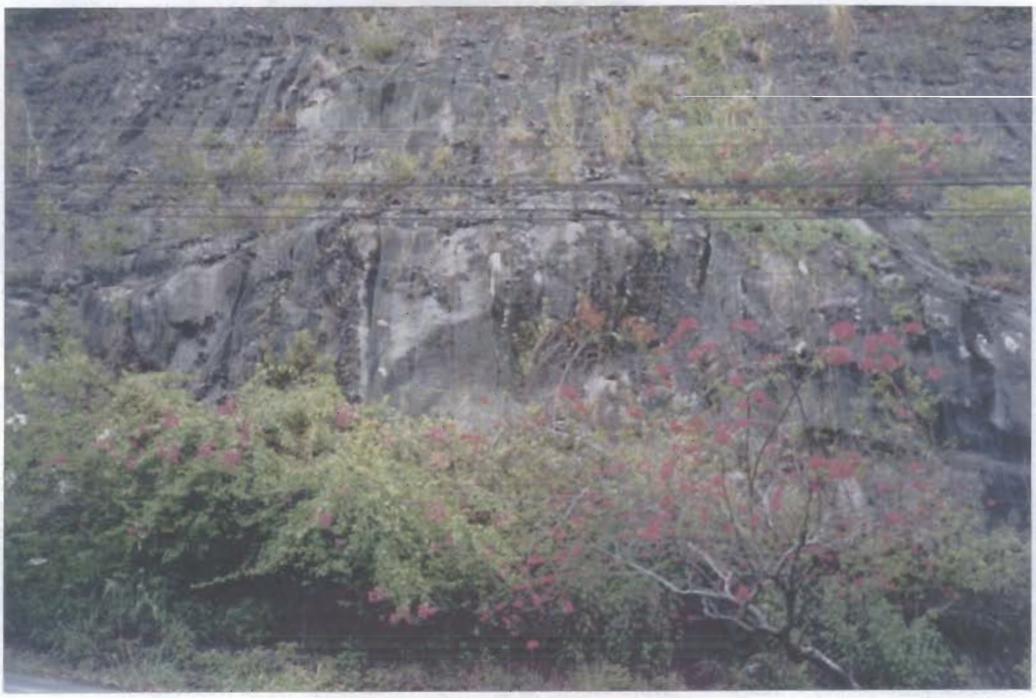


Figure 4.4 Remedy and control the failure along the road between Patong beach-Karon beach, Grid Ref. 232E 640N.

Figure 4.5a Construction building on hillslope at Patong beach, Grid Ref. 206E 755N.

Figure 4.5b Construction building on hillslope at Patong beach, Grid Ref. 234E 616N.

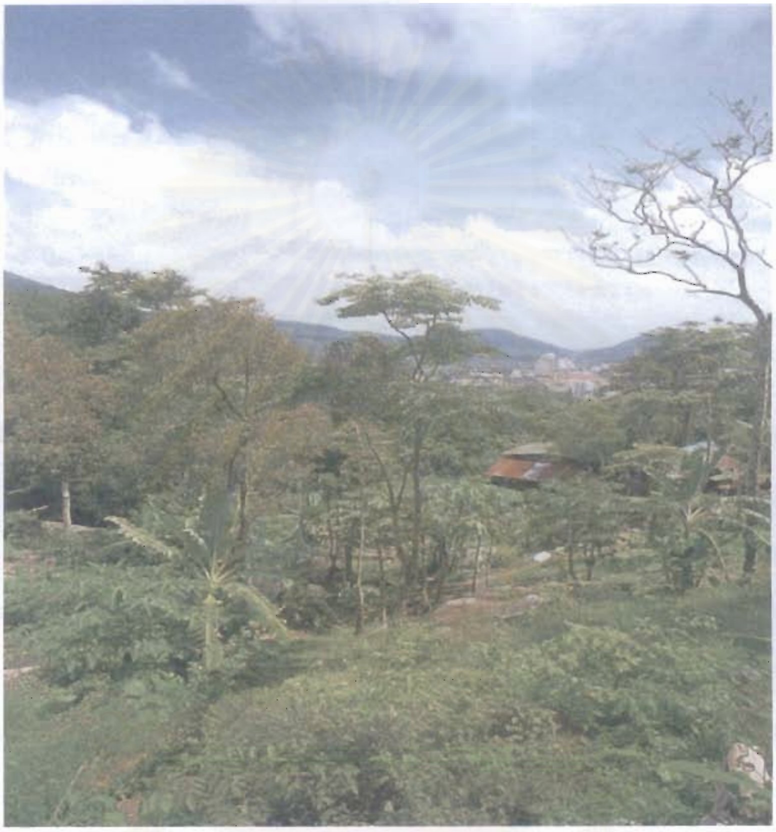


Figure 4.6 Cultivation on hillslope of local community at Patong beach,

Grid Ref. 206E 755N.

Table 4.1 General trends in landslide hazard analysis methods

Type of landslide hazard analysis	Main characteristics
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 analyses are used to obtain predictions of the mass movement hazard from a number of parameters 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

(After; van Westen,1994)

Some early investigations in assessing the role of parameters that contribute to slope stability have applied a numerical rating system. Stevenson (1977) used a simple but apparently affective empirical rating system approach for evaluating and mapping relative landslide hazard and risk in clay slope of northern Tasmania. On the basis of his expert knowledge on the causal factors of slope instability, he assigned weighting values to different classes in a number of parameter maps. This method has become very popular in slope stability zonation. The problem with this method is that the exact weighting of the various parameter maps is often based on insufficient knowledge of the important factors, which leads to unacceptable generalizations. Later on, Meneroud (1978) used a numerical system in preparing his linear map of risks on a highway route in order to make his evaluation as objective as possible. Vecchia (1978) proposed a terrain index for stability of hillsides or scarps that includes numerical rating for lithology, attitude of beds relative to slope, and for friction along potential failure planes.

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 of the influencing factors was subdivided into subclasses and given index numbers called ‘a rating’. 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.

For the proposed of this study, a simplified formula has been develpped to assume the potential of an area. This results in the formula:

$$S = W_1R_1 + W_2R_2 + \ldots + W_nR_n$$

Where S = total scores in each area

W = value of the importance factor

R = value of subclasses of the importance factor

Under the present study, an attempt has made to apply the numerical rating of contributing parameters to the analysis of landslide potential of Changwat Phuket area. The parameters concerned earlier described in 4.1 have been assigned the weight factors ranging from 1 to 5 according to their increase in potential level, respectively. The assigned weight system to parameters influencing the landslide in Changwat Phuket are summarised and presented in Table 4.2.

Besides, further attempt has been made to distribute the weight of main parameters into suitable sub-parameters for consideration. The weight factors of these parameters and sub-parameters are also presented in Table 4.2. For the parameters concerning geology, it is further divided into 2 sub-parameters, namely, lithology and lineament zone (zones represent faults, joints and fractures). The lineament zone is measured 20 metres on both sides of lines of fault or joint or fracture. The landform parameter is also divided into 2 sub-parameters, namely, slope and elevation. For surface drainage zone, it is assigned as distance of 10 metres on both sides of one stream.

Among six main parameters influencing the landslide in the study area; geological factor has given the highest value of 5 similar to that of the rainfall intensity. The reasons for the relatively high weight value for geology are besed on the devastating case studies of previous landslide in Khao Luang Mountain Range in 1988 (Tingsanchali, 1989; DeGraff, 1991; Aung, 1991; Zhibin, 1991; Nutalaya, 1991; Tantiwanit, 1992; Khantaprab, 1993; Nilaweera, 1994; Phantanahiran, 1994; Jworchan, 1995 and Happer, 1996).

Under the present study only two sub-parameters, namely, rock type and lineament, are taken into consideration. The rock type and their weathered products underlying the areas are weighted relatively higher than those of the lineament zone.

The lineament systems that posses low strength and can only acts as media for rapid water infiltration and lubrication, whereas intense physical and chemical weathering of the rock types under tropical climate directly produced the unstable earth materials (or regolith) for landslide.

Regarding the landform or geomorphic setting parameters, the relative weight value of four have been given to this parameter. Various hill slope characteristics include the relief, steepness of slope, shape of the land surface, slop orientation and aspects, etc. However, only two sub-parameter, namely, slope gradient and elevation are taken into consideration under the present study due to many limitation. The weight value for slope gradient has been assigned as three, whereas the elevation has been assigned only as one. The reasons for the relatively higher weight for slope gradient is that the shear stress caused movement of the body parallel to the slope. The primary fracture influencing shear stress is the pull of gradient, which is related to the slope gradient.

With respect to the role of surface drainage zone parameter, the reason for assigning the weight value of two is given earlier described in this chapter.

Similarly, the weight value of three have been given to the land use and land cover parameter with reason earlier described in the beginning of this chapter.

Under the present study the soil characteristics parameter has been given the weight value of two. The terminology 'soil' used is defined that: bedrock commonly overlain by a great variety of unconsolidated materials both natural and artificial. The reason of assigning the relatively low weight value is earlier given in this chapter.

Regarding the causes of landslide by independent external factors which are termed the triggering mechanisms because they provide the immediate stress that initiates movement of the earth materials. In this study the rainfall intensity has been given the highest weight value of 5. This is because the magnitude, intensity, and duration of the storm all play a role in determination whether a hill slope will fail. Excessive rainfall weakens earth materials by displacing air and increasing the poor water pressure along shear surfaces.

Table 4.2: The numerical weight assignment to the parameters influencing the landslide in Changwat Phuket

Parameters and Sub-parameters	Weight Value	
	Parameters	Sub-parameters
1. Geology	5	
1.1 Rock type		3
1.2 Lineament zone		2
2. Landform	4	
2.1 Slope (%)		3
2.2 Elevation (m.)		1
3. Surface drainage zone	2	
4. Land use and land cover	3	
5. Soil characteristics	2	
6. Rainfall intensity	5	

With respect to the determination of rating values, various assumptions regarding the detailed characteristics of the parameters and sub-parameters concerned are assigned the rating value according to their significance. For example, the rock type sub-parameters are classified into 3 groups, namely, igneous rocks, sediments and sedimentary rocks, and metamorphic rocks with the decreasing rating value of 5, 3 and 1, respectively. Decomposed crystalline rocks, or igneous rocks are susceptible to a large increase in moisture content. Weathering of these rocks may quickly reduced there shear strength to critical limit. Inclined bedding of cohesive sedimentary rocks are likely to become saturated with water and consequently lubricated in conclusion. The lithological factor has been broadly determine in terms of the sensitivity to weathering and their the overall characteristics of weathered products.

The detailed descriptions of different rating values of each parameter and sub-parameters as well as the weight values are summarized and presented in Table 4.3.

Table 4.3: The numerical weight and rating assignment to the parameters and sub-parameters influencing the landslide in Changwat Phuket

Parameters and Sub-parameters	Weight Value		Rating Value	
	Weight (1-5)	Sub-weight	Description	Rating (1-5)
1. Geology	5			
1.1 Rock type		3	A. Igneous rocks	5
			B. Sedimentary rocks	3
			C. Metamorphic rocks	1
1.2 Lineament zone		2	A. Inside lineament zone	3
			B. Outside lineament zone	1
2. Landform	4			
2.1 Slope(%)		3	A. > 70 %	5
			B. 50-70 %	4
			C. 30-50 %	3
			D. 15-30 %	2
			E. 0-15 %	1
2.2 Elevation (m)		1	A. >401 m	5
			B. 301-400 m	4
			C. 201-300 m	3
			D. 101-200 m	2
			E. 0-100 m	1

Table 4.3 (continued)

Parameters and Sub-parameters	Weight Value		Rating Value	
	Weight	Sub-weight	Description	Rating
3. Surface drainage zone	2		A. Inside surface drainage zone	2
			B. Outside surface drainage zone	1
4. Soil characteristics	2		A. Gravel loam/ Gravelly sand	5
			B. Sand	4
			C. Sandy loam	3
			D. Clayey loam / loam	2
			E. Clay, Mud	1
5. Land use and land cover	3		A. Agriculture area	4
			B. Urban and build-up area	3
			C. Other deforestation	2
			D. Forest area	1
6. Rainfall intensity (mm.)	5		A. > 2826	3
			B. 2726-2825	2.5
			C. 2626-2725	2
			D. 2476-2675	1.5
			E. 2325- 2475	1

4.4 The Assessment of Landslide Potential

After the parameters influencing the landslide in Changwat Phuket have been identified as earlier discussed, the appropriate data acquisition and data compilation have been accordingly undertaken. These basic data and information of the parameters concerned, namely, geology, landform, surface drainage zone, soil characteristics, landuse and land cover and rainfall intensity are available both in the digital and non-digital forms. Besides, many of them are available not in the required format. Therefore, a certain degree of modification has been made. Finally, all of the required data and information are presented as a series of derivative maps.

With respect to the geology parameters, two types of derivative maps have been further prepared. They are the rock type map and the lineament map as shown in Figures 3.18 and 3.19. For the landform parameters, an attempt has been made to prepare two derivative maps, namely, slope map and hypsometry map as shown in Figures 3.15 and 3.16. With respect to surface drainage zone parameter, the derivative map called surface water map, illustrating the drainage pattern, major and minor drainage basins, and direction of flows are prepared (Figure 3.20). The soil characteristics parameter is presented in the form of surficial deposit map as shown in Figure 3.22. For the land use and land cover parameter, several patterns both natural and anthropogenic categories have been included in the derivative map for land use and land cover map (Figure 3.21). The last parameter is the triggering parameter of rainfall intensity with is presented as the isohyetal map (Figure 3.12).

In determining the numerical rating of altogether 8 parameters/sup-parameters responsible for the landslide in Phuket Island. An area of 20x20 square metres grid cell has been employed for the analysis. After that, the weight-rating values of each parameters/sub-parameters or each derivative map will be determined in each square grid cell. Finally, the total scores of weight-rating in each 20x20 square metres grid cell will be obtained from the summation of weight-rating values of each derivative maps.

These means that the overall areas of Phuket Island is subdivided into a small 20x20 square grid cell.

The actual total scores of weight-rating system for the landslide potential assessment of Changwat Phuket vary between 21-82. Additional attempt has been made to classify the landslide potential, on the basis of total scores, into 5 categories, namely; very high susceptibility, high susceptibility, moderate susceptibility, low susceptibility and very low susceptibility to nil. The classification, the landslide potential and the range of total scores are summarised and presented in Table 4.4.

Table 4.4 The landslide potential and the range of total scores

Landslide Susceptibility Classes	Range of Scores
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

4.4 The Result of Potential Landslide Assessment of Changwat Phuket

Upon the application of the weight-rating system developed under the present study. To determined the landslide potential of Changwat Phuket, the findings can be summarised as follows :

(a) The assessment for landslide potential of Changwat Phuket is confined within the Phuket Island, covering an area of 543 square kilometres excluding all other small islands under the administration of Changwat Phuket (Figure 4.7).

(b) The landslide susceptibility of the Phuket Island is categorised, according to the total weight-rating scores, into five classes. They are very low susceptibility to nil, low susceptibility, moderate susceptibility, high susceptibility, and very high susceptibility to landslide in their increasing, respectively. (Table 4.4 and Figure 4.7).

(c) The map of landslide susceptibility of the Phuket Island has been accordingly prepared (Figure 4.7) showing the area under different classes of susceptibility to landslide as summarised in Table 4.5.

(d) There are two main areas with very high susceptibility to landslide in the vicinity of Khao Mai Thao Sip Song and Khao Khuan Wa. The very high susceptibility to landslide area of Khao Mai Thao Sip Song is confined to the summit area around the peak (529 m. MSL.), underlain by, weathered granitic rocks. It is located within the administration of Tambon Kamala, Amphoe Kathu. The potential direction of landslide is north-west towards the entertainment complex of "Phuket Fantasy", located at the bottom of the valley.

The other very high susceptibility to landslide area is in the vicinity of Khao Khuan Wa (528m. MSL.). It lies within the administration of Tambon Srisoontorn and Tambon Kamala of Amphoe Kathu. Khao Khuan Wa which are underlain by weathered granitic rocks, and the potential of landslide direction is in the south-west towards the entertainment complex of the "Phuket Fantasy".

Besides, there are a few small areas in the northern part of the island which show the very high susceptibility to landslide in the vicinity of Khao Kho En (210m MSL) and Khao Ban Bang Duk(268m MSL). In the southern part of the island especially in the mountainous areas of Ao Kata in the vicinity of Khao Krabok(447m MSL) southwardly to Khao Sai Maen and Khao Tut, there are also a few small areas of very high susceptibility to landslide in the northern and southern part of the island which are underlain by the weathered granitic rocks (Figure 4.7).

(E.) With respect to the high susceptibility to landslide areas, there are altogether four major zones, namely, the mountain range on the eastern part of the island, the Khao Pra Thiu mountain range on the eastern part of Amphoe Thalang, the horse-shoe shaped mountain range on the west of the central part of the island, and the mountain range on the west of the southern part of the island (Figure 4.7).

The first zone extends southwardly from Khao Sai Khru, Khao Muang, and Khao Takieng. The potential direction of landslide from these granitic mountain is to the west towards the vicinity of Ban Sakhu, Ban Naithon, Ban Layan located along the road No.4031.

The second zone is confined within the Pra Thiu granitic mountain range extending southwardly from Khao Para(442m MSL), Khao Bang Phae(388m MSL), and Khao Pra Thiu(384m MSL). The potential direction of landslide is diversified towards Ban Para, Ban Muang Mai, Ban Tha Maphao, Ban Bang Kanun, Ban Lipuan, and Ban Paklog.

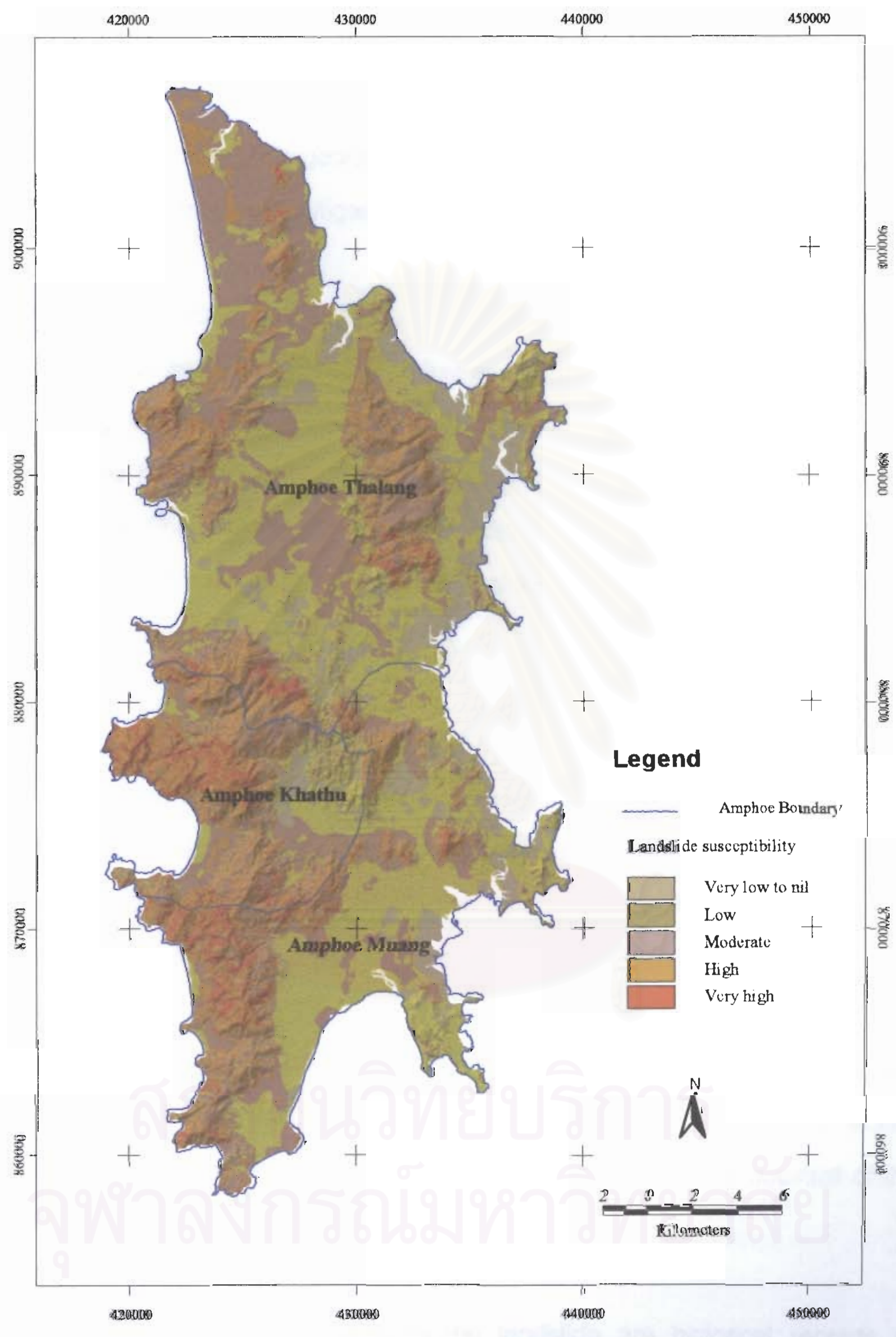
The third zone is the circular granitic mountain range on the easthern part of Kamala beach resorts especially in the neighbourhood of Khao Get Ni (503m MSL) and Khao Kuan Wa(528m MSL). The potential landslide direction is towards one of the most famous tourist resorts of the island, such as the “Phuket Fantasy” entertainment complex, beach resorts, numerous hotels and restaurants, etc.

The last zone is the granitic mountain range in the southern part of the island extending southwardly from Khao Mai Thao Sip Song(529m MSL), Khao Sai Mean, Khao Krabok(447m MSL), Khao Tut, Khao Phlu Ruan(318m MSL), and Khao Khiri Manun. The potential direction of landslide from these granitic mountains is to the west towards beach resorts of Patong, Karon, Kata, Naihan, and Phromthep Cape.

The rest of the areas of Phuket Island have been identified as moderate, low, and very low susceptibility to landslide. These areas are shown in Table 4.5 and and presented in Figure 4.7.

Table 4.5 The area under different classes of susceptibility to landslide

Landslide Susceptibility	Range of Scores	Per cent of Area	Area (sq.km.)
Very low to nil	21-33	10.58	57.5
Low	34-45	34.90	189.5
Moderate	46-58	33.63	182.6
High	59-70	17.40	94.5
Very high	71-82	3.48	18.9



POTENTIAL LANDSLIDE ASSESSMENT OF CHANGWAT PHUKET	
Hathaithip Thassanapak Department of Geology, Faculty of Science Chulalongkorn University 2001	Figure 4.7 Landslide potential map of Changwat Phuket

CHAPTER V

CONCLUSION

An understanding of the geological surface process of landslide is fundamental to the avoidance, warning, and mitigation of the catastrophic losses of life and property.

Under the present investigation, an attempt has been made in the light of updated knowledge and the availability of data and information to describe the cause of landslide using the Phuket Island as a pilot area. The appropriate methodology employed in the landslide assessment study has been developed and brought into practice using the Phuket Island as the target area. Finally, the landslide susceptibility map will be prepared to serve as the scientific tool for the prediction and forecasting of future landslide movements, if any.

Prior to the assessment of the landslide potential of the Phuket Island, the environmental setting of Changwat Phuket has been reviewed for both socio-economic and physical conditions. For the socio-economic conditions, they include administration, population, education, religion and health services, transportation, electricity, and water supply, economy and recreation, and tourist attraction.

Regarding the physical environment, it embraces climate, topography and landform, geology, water resource, land use and soil. It is against the exiting environmental condition of Changwat Phuket, the analysis of landslide potential of the Phuket Island has been made.

In general, parameters influencing the landslide are historical records of landslide distribution, geology, landform, hydrology and hydrogeology, seismicity, climate, soil and vegetation, land use and land cover, etc. However, only six parameters, namely, geology, landform, surface drainage zone, land use and land cover, soil characteristics, and rainfall intensity have been chosen for the analysis of the landslide potential assessment of the Phuket Island. This is basically due to the technical limitation on the availability of required data and information in the study area of Phuket Island. The weight-rating system has been employed in the numerical/ catographical analysis of landslide susceptibility.

Regarding the two parameters influencing the landslide under the present study, notably, geology and landform, they are further divided into sub-parameters. The geology is further divided into rock type and lineament zone sub-parameters, whereas the landform is further divided into slope and elevation sub-parameters.

The numerical weight have been assigned to parameters and sub-parameters concerned ranging from 1 to 5 in their increasing order of significance, respectively. With respect to the numerical assignment of rating, numerous assumptions have been proposed for each parameter and sub-parameters with respect to the rating, the numerical values ranging form 1 to 5 are assigned according to their increasing probability of landslide, respectively.

After that, the weight-rating values of each parameters/ sub-parameters on each derivative map were determined. Finally, the total scores of weight-rating in each 20×20 square metres grid cell were obtained from the summation of weight-rating values of each derivative maps.

The actual total scores of weight-rating system for the landslide potential assessment of Changwat Phuket vary between 21 to 82 . These total scores are further classified into five categories regarding the susceptibility to landslide, namely, very high susceptibility, high susceptibility, moderate susceptibility, low susceptibility, and very low susceptibility to nil.

Finally, a landslide potential map of Phuket Island has been prepared to illustrate different degree of susceptibility to landslide. Additional discussions on the areas to be affected by the potential landslide are carried out. It is important to note that most of the famous tourist resorts of Phuket Island are located in the neighbourhood of potential areas to be affected by very high and high susceptibility to landslide.

Although an attempt has been made under this study to establish and evaluate the relationships between major influencing parameters to landslide and spatial data, the application of the weight-rating technique needs further modification to get the better landslide susceptibility mapping. Besides, the detailed examination of the properties of many parameters in the field areas, notably, slope aspects, land use and land cover, characteristics of regolith, geology, especially lithological and structural characteristics as well as the degree of weathering should be undertaken for the GIS analysis.

It is realize that difficultly has arisen in areas without any historical records of landslide. This is because the number of landslides that have occurred in the past within a land unit is a good indication of what can be expected to occur in the near future. The only problem is that it is not possible to predict exactly when a hazard will recurred. Therefore, the classification of the landslide susceptibility map do not give more information than relative indications, such as high, medium, and low probability of the occurrence of geohazard without any determination of the magnitude, intensity, and frequency aspect.

This study is only the first attempt to develop the assessment system for the landslide potential in the tropical monsoon terrain. The proposed weight-rating system is indeed far from perfection. The assignment of the weight values and rating values is most reliable when the conclusion in drawn from the corrective opinion of experts in the field of landslide and slope stability.

Finally, it will be of great benefits if the landslide hazard and risk management are intimately linked. The key aspect of risk management should included the risk assessment, risk perception, and risk communication.

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APPENDIX

Table 1. Conversion between methods of expressing slope angle.

A. Base on degrees

Degrees and minute	Degrees and decimals of a degree	Altan	Percentage Grade	Gradeint, or unit rise. 1 in:
0°00'	0.00	0.00*	0.0	□
0°10'	0.17	4.6	0.3	344
0°20'	0.33	7.6	0.6	172
0°30'	0.50	9.4	0.9	115
0°40'	0.67	10.7	1.2	85.9
0°50'	0.83	11.6	1.5	68.8
0°06'	0.10	2.4	0.2	573
0°12'	0.20	5.4	0.4	287
0°18'	0.30	7.2	0.5	191
0°24'	0.40	8.4	0.7	143
0°30'	0.50	9.4	0.9	115
0°36'	0.60	10.2	1.1	95.5
0°42'	0.70	10.9	1.2	81.9
0°48'	0.80	11.5	1.4	71.6
0°54'	0.90	12.0	1.6	63.7
1	1	12.4	1.8	57.3
2	2	15.4	3.5	28.6
3	3	17.2	5.2	19.1
4	4	18.4	7	14.3
5	5	19.4	8.8	11.4
6	6	20.2	10.5	9.5
7	7	20.9	12.3	8.1
8	8	21.5	14.1	7.1
9	9	22.0	15.8	6.3
10	10	22.5	17.6	5.7
11	11	22.9	19.4	5.1
12	12	23.3	21.3	4.7
13	13	23.6	23.1	4.3
14	14	24.0	24.9	4
15	15	24.3	26.8	3.7
16	16	24.6	28.7	3.5
17	17	24.9	30.6	3.3
18	18	25.1	32.5	3.1
19	19	25.4	34.4	2.9
20	20	25.6	36.4	2.8
21	21	25.8	38.4	2.6
22	22	26.1	40.4	2.5
23	23	26.3	42.5	2.4
24	24	26.5	44.5	2.2
25	25	26.7	46.6	2.1
26	26	26.9	48.8	2.1

Table 1. A (continued)

Degrees and Minute	Degrees and decimals of a degree	Altan	Percentage Grade	Gradeint, or unit rise. 1 in:
27	27	27.1	51.0	2.1
28	28	27.3	53.2	1.9
29	29	27.4	55.4	1.8
30	30	27.6	57.7	1.7
31	31	27.8	60.1	1.7
32	32	28	62.5	1.6
33	33	28.1	64.9	1.5
34	34	28.3	67.5	1.5
35	35	28.5	70.0	1.4
36	36	28.6	72.7	1.4
37	37	28.8	75.4	1.3
38	38	28.9	78.1	1.3
39	39	29.1	81.0	1.2
40	40	29.2	83.9	1.2
41	41	29.4	86.9	1.2
42	42	29.5	90.0	1.1
43	43	29.7	93.3	1.1
44	44	29.8	96.6	1.0
45	45	30	100.0	1.0
50	50	30.8	119.2	0.84
60	60	32.4	173.2	0.58
70	70	34.4	274.8	0.36
80	80	37.5	567.1	0.18
90	90	60.0*	--	0.00

* Values conventionally assigned

Table 1. (continued)

B. Base on Altan

Altan	Degrees and minute	Degrees and decimals Of a degree	Percentage Grade	Gradeint, or unit rise. 1 in:
0	0°00'-0°03'	0.00-0.06	0.0-0.1	□□□□□□□
1	0°04'	0.07	0.1	859
2	0°05'	0.09	0.2	688
3	0°07'	0.12	0.2	491
4	0°09'	0.15	0.3	382
5	0°11'	0.18	0.3	313
6	0°14'	0.23	0.4	246
7	0°17'	0.29	0.5	202
8	0°22'	0.37	0.6	156
9	0°27'	0.45	0.8	127
10	0°34'	0.57	1.0	101
11	0°43'	0.72	1.3	79.9
12	0°54'	0.90	1.6	63.7
13	1°09'	1.15	2.0	49.8
14	1°26'	1.43	2.5	40.0
15	1°49'	1.82	3.2	31.5
16	2°17'	2.28	4.0	25.1
17	2°52'	2.87	5.0	20.0
18	3°37'	3.62	6.3	15.8
19	4°33'	4.55	8.0	12.6
20	5°43'	5.72	10.0	10.0
21	7°11'	7.18	12.6	7.9
22	9°01'	9.02	15.9	6.3
23	11°18'	11.30	20.0	5.0
24	14°07'	14.12	25.1	4.0
25	17°33'	17.55	31.6	3.2
26	21°43'	21.72	39.8	2.5
27	26°38'	26.63	50.1	2.0
28	32°16'	32.27	63.1	1.6
29	38°28'	38.47	79.4	1.3
30	45°00'	45.00	100.0	1.0

Table 1. (continued)

C. Base on percentage grade

Percentage Grade	Degrees and minute	Degrees and decimals of a degree	Altan	Gradeint, or unit rise. 1 in:
0.0	0°00'	0.00	0.00	□
0.1	0°03'	0.05	0.0	1146
0.2	0°07'	0.12	3.1	491
0.3	0°10'	0.17	4.6	344
0.4	0°14'	0.23	6.1	246
0.5	0°17'	0.28	6.9	202
0.6	0°21'	0.35	7.9	164
0.7	0°24'	0.40	8.4	143
0.8	0°28'	0.47	9.1	123
0.9	0°31'	0.52	9.6	111
1	0°35'	0.58	10.8	98.2
2	1°09'	1.15	13.0	49.8
3	1°43'	1.72	14.8	33.4
4	2°18'	2.30	16.0	24.9
5	2°52'	2.87	17.0	20.0
6	3°26'	3.43	17.8	16.7
7	4°00'	4.00	18.4	14.3
8	4°35'	4.58	19.0	12.5
9	5°09'	5.15	19.5	11.1
10	5°43'	5.72	20.0	10.0
11	6°17'	6.28	20.4	9.1
12	6°51'	6.85	20.8	8.3
13	7°24'	7.40	21.1	7.7
14	7°58'	7.97	21.5	7.1
15	8°32'	8.53	21.8	6.7
16	9°06'	9.10	22.0	6.2
17	9°39'	9.65	22.3	5.9
18	10°12'	10.20	22.6	5.6
19	10°46'	10.77	22.8	5.3
20	11°19'	11.32	23.0	5.0
25	14°02'	14.03	24.0	4.0
30	16°42'	16.70	24.8	3.3
35	19°18'	19.30	25.4	2.9
40	21°48'	21.80	26.0	2.5
45	24°14'	24.23	26.5	2.2
50	26°34'	26.57	27.0	2.0
55	28°49'	28.82	27.4	1.8
60	30°58'	30.97	27.8	1.7
65	33°02'	33.03	28.1	1.5
70	35°00'	35.00	28.5	1.4
75	36°52'	36.87	28.8	1.3
80	38°40'	38.67	29.0	1.2

Table 1. C (continued)

Percentage Grade	Degrees and minute	Degrees and decimals of a degree	Altan	Gradeint, or unit rise. 1 in:
85	40°22'	40.37	29.3	1.2
90	42°00'	42.00	29.5	1.1
95	43°32'	43.57	29.8	1.1
100	45°00'	45.00	30.0	1.0

D. Base on gradient

Gradeint, or unit rise. 1 in:	Degrees and minute	Degrees and decimals of a degree	Altan	Percentage Grade
1000	0°03'	0.05	0.0	0.1
900	0°04'	0.07	0.7	0.1
800	0°04'	0.07	0.7	0.1
700	0°05'	0.09	1.6	0.1
600	0°06'	0.10	2.4	0.2
500	0°07'	0.12	3.1	0.2
400	0°09'	0.15	4.2	0.3
300	0°11'	0.18	5.1	0.3
200	0°17'	0.29	6.9	0.5
100	0°34'	0.57	10.0	1.0
90	0°38'	0.63	10.4	1.1
80	0°43'	0.72	11.0	1.3
70	0°49'	0.82	11.5	1.4
60	0°57'	0.95	12.2	1.7
50	1°09'	1.15	13.0	2.0
40	1°26'	1.43	14.0	2.5
30	1°55'	1.92	15.2	3.3
20	2°52'	2.87	17.0	5.0
10	5°43'	5.72	20.0	10.0
9	6°20'	6.33	20.5	11.1
8	7°07'	7.12	21.0	12.5
7	8°08'	8.13	21.6	14.3
6	9°28'	9.47	22.2	16.7
5	11°19'	11.32	23.0	20.0
4	14°02'	14.03	24.0	25.0
3	18°26'	18.43	25.2	33.3
2	26°34'	26.57	27.0	50.0
1	45°00'	45.00	30.0	100.0

BIOGRAPHY

Ms.Hathaithip Thassanapak was born in Roi-Et, north-eastern part of Thailand on January 23,1976. In 1998 she graduated with a B.Sc. degree in geotechnology from the Department of Geotechnology, Faculty of Technology, Khon Kaen University. After graduation she has decided to continue for her advanced study in the Department of Geology, Faculty of Science, Chulalongkorn University.