CHAPTER II

LITERATURE REVIEW

Landslide is a general term used to describe the movement of a mass of rock and soil downslope under gravitational influence (Varnes, 1984). According to Cruden (1991), a *landslide* is defined as "the mass movement of rock, debris, or earth down a slope. Other terms used to refer to landslide events include mass movement, slope failures, slope instability, and terrain instability (Cruden and Varnes, 1996) propose that basically the term *landslide* includes all types of gravity-caused mass movement, ranging from rock falls through slides, avalanches and flows, which in this case is more or less equivalent to the "mass movement". Common landslide triggers include intense rainfall, rapid snowmelt, water-level changes, volcanic eruptions, and strong ground shaking during earthquakes activity (Turner and Schuster, 1996). Landslide can be classified in terms of state of activity (e.g. active or inactive landslides), distribution of activity (e.g. retrogressive or progressive landslides), and style of activity (e.g. single or complex landslides) (Turner and Schuster, 1996).

2.1 Classification of Landslides and Causes

The classification system for the classification of landslide is based on several parameters as shown in table 2.1. According to Cruden and Varnes (1996), the various types of landslides can be differentiated by kinds of materials involved modes of movement.

2.1.1 Material Types involved in landslide

The material types involved in landslides are classified into two groups, viz. bedrock and soil. Soil is generally unconsolidated surface material. It is further subdivided into debris and earth depending upon its textures.

Table 2.1 Types of landslides based on the work of Cruden and Varnes (1996).

Type of Movement		Type of Material		
		Bed Rock	Engineering Soils	
			Predominately Coarse	Predominantly Fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris slide	Earth slide
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLSTIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (Deep creep)	Debris flow	Earth flow
			(soil creep)	
COMPLEX		Combination of two or more principle types of movement		

Bed rock: Bed rock refers to earth materials that have lithified by rock forming process. It strength depends on the rock type, degree of weathering and the density, and orientation of the discontinuities, which are generally the planes of weakness in the rock mass. For instance, if a dense and hard granite rock contains many fractures, the rock mass may be no stronger than a coarse-grained soil.

Debris: Debris is composed of predominantly coarse-grained soil including boulder to gravel and sand sized materials. It can also include highly fractured bedrock. The strength of coarse-grained soil is generally derived from friction between the grains. Woody debris such as tree or logs, or other organic material, is sometimes mixed with the inorganic debris.

Earth: Earth refers to predominantly fine-grained soil (silt and clay sized materials). The strength of fine-grained soil is generally derived from cohesion, the chemical and electrical bonding between the small particles.

2.1.2 Type of landslides

The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope forming materials (Figure 2.1b) including rock, soil, artificial fill or a combination of these. The material can be moved by sliding, falling, topping, spreading, or flowing. Figure 2.1a shows a graphic illustration of a landslide, with the commonly accepted terminology describing its features (from http://www.nationalatlas.gov, 2005).

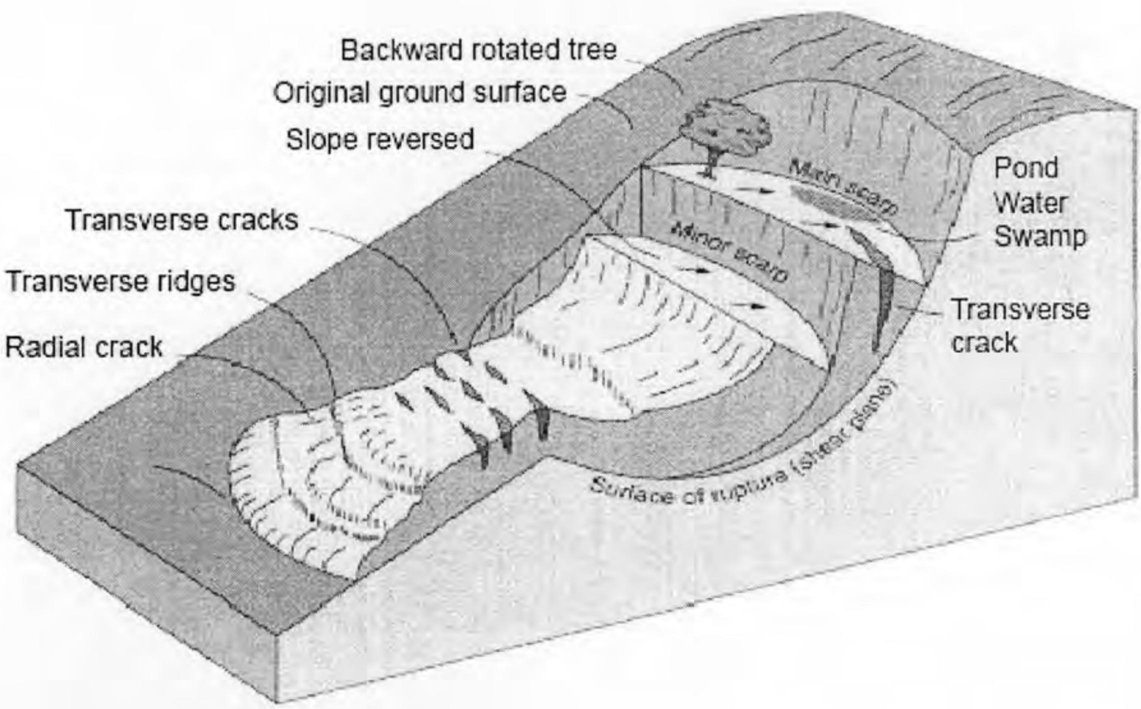


Figure 2.1a The graphic shows commonly aspect terminology of landslide features. (modified from http://www.nationalatlas.gov, 2005).

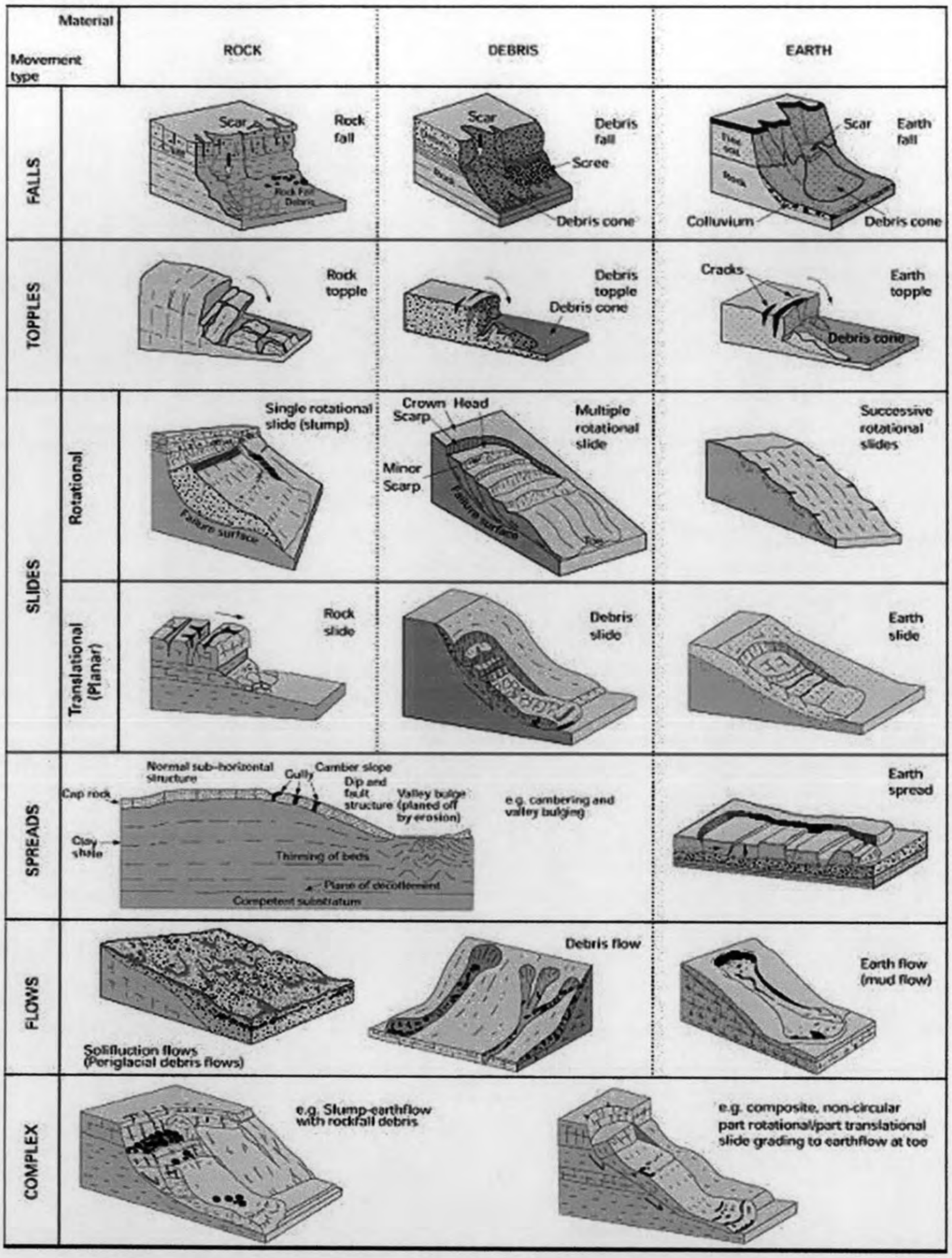


Figure 2.1b The graphic shows classification of landslide features based on classification of Cruden and Varnes (1996).

Falls: Falls are abrupt movements of masses of geological material such as separated rock and boulders from steep slope or cliff by free-fall, bouncing and rolling. Separation rocks occur along fractures, joints and bedding planes. Fall is strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.

Topples: Topples are distinguished by the forward rotation of unit of rock or soil about some pivot point, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.

Slides: Slides refer the movement along one or more distinct surfaces. Slides are subdivided into rotational slides and translational slides, depending on the shape of the failure plane.

1) *Rotational slide* is a slide, which the surface of rupture is curved concavely upward. The slide movement is roughly rotational. The axis of slide movement is parallel to the ground surface and transverse across the slide. Rotational slides are referred to slumps, involve movement along a curve failure planes.

2) *Translational slide* is a slide, which the landslide mass moves along roughly planner surface. The failure plane is often existed before the occurring of movement.

Lateral spreads: Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear and tensile fractures. The failure is caused by liquefaction and usually triggered earthquake.

Flows: Flows refer to movement as viscous fluid. There are five basic categories of flows that differ from one another in fundamental ways.

1) Debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water flows down slope as a slurry. Debris flows are commonly caused by intense surface-water flow, due to heavy rainfall or rapid snowmelt. They are also commonly transform from another types of

landslides that occur on steep slope and nearly saturated and consist of large proportion of silt and sand sized material. Debris flow source areas are often associated with steep gullies. Debris flow deposits are usually indicated by the presence of debris fans at the mouths of gullies.

2) Debris avalanche is a variety of very rapid to extremely rapid debris flows.

3) Earth flow is elongate flow and usually occurs in fine grained materials or clay bearing rocks on moderate slope and under saturated conditions. The slope material liquefies and run out, forming a bowl or depression at the head. However, dry flows of granular material are also possible occurred.

4) Mud flow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand, silt, and clay sized particles.

5) Creep is the very slow movement of slope forming soil or rocks. The movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. It is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or bridges.

Complex landslides: Complex landslides are involving the combination of two or more types of movement. Commonly one type of movement starts the materials moving, such as debris slide, and once underway the materials take on the character of another type of movement such as a debris flow. The name of the complex movement is a combination of the type of movement, in order to occurrence, such as a debris slide-debris flow. The rate of movement depends on the types of movements and material types.

The very common types of landslides are fall, topple, rotational slide, translational slide, translational slide, lateral spread, debris flow, and creep described as follow (Figures 2.2a-2.2g).

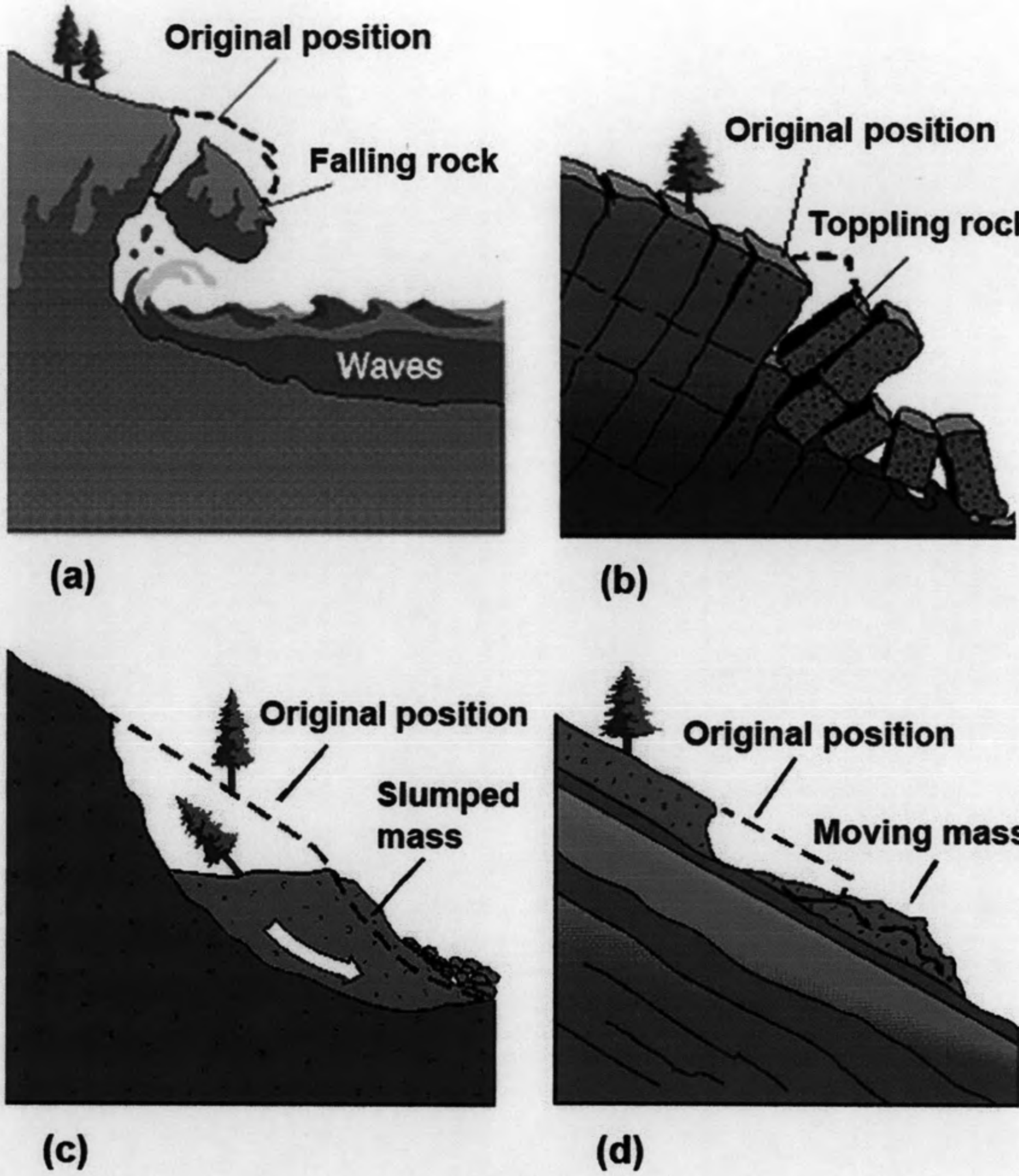


Figure 2.2a The most common types of landslide (modified from http://www.em.gov.bc.ca).

(a) Fall (b) Topple

(c) Rotational slide (d) Transitional slide

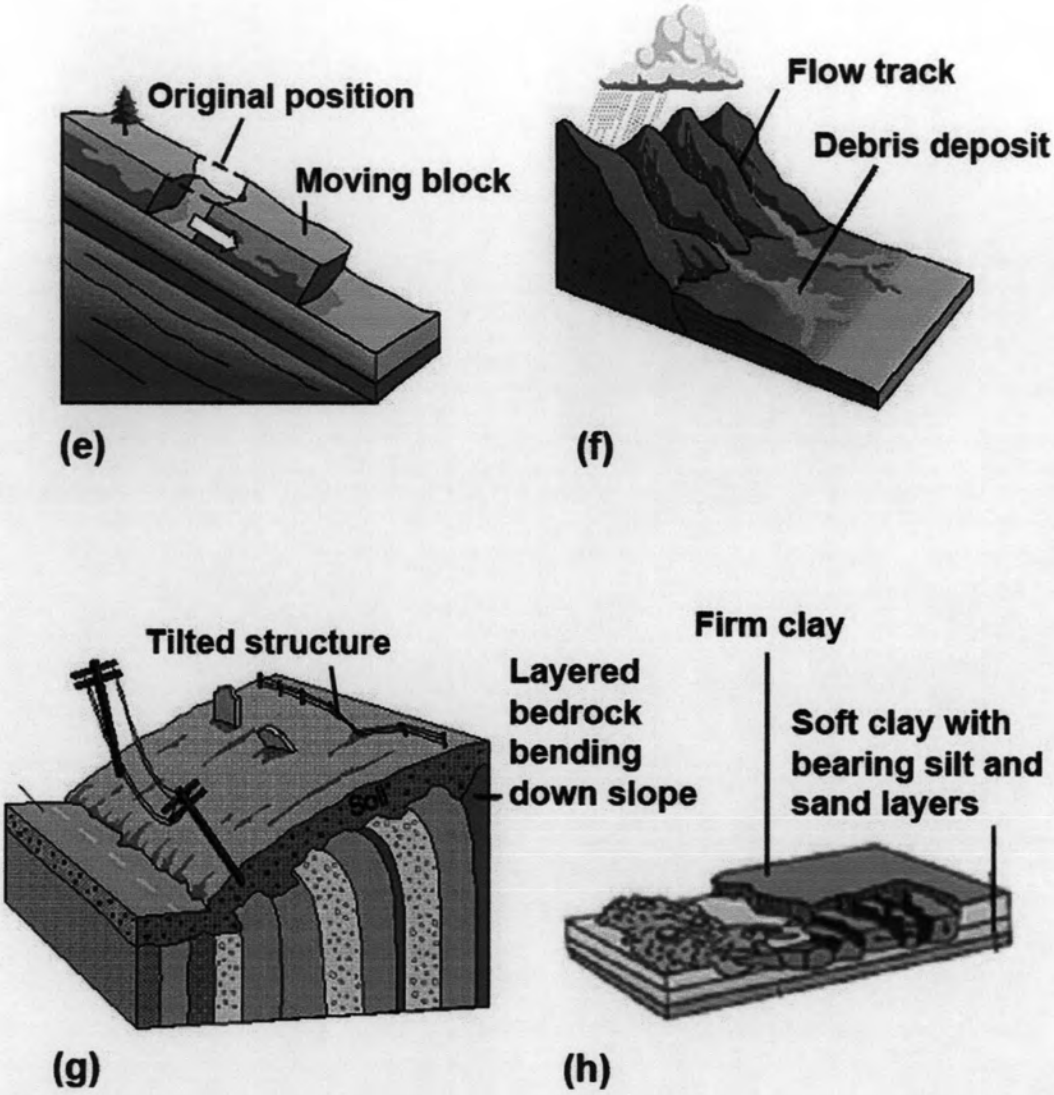


Figure 2.2b The most common types of landslide (continue) (modified from http://www.em.gov.bc.ca).

(e) Transitional rock slide (f) Debris flow

(g) Creep (h) Lateral spread

Falls and topples are easy to visualize. In a fall, material detached from a steep slope or cliff descends through the air, and may bounce and roll. In a topple, a mass rotates forward on a pivot point. If a toppling mass pivots far enough, a fall may result.

Slides are characterized by shear displacement along one or several surfaces. Two general types of slides are recognized, rotational and translational. In a rotational slide, the surface of rupture is concave upward, and the mass rotates along the concave shear surface. Rotational slides are usually called slumps and they can occur in bedrock, debris or earth. In a translational slide, the surface of rupture is a planer or gently undulatory surface. In bedrock and earth, translational slides are usually called block slides if an intact mass slides down the slope. If rock fragments or debris slide down a slope on a distinct shear plane, the movements are called rock slides or debris slides. It is easy to see that confusion can result by applying the term "slide" to all types of landslides.

Lateral spreads are characterized by lateral extension movements in a fractured mass. Lateral spread movements may occur in bedrock and soil as a result of liquefaction or plastic flow of subjacent materials, or in bedrock without a well-defined basal shear surface or zone of plastic flow. Lateral spreads in bedrock without a well-defined zone of shearing or flow, usually occur on ridge crests.

In general, a flow is a moving mass that has differential internal movements that are distributed throughout the mass. While most flows occur in debris and earth, one type of flow, gravitational sagging, does occur in bedrock. Flows in debris and earth can be cohesive or non-cohesive. Both cohesive and non-cohesive flows are further subdivided by water content and material properties.

Cohesive flows in debris include soil creep, solifluction, block streams, talus flows, and rock glaciers. Soil creep is an imperceptibly slow deformation that continues under constant stress. Solifluction is a slow flow in soil that is often observed in areas with perennially or permanently frozen ground. Block streams are slow moving tongues of rocky debris on steep slopes, and are often fed by talus cones. Talus flows are slow flows that occur in the basal portions of talus slopes. Cohesive flows in earth include soil creep, solifluction, earth flows, and debris flows. Soil creep and solifluction in earth are similar to that debris. Earth flows are very slow to rapid flows that have a distinct source area, a main flow track, and a depositional area.

2.1.3 Landslide Causes

Causes of landslide occurrence at a given location depend on a number of conditions, which may consider as controlling factors and triggering events. According to Cruden and Varnes (1996) controlling factors can be broadly divided in to *material properties* (rock and soil type, and in-situ and post movement strength, etc), and *terrain conditions* (slope, aspect, fracturing and cultivation, etc).

Triggering events of landslide can be divided into natural events and human activities (Turner, 1996). These will include earthquakes, intense rainfall and possibly new construction and development. Although there are multiple types of causes of landslides, the factors that cause the most of damaging landslides around the world are three of these causes (Wang, 2001).

Landslide and water: A primary cause of landslides is slope saturation by water. This effect can occur by intense rainfall, snow melt, changes in ground water levels, and water-level changes along the coastlines, earth dams, the bank of lakes, reservoirs, canals, and rivers. Landslide and flooding are closely affiliated because both are related to precipitation, runoff, and the saturation of the ground by water. In addition, debris flows and mud flows usually occur in small, steep stream channels, that causes a special flood in the flat areas. Landslide can causes flooding by forming landslide dams that block valleys and stream channels, trapping large amounts of water to back up. This causes backwater flooding and, if the dam fails, subsequent downstream flooding. Solid landslide debris can add volume and density to normal stream flow or cause channel blockages and diversions creating flood condition or localized erosion. Landslides can also cause overtopping of reservoirs and/or reduces capacity of reservoirs to store water. Rainfall triggering action in mountainous region is caused landslides in the Nan Province area.

Landslides and seismic activity: Many mountainous areas like Nan Province that are vulnerable to landslides have also experienced at least moderate rates of earthquakes occurrence in records times. The occurrence of earthquakes in steep landslide prone areas greatly increases the likelihood that landslide will occur, due to ground shaking alone or shaking-caused dilation of soil materials, which allows rapid infiltration of water. Widespread rock falls also are caused by loosening of rocks as a result of ground shaking.

Landslides and volcanic activity: Landslide due to volcanic activity is same of most devasting types. Volcanic lava may melt snow at rapid rate, causing a torrent of rock, soil, ash, and water that accelerates rapidly on the steep slopes of volcanoes, devasting anything in its path. These volume debris flow reach great distances, once they leave the flanks of the volcano, and can damage structures in flat areas surrounding the volcanoes.

In Thailand, most of landslides occurrence depend on the material and terrain conditions combined with human activities, and rainfall triggering actions such as Kathun area in Nakhon Si Thammarat Province, Nam Ko area in Phetchabun Province and Wang Chin area in Phrae Province.

2.2 Landslide Hazards

The following summarizes some of the terms relating to “terrain stability” or “landslide hazard” and “risk assessment”. It is adapted from Morgan et al. (1992), Fell (1994) and Sobkowicz et al. (1995).

2.2.1 Landslide hazard definition

The word "hazard" is derived from the Arabic word for "a die" (singular of dice) and is often related to chance or probability as in the phase to hazard a guess. The United Nations definition of natural hazard is "the probability of occurrence of a potentially damaging natural phenomenon" (Varnes, 1984). In reference to landslides, Fell (1994) defines hazard as "the magnitude of the event times the probability of its occurrence". However hazard is also often used to describe the damaging phenomenon as in natural hazard, geological hazard, landslide hazard, or a specific type of landslide hazard, such as a debris flow hazard.

Hazard (H): Hazard as used in this thesis is the condition or event that puts something or someone, in a position of loss or injury, or in a position of potential or actual landslide occurrence. Landslide hazard is represented by susceptibility, which the probability of potentially disastrous landslide is occurring within the given area.

Probability of occurrence (P): Probability of occurrence is the chance or probability that a landslide hazard will occur. It can be expressed in relative (Qualitative) terms or probabilistic (quantitative) terms. Examples of relative terms are very high, high, moderate, and low, or very frequent, frequent, infrequent, and seldom.

The results of probabilistic are often presented in ranges of value, such as > 1/20, 1/100 – 1/20, 1/500 – 1/100, and 1/2,500 – 1/500 as shown in Table 2.2.

Table 2.2 Example of relative terms and ranges of annual probability of occurrence (from Resources Inventory Committee Government of British Columbia, 1996).

Relative term of probability	Range of probability of occurrence (Pa)	Comments
Very high	> 1/20	Pa of 1/20 indicates the hazard is imminent, and well within the lifetime of a person. Landslides occurring with a return interval of 1/20 or less generally have clear and relatively fresh signs of disturbance.
High	1/100 to 1/20	Pa of 1/100 indicates that the hazard can happen within the approximate lifetime of a person. Landslides are clearly identifiable from deposits and vegetation, but may appear fresh.
Moderate	1/500 to 1/100	Pa of 1/500 indicates that the hazard within a given lifetime is not likely, but possible. Signs of previous landslides, such as vegetation damage may not be easily noted.
Low	1/2,500 to 1/500	Pa of 1/2,500 indicates the hazard is of uncertain significance. A similar probability was at one time used to define the Maximum Credible Earthquake for dams, but this definition has been dropped.

2.2.2 Landslide consequences

Landslide hazards can result in a wide variety of down slope consequences, including environmental, social and/or economic (Aleotti and Chowdhury, 1999). Therefore, there must be something or someone vulnerable to loss or injury, as describe below.

Element at risk (E): Element at risk include any land, resources, environmental values, building, economic activities and/or people in the area that may be affected by the landslide hazard. The elements at risk can be quantified by placing money value or some other form of value on them.

Vulnerability (V): Vulnerability is the degree of damage caused by a landslide hazard to the elements at risk. It is usually expressed in relative terms, using words such as no damage, some damage, major damage, and total loss, or by a numerical scale between 0 (no damage) and 1 (total loss). An assessment of vulnerability often requires specialist input, such as engineers for structures and resource managers for natural resources.

Consequence (C): Consequence is the resulting loss or injury, or the potential loss or injury. It is the product of the elements at risk and the vulnerability (E x V), and can be quantified if the element at risk is expressed as value and the vulnerability is expressed numerically.

When a consequence is expressed qualitatively, it is referred to as a consequence rating (Aleotti and Chowdhury, 1999). The phrase, there is a high probability that landslide debris will reach the creek, cause siltation and damage fish habitat, is an example of a consequence rating.

2.2.3 Landslide risks

Landslide risk (R): Landslide risk considers both the landslide hazards and the consequence. Humbert (1977) stated that risk is the product of the probability that a landslide hazard will occur and the consequence of that occurrence ($R = P \times C$).

Specific risks (R_s): Specific risk is the product of the annual probability and the vulnerability ($R_s = P_a \times V$) for a specific element at risk.

Total risks (R_t): Total risk is the sum of the specific risks, or the sum of the product of the annual probability of occurrence, the elements at risk and the vulnerability ($R_t = P_a \times E \times V$).

Risk cost (R_c): Risk cost is the annual cost, or annualized cost, of the expected losses from the landslide hazard.

Probability of death of an individual (PDI): Probability of death of an individual, also known as risk of life is the probability that a specific person will be killed as a result of a specific landslide hazard (Wold and Jochim, 1989). It is a variation of the risk procedures described above. PDI is the product of the annual probability of the hazard, the person being specially in the path of the event when it occurs, the person being temporally in the path of the event when it occurs and the person being killed as a result.

Probability of death of group (PDG): Probability of death of group is the probability that a specific hazard will result in a minimum number of casualties (Wold and Jochim, 1989). Because the numbers of people vary in space and time, PDG is much more complex to determine.

Severity (S): Severity is sometimes used in association with PDI and PDG, and is the product of the spatial probability of impact (P_s), temporal probability of impact (P_t), and probability of loss of life (P_l), ($S = P_s \times P_t \times P_l$).

2.3 Technical Aspects of Remote Sensing, GIS and Their Integrations

2.3.1 Technical Aspects of Remote Sensing

Remote sensing refers to specific uses for obtaining information about the Earth's surface, which sense electromagnetic (EM) radiation (Gupta, 2002). Remotely sense has no direct contact between the sensors carried by either aircraft or satellite and the objects being observed. Remote sensing utilizes EM radiation principally in the ultraviolet, visible light, infrared, and microwave portions of the EM spectrum. Single (e.g. IRS-1D Panchromatic) and multi-band (e.g. Landsat 7 ETM) data acquisition systems are used as tools for gathering remotely sensed data. Interaction of EM radiation with the Earth's surface provided information about the reflecting or absorbing surface. Due to the short wave length of the EM radiation (centimeter to nanometer range), there is limited penetration of the target objects (Gupta, 2002). Therefore, data and images are obtained only from the earth surface. Consequently, remote sensing information on conditions and structures underlying a natural or artificial terrain surface can be derived only by "interpretation". Thus, the reliability of an interpretation depends on the knowledge and experience of the interpreter.

In recent years, remote sensing has been increasingly recognized as a means of obtaining geo-scientific data for regional and site-specific investigations (Rajbhandri, 1995). Remotely sensed data provides a synoptic perspective view, and covers large areas in a relative short time, which is unachievable with traditional field studies. Remote sensing is an excellent tool for site characterization because it is not limited by extremes in terrains or hazardous conditions, which may be encountered during an on-site appraisal. These are effective for basic and applied research covering a wide range of subject, including mineral exploration, geo-environmental and geo-hazard evaluation.

Remote sensing data should be acquired and integrated into early stages of the investigation and used in conjunction with traditional mapping techniques. It is the best suited method for the following purposes.

(A) Preliminary assessment and site characterization of an area prior to the application of more costly and time-consuming traditional assessment techniques, such as field mapping, drilling, and geographysical surveys.

(B) Clarification of geo-scientific problems using the broad perspective provided by an aircraft or satellite image.

(C) Geo-scientific assessment of regions with limited or no access, such as rugged terrain, hazardous sites, and disaster areas.

Most of remote sensing data from satellite based systems are best suited for regional studies, particularly those at scales of 1:100,000 to 1:50,000 (eg. general site characterization, topographical and land-use/land-cover mapping, structural mapping). The high resolution satellite image data, such as IKONOS, QUICK BIRD can be used for the scale of 1: 50,000 to 1:10,000 (Temesgen et al., 2001). These data are commonly used to characterize natural resources that have a wide distribution (e.g. tropical rain forests), to monitor flooding, ice cover of polar waters, as well as detect and monitor environment problems (e.g. impacts on soil and ground water, land subsidence, collapse-prone ground, hazard due to landslide, forest fires and soil spills). Satellite images have also been shown to be an effective tool for characterizing and assessing areas of human activity, such as deforestation, open-pit mines and extension of land development areas.

Consequently, remotely sensed data can be used to effectively detect and to assess factors related to landslide occurrence (Franco et al., 1995). The interpreter should have a working knowledge of remote sensing techniques and capability to assess the reliability of an interpretation, as well as the ability to use the derived information. For instance, the interpreter of remote sensing for landslide assessments should be having a knowledge and experience of the characteristics of landscape of landslide and factors related to landslide, and how these factors interact and affect the resulting information.

The factors that determine the utility of remote sensing in landslide hazard assessments are scale, resolution, and tonal or color contrast of the data. Other factors include areas of coverage, repetition cycle (days), and data cost and availability. Resolution of satellite image is determined by size and numbers of picture elements or pixel used to form an image. The smaller pixel size of an image is the greater the resolution of the data. For example, the pixel size of an image 30 m x 30 m is low resolution than 5 m x 5 m pixel size of an image. Spectral resolution also needs to be taken into consideration when selecting the type of data since different sensors are designed to cover different spectral regions. Spectral resolution refers to the number of spectral bands and the bandwidth offered by the sensor. The temporal occurrences of natural events will also affect the utility of remotely sensed data. For instance, Landsat sensor can detect a phenomenon; according to their repeat coverage are very 16 days and 5 days. Events, which are seasonal, predictable, or highly correlated with other events, are more likely to benefit from imagery than events that occur randomly such as earthquakes, tsunamis or landslides.

However, in order to assess landslide-prone ground as a precursory measure for effective disaster in mitigation, remote sensing can contribute with exclusive data and information. Remote sensing imagery should be regarded as data available to assist the study in the assessment of landslide hazard throughout the study area. The meaning and value of remote sensing data is enhanced through target-oriented data processing and skilled interpretation used in conjunction with conventionally mapped information (e.g. topographic map and geologic map) and ground-collected data.

A map derived from the interpretation of remote sensing data is influenced by subjective factors. For example, maps generated based on automatic classification techniques depend largely on the quality and appropriateness of the input data and analysis techniques used. Therefore, it is particularly important to spot-check interpretations of remote sensing data in the field. Field or ground checks may be necessary at the start and during a remote sensing project to establish a key for interpreting the data or to check intermediate interpretations (Temesgen et al., 2001).

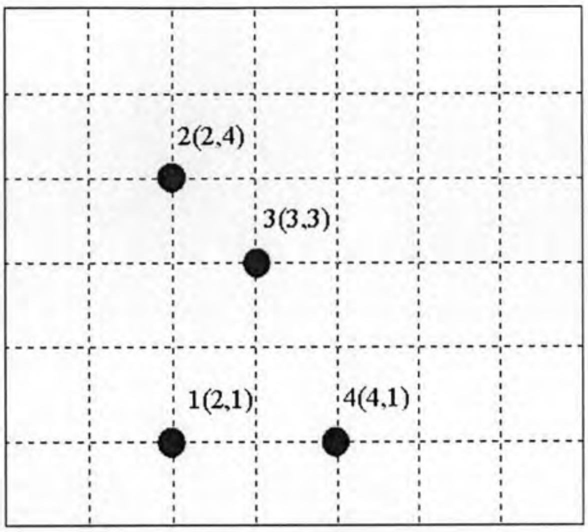
This study outlines the scope of a typical remote sensing work, starting with definitions and goals of remote sensing, covering digital data rectification and enhancement techniques, and describing data interpretation and map production approaches, referring to the Nan Province area.

2.3.2 Technical Aspects of Geographic Information Systems

Geographic information systems (GIS) are computer-based systems for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output, with its excellent spatial data processing capacity. In addition, it has been used widely in landslide hazard assessment (Carrara et al., 1999). GIS is very useful tool for spatially distributed data processing and analysis. Conceptually, GIS should be able to utilize spatial data in any form, whether raster, vector or tabular. GIS provides the following tasks of capabilities to handle geo-reference data.

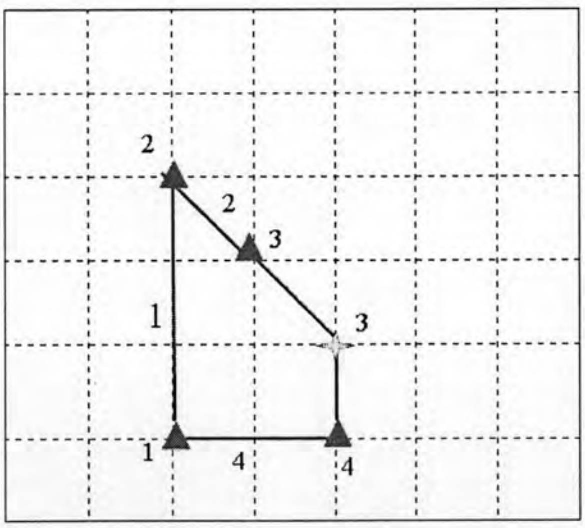
Data Input: Data input components convert data from their existing form into the other one that can be used by GIS. The input data are usually derived from available data (paper maps, and tables of attribute, etc.) assessment during field visits, and significantly supported by satellite image interpretation. Geographic reference and attribute data must be entered into GIS. Geographic reference data are coordinates (either in terms of latitudes and longitudes or columns and rows), which give the locations of information being entered. Attribute data are associated with a numerical code to each cell or set of coordinates and for each variable, or to represent actual values (e.g., 1,200 m elevation, 20 degree slope gradient) or to geo-information (land use category, vegetation type, and rock type, etc.)

Data Structures: The input data from the earlier step are needed to store in GIS as a spatial database. The spatial data (vectors and raster model) are structured and organized within the GIS according to their location, interrelationship, and attribute design as a systematic database of analysis. These databases can be easily to update, deletion and retrieval in GIS. In this study, vector and raster model are used for landslide analysis. **Vector model**: The vector model represents all information as points, lines or polygon, assigns as a unique set of x, y coordinates to each piece of information (Figures 2.3–2.5). Vector data can offer a large number of possible overlay inputs or layers of data. The vector model does represent the mapped areas more clearly than a raster model. However, each layer of vector-based model defined uniquely, analyzing information from different layers is considerable more difficult than raster model. **Raster model**: The raster model uses grid cells to reference and store information. The spatial data map is divided into a grid or matrix of square cells identical in size, and information attribute of the database (Figure 2.6). A cell can display either the dominant feature found in that cell or percentage distribution of all attributes found in the same cell. Raster-based model define spatial relationship between variables more clearly than vector-based, but the coarser resolution caused by using a cell structure reduces spatial accuracy.



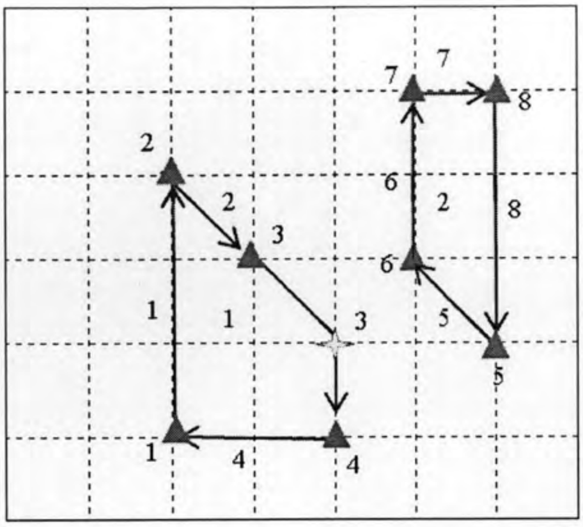
Point list	
ID	X,Y
1	2,1
2	2,4
3	3,3
4	4,1

Figure 2.3 Vector data of points with x,y coordinates (modified from Yamakawa et al., 1998).



Arc-coordinate list	
Arc#	x,y coordinate
1	(2,1) (2,4) Arc-node list 1,2
2	(2,4) (3,3) Arc-node list 2,3
3	(3,3) (4,2) (4,1) Arc-node list 4,4
4	(4,1) (2,1) Arc-node list 4,1

Figure 2.4 The data structure of line data model (modified from Yamakawa et al., 1998).



Polygon/Arc list	
Polygon#	**Arc#**
1	1,2,3,4
2	5,6,7,8

Figure 2.5 The data structure of an area data model (modified from Yamakawa et al., 1998).

The raster model uses grid cells to reference and store information. An area for study is divided into a grid or matrix of square cells identical in size, and information attribute of the database (Figure 2.6). A cell can display either the dominant feature found in that cell or percentage distribution of all attributes found in the same cell. Raster-based define spatial relationship between variables more clearly than vector-based, but the coarser resolution caused by using a cell structure reduces spatial accuracy.

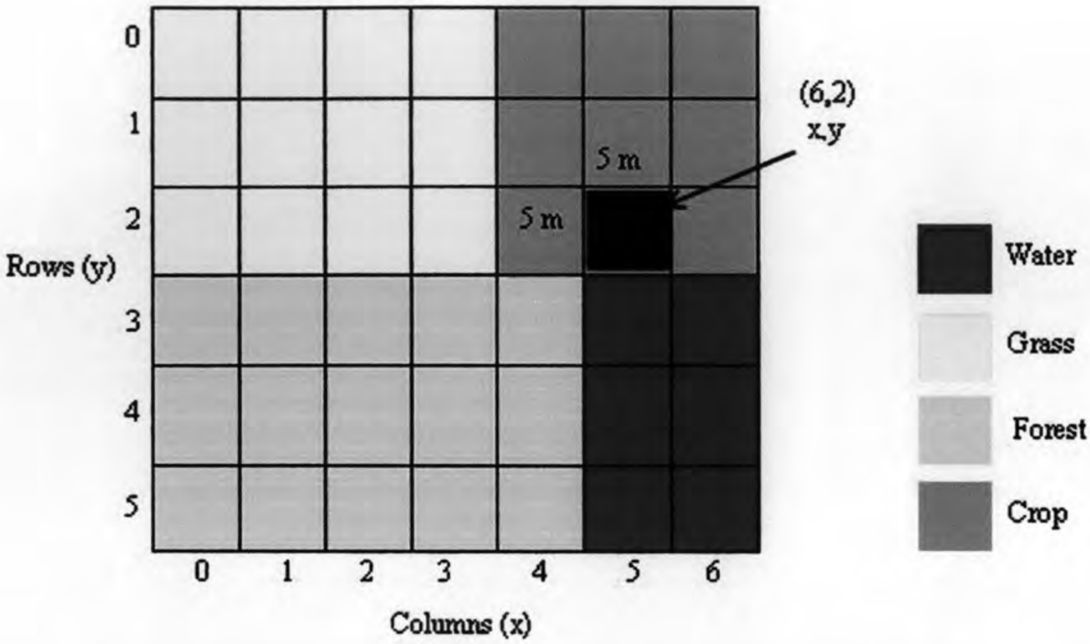


Figure 2.6 Typical file coordinate with resolution and information attribute of raster data model (modified from Yamakawa et. al., 1998).

The establishment of a database of information relating to landslides is a major task involving various inputs. The input data are usually derived from available data, assessment during field visits, possible supported by satellite image interpretation. Two different types of data must be entered into the GIS, geographic references and attributes. Geographic reference data are the coordinates (either in terms of latitude and longitude or columns and rows) which give the location of the information being entered. Attribute data associate a numerical code to each cell or set of coordinates and for each variable, or to represent actual values (e.g., 1,200 m elevation, 20 degree slope gradient) or to connote categorical data types (land uses, vegetation type, rock type, etc.)

Once the GIS has been acquired, and information system must be designed. The spatial data are structured and organized within the GIS according to their location, interrelationship, and attribute design as a systematic database for analysis.

Data manipulation and processing are performed to obtain useful information from a systematic database in the GIS system. These are the operations using analytical techniques to answer specific question formulated by the user. The manipulation process can range from the simple overlay of two or more maps to a complex extraction of output data and information from a wide variety of data sources. Data output refers to display or presentation of data and information employing commonly used output formats that include maps, graphs, reports, tables, and charts, either as a hard-copy, as an image on the screen, or as a text file that can be carried into other software programs for further analysis.

2.3.3 Integrating remote sensing and GIS for geo-spatial analysis

Data integration techniques for landslide hazard assessment are based on two important assumptions (Ward *et al.*, 1993) as follow: 1) the occurrence of the past landslides in the area are dependent on the input spatial geo-scientific data, and 2) the future landslides will occur under similar conditions in which the past landslides have occurred.

The concept of integrate landslide assessment analysis requires designing a database system as a basis for landslide hazard analysis. The parameters relevant to the landslide hazard phenomena were grouped into thematic categories. The relationships between parameters and phenomena were documented. Subsequently, there is need to quantitatively describe the landslides and their attributes, identifying the data categories and general data groups with variables that could be mapped from remote sensing imagery. There are various integration methods which can be utilized to combine spatial data from diverse sources together, to describe and analyze interactions, to make predictions and to prepare Landslide Hazard Zonation (LHZ) maps.

The propose of this review is to present some heuristic and statistical models/techniques (Greenbaum et al., 1995 and Lee, 2004) which can be used as a methodology or can be integrated in a methodology for landslide hazard assessment. Data integration techniques can be accomplished through a variety of methods, qualitative or quantitative, direct or indirect. Qualitative, direct methods essentially consist of the geomorphological mapping. Among the indirect methods, the heuristic (index) and the statistical approaches have been more frequently applied in mapping landslide hazard over wide regions with the aid of GIS-related techniques.

The further discussed techniques are suited to work with spatial data base consisting of information derived from ancillary sources and remotely sense data products.

Heuristic: The heuristic approach is based on the priority knowledge of the causes of landsliding in the area under investigation. Hence, instability factors are ranked and weighted according to their expert opinions to estimate landslide potential from data on preparatory variables. Its reliability is directly dependent on the knowledge of surveyors in the geomorphological processes acting upon the terrain. Landslide hazard maps obtained by this method cannot be evaluated in term of reliability or certainty. Barredo et al. (2000) provide a good application example of this expert-driven approach, where geomorphology experts decide on the type and degree of hazard for each area, using either a direct or indirect mapping approach. In the direct mapping approach the degree of hazard is mapped directly in the field, or determined after fieldwork using a very detailed geomorphologic map, that is derived from large scale aerial photographs. The indirect approach uses data integration techniques, including qualitative parameter combination, with the analyst assigning weighting values to a series of terrain parameters and to individual classes with in each parameter. The parameters are then combined within a GIS to produce hazard values.

Statistical or probabilistic: The statistical or probabilistic approach is based on the observed relationship between each factor and the past and present landslide distribution. Therefore, landslide hazard evaluation can become an objective an operation as possible. Statistical approaches have generally taken the form of bivariate or multivariate statistical analyses of terrain characteristics that have lead to landslides in the past (Carrara et al., 1991; Lorente et al., 2002) or weighted hazard ratings based on environmental attributes related to landsliding (Donati and Turrini, 2002; Lin et al., 2002; Lineback et al., 2001). The reliability of this functional approach is directly dependent on the quality and quantity of the collected data. The conceptually simplest technique is conditional analysis which attempts to assess the probabilistic relationship between relevant environmental factors and the occurrence of landslides over a given area. The technique is based on "Bays theorem" (Morgan, 1968) according to the frequency of data. Landsliding area or number of landslides can be used to calculate probabilities that depend on knowledge of previous events. Conditional analysis can be readily applied with a classification of the study area into unique-condition units (UCU). For each UCU, resulting from overlay of two or more map factor maps, the landslide frequency (LF) is simply calculated as shown in equation (2.1).

LF = Landslide area /UCU area..(2.1)

According to Bays theorem, Landslide frequency or LF is equal to the conditional probability (P) of landslide occurrence (L) given the set of environmental characteristics (rock type, slope angle class, land use type, etc.) featuring the UCU, and can be specified as shown in the equation (2.2).

P(L/UCU) = Landslide area/UCU area..(2.2)

By comparing the different probabilities conditional to different environmental characteristics occurring in the region under the investigation, with the average landslide probability over the entire region investigated (ER), which can be shown as equation (2.3).

P(L/ER) = Landslide area/ER area..(2.3)

It is possible to rank the region into belts at different hazard levels as the latter grouped into appropriate classes.

Some authors such as Neuland (1976), Reger (1979) and Mark and Ellen (1995) have used multivariate models to evaluate the landslide hazard. A model of slope instability is built up on the assumption that the factors which caused slope failure in the area are the same as those which will generate landslide in the future. The general linear model will assume as shown in equation (2.4).

$$L = B0+B1X1+B2X2+B3X3+\ldots\ldots+BmXm \qquad (2.4)$$

Where L is the presence/absence (the aerial percentage) of landslides in each terrain unit. The X's are input predictor variables measured or observed for each terrain unit. The B's are coefficients estimated from the data through technique which are dependent on the selected statistical tool (multiple regression, discriminate analysis, etc.)

2.4 Landslide Assessments

Landslide assessments are most commonly directed toward landslide initiation zones, and these are sometimes referred to as landslide initiation maps. There are several aspects of the assessment for the landslide hazard and risk. The two mainly used approach are qualitative and quantitative methods that have been developed and tested by many researcher worldwide (Aleotti, 1999). They often delineate areas of equal probability of landslide initiation, such as a probability of occurrence, or the probability of occurrence combined with magnitude and/or some other characteristics of the landslide. In the runout zones, landslide hazard maps delineate the probability of certain areas being affected by run out zones. The probability in both the initiation and run out zone can be expressed either qualitatively or quantitatively. The qualitative approach is mainly based on the site-specific experience of experts with the hazard determination directly in the field or by combining different index maps. Quantitative techniques utilize the statistical analysis (bivariate or multivariate) and the deterministic methods that involve the analysis of specific sites or slope based on geo-engineering models. Finally, several considerations involving the concept of acceptable hazard and risk assessment are presented.

The concept of landslide assessment is focussed to the phase of spatial analysis and hazard prediction of landslide occurrence. According to Varnes (1984), zonation refers to the division of the land in homogeneous areas and their ranking according to degree of actual or potential hazard caused by mass movements. Consequently, it requires knowledge of the factors determining the probability of landslide for a particular area. Remote sensing has been used in the detection and identification factors related to landslide occurrence such as, landslide detection, geology and structure, slope gradient and aspect, elevation, vegetation cover, and land use/land cover. The interpreter should have a working knowledge of remote sensing techniques and capability to assess the validity of an interpretation, as well as the ability to use the derived information. For instance, the interpreter of remote sensing for landslide assessments should have a knowledge and experience of the characteristics of landscape of landslide and factors related to landslide, and how these factors interact and affect the resulting information. The factors that determine the utility to remote sensing data in landslide hazard assessments are scale, resolution, and tonal or color contrast. Other factors include area of coverage, frequency, and data cost and availability.

Image resolution is determined by the sized and number of picture elements or pixel used to form an image. The smaller the pixel size is the greater the resolution. Spectral resolution also needs to be taken into consideration when selecting the type of data since different sensors are designed to cover different spectral regions. Spectral resolution refers to the band range or band width offered by the sensor. The temporal occurrences of natural events will also affect the utility of remotely sensed data. Certain sensors can detect a phenomenon quite readily although their repeat coverage is very 16 days for Landsat 7 ETM. Events which are seasonal, predictable, or highly correlated with other events are more likely to benefit from imagery than events which occur randomly such as earthquakes or tsunamis.

In summary, remote sensing imagery should be regarded as data available to assist the study in the assessment of landslide hazard throughout the study area. The meaning and value of remote sensing data is enhanced through skilled interpretation used in conjunction with conventionally mapped information (e.g. topographic map and geologic map) and ground-collected data.

2.5 Landslides in Thailand

In Thailand, landslides have been reported to occur from times to times (Chotikasathien, 2004, Kosuwan, 2005 and Tantiwanit, 2005). In the past, landslides seem to limit in remote areas. Due to the DMR database, it is noted that there are about 48 landslides that were reported to have occurred in Thailand. However, due to a rapid increase in population and a great deal of deforestation and urbanization, landslide sometimes happened recently near towns and living areas. It has been widely accepted that heavy rainfall is a major cause of landslides in Thailand (Tantiwanit, 2005 and Yumuang, 2006). It was also reported that in areas with past landslide records, at least 100 mm rainfalls were recorded.

In November, 1988, there was a tremendous landslide occurring in the Kathun area, Nakorn Si Thammarat Province, southern Thailand, approximately 230 persons were killed, 1,500 houses were damaged, and the total amount of 1,000 million baht was estimated for the economic lost. The rainfall before the trigger of landslide movement was about 280 mm (Chotikasathien, 2004).

The landslide, that took place in August, 2001, Nam Kor – Nam Chun area, Phetchabun Province, northern Thailand, killed 150 persons and damaged 600 houses. The total amount of 645 million baht was estimated for the economic lost. During that time, the amounts of rainfalls up to 150 mm were reported (Yumuang, 2007).

Recently, the landslide that occurred in May, 2004 in Mae Ramat area, Tak Province, western Thailand, created the lost of 400 casualties, 2,000 damaged houses, and 500 million baht. There were approximately 200 mm of precipitation prior to the landslide movement (Kosuwan, 2005). This is the main reason that people seem interested in the amount of rainfall as the main trigger mechanism for landslide movement.

In southern Thailand, the mega-scale tsunami-related earthquake on 26 December 2004 induced many subsequent small-scale landslides in southern Thailand (Tantiwanit, 2005 and Nawavitphaisit, 2005). People in many villages located within high hill terrains of the Phang Nga province were suffered from this disaster.

In Phang Nga province, landslides have been recorded since 1988 to 2004 by Nawavitphaisit (2005). The rainfall at that time is as about 220 mm. It was reported that no death people. There are about 20 scars detected by Akkrawintawong et al. (2008) using remote-sensing and field information. They occurred where the mountain slope ranged from 30-40%. It was concluded that not only the strong rainfall but also highly slopes and fractures in the granitic terrains may be much important physical factors.

2.6 Previous Works

The previous works on landslide hazard assessment have been studied in many parts of the world. Some important literatures have been briefly reviewed below in chronological order to be the background information.

The GIS has been recognized as a useful tool to process spatial data and display results. GIS offers map overlaying possibilities and calculation facilities of superior to conventional techniques. It is very important in analyzing the complex combination of factors leading to the slope instability. Numerous methods of analysis have been proposed for landslide assessment using GIS. One significant advantage of GIS over traditional field investigation and mapping methods is its capacity of processing large amount of different layers of data and displaying the results of spatial assessment.

Many GIS based approaches in assessing landslides hazards are reported in recent years. The use of multivariate statistics with GIS has been studied for a long time (Carrera *et al.*, 1983, 1991, 1992 and 1995). At the beginning stage of landslide hazard modeling large grid cells with a ground resolution of 200 by 200 m were used. Although the method based on spatial correlation has not undergone major changes, the basic modeling element (cell size) and the tools for modeling have improved significantly.

The statistical model developed by Carrera et al. (1991) is built up in a training area where the spatial distribution of the landslides is well known. After the model is extended to the entire study area, it is assumed that factors that cause slope failure in the study area are the same as these in the training area. The landslide hazard modeling is achieved by discriminate analysis and multiple regressions.

In recent years, there are many studies such as Nash (1987), Anbalagan (1992), Evans et al. (1997), and Guzzetti et al. (1999) involving landslide hazard evaluation and numerous methods have been proposed for landslide zonation of the landscape. The use of Geographic Information Systems (GIS) and Remote Sensing (RS) has increased because of the development of commercial systems and the quick of access to data obtained through Global Positional System (GPS) and RS (Gorsevski et al., 2000).

Mark and Ellen (1995) applied logistic regression for predicting sites of rainfall induced shallow landslides that initiate debris flow. In there study, statistics were used to determine the based correlation between mapped debris flow sources and physical attributes thought to influence shallow landsliding.

Mantovani (1995) concluded that the used of remote sensing data can be differentiated for the various phase within landslide study, such as, detection and classification of landslides, monitoring the activities of existing landslide, analysis and prediction in space and time of slope failure according to the remote sensing techniques for landslide studying and hazard zonation in Europe.

Montovani et al. (1996) summarize the feasibility and usefulness of obtaining information needed for the approaches of hazard zonation using remote sensing techniques at three different scales (Table 2.3). According to their work, landslide hazard mapping based on landslide inventory maps benefits most from information collected using remotely sensed data, followed by heuristic approaches at regional and medium scales, statistical and landslide frequency analysis using indirect methods (for medium and large scale studies).

However, the spatial resolution of the most widely used satellite data (TM and SPOT images) are generally too coarse for landslide characterization unless the landslide is very large in size, or the image data is re-sampled and merged with other higher resolution satellite images (Rengers et al., 1992; Koopmans and Ferero, 1993; Singhroy, 1995). In recent year, the high spatial resolution satellite imagery from IKONOS, Quickbird, SPOT-5 and the Indian satellites of the IRS series are available for the production of landslide inventory maps. Some research has been conducted using the 5.8 m resolution IRS-1D (Gupta and Saha, 2001), or simulated simulated IKONOS data (Hervas et al., 2003).

Table 2.3 Summary of the feasibility of usefulness of applying remote techniques for landslide hazard zonation in three working scales (Montavani et al., 1996)

Type of landslide hazard analysis	**Main characteristics**	**Regional scale**	**Medium scale**	**Large scale**
Distribution analysis (landslide inventory approach)	Direct mapping of mass movement features resulting in a map that gives information only for those sites where landslide occurred in the past.	2-3	3-3	3-3
Qualitative analysis (heuristic approach)	Direct or semi-direct method in which the geo- morphologic map is reclassed to a hazard map, or in which several maps are combined into one using subjective decision rules based expert-knowledge.	3-3	3-2	3-1
Statistical approach (stochastic approach)	Indirect methods in which statistical analysis are used to obtain predictions of mass movement from a number of parameter maps.	1-1	3-3	3-2
Deterministic approach (process-based)	Indirect methods in which parameter are combined in slope stability calculation.	1-1	1-2	2-3
Landslide frequency analysis	Indirect methods in which earthquakes and/or rainfall records or hydrological models are used for correction with known landslide dates to obtain threshold values with a certain frequency.	2-2	3-3	3-2

(Note that for the first number 1=low, 2=moderate, and 3=good, for the second number 1=no use, 2=limited use, and 3=useful) As shown in Table 2.2 the first number indicates the feasibility of obtaining the information using remote sensing (1 = low: it would take too much time and money to gather sufficient information in relation to the expect output; 2 = moderate: a considerable investment would be needed, which only moderate justifies the output; 3 = good: the necessary input data can be gathered with a reasonable investment related to expected output. The second number indicates the usefulness

Lee and Min (2001) proposed the statistical analysis of landslide susceptibility at Yougin, Central Korea, in year 2000. Using a GIS and RS, landslide locations were identified from interpretation of aerial photographs and field surveys. The relationship between landslide occurrence and cause factors were analyzed using probability, logistic regression, fuzzy logic, and neural network methods for landslide susceptibility assessment. Instability factors include surface and bedrock lithology and structure, bedding, altitude, seismicity, slope steepness and morphology, stream evolution, groundwater condition, climate, vegetation cover, land use, and human activities. The result of these studies is landslide susceptibility map.

Lin et al. (2002) was studied in the assessing debris flow hazard in a watershed in Taiwan, stated that initiation of debris flow requires three fundamental condition and at least one trigger condition. The three fundamental conditions are geology, topography, and hydrology. These can be divided into nine factors. The first three factors, rock formation, fault length and landslide areas are group under the category of geology. These factors influence the production of abundant debris. The next three factors, slope angle, slope aspect and stream slope are associate to the topographic condition. These factors have impact on the initiation and transportation of debris flows. The last three factors, watershed area, form factor and cultivation factor are influent the peak flow rate of stream that is the initiation and transportation of debris flows. These factors are grouped under the category of hydrology.

Zomer et al. (2002) is used satellite remote sensing data for DEM extraction in complex mountainous terrain of the Makalu Burun National Park of Eastern Nepal. It is extremely useful for terrain analysis of topographic condition. Hydrologic model, automated stream and watershed delineation is easily facilitated by the extracted DEM. Three dimension terrains are able to visualization from DEM.

Singhroy and Molch (2004) mention two different approaches that can be adopted for determining the characteristics of landslides from remotely sensed data. The initial approach determines more qualitative characteristics such as number, distribution, type and character of debris flows. This can be achieved with either satellite or air-born imagery collected in the visible and infrared region of the spectrum. The second approach complements are qualitative characterization, estimating dimension (e.g., length, width, thickness and local slope, motion, and debris distribution) along and across the mass movement using stereo SAR, interferometric SAR and topographic profiles.

In Thailand, the literatures on the landslide investigations and similar phenomena are also reviewed. Perhaps, the first investigation on landslide in Thailand was made by Ruenkrairergsa and Chinpongsanond (1980) for the Department of Highways. They reported the incident landslides in northern Thailand. Causes of landslides were due to geological factors especially lineament, water infiltration, and microseismic activities.

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

Wannakao et al. (1985) studied the engineering properties of rocks causing of slope failures along the Lom Sak – Chum Phae Highway between Km 18 – 24 where the failures were most intensified. Slope failures at this site could be classified into planar, circular, wedge and block falls.

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

Aung (1991) reported that most failures took place on slope with gradient between 10 – 30 degrees and extended from the ground surface to the depth of 1 – 3 meters 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 Phi Pun District, Nakhon Si Thammarat Province.

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, the destruction of natural forest and changing to para-rubber plantation, the important of subtle landform on the landslides. Typical weathering profile of granite terrain was summarized and correlated to the landslides. Landslide type 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 1998, Khao Luang Mountain Range. They included (1) deforestation of areas which significant by caused the erosion of steep slopes; (2) steep gradient over 35 percent and sharp change in gradient which occurred when the mountain streams met 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 summarized as follows: (1) residual soil from weathered granitic rocks was most susceptibility to landslide; (2) steep gradient over 30 percent; (3) the change of vegetation cover to para-rubber plantations and (4) the triggering factor was highly rainfall intensity.

Khantaprab (1993) conducted a study on the same 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 terrain with residual soils of weathering granite and (4) the triggering factor, high cumulative rainfall intensity.

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 could cause instability to soil slopes. From the event, the slope between 10 – 40 degrees in gradient was the most of landslides location occurred.

Pantanahiran (1994) summarized the primary factors that controlled landslides in the Khao Luang Mountain Range during November 1988 storm as follows: (1) fractured limestone and granitic bedrock; (2) shallow sandy soil from the weathering of granitic rock; (3) steep slope of more than 30 percent; (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 included eight parameters namely, elevation, aspect of slope, TM4 (Thematic Mapping Band-4), flow accumulation, brightness, wetness, slope and flow direction. This model was capable of classifying 82 percent of landslides in the Tha Di stream basin at a 0.4 cutoff probability.

Tangjaitrong (1994) developed a framework for integrating the techniques of geographic information system (GIS), remote sensing, and knowledge based system to predict landslide hazard zones in the study area comprising approximately 200 square kilometers that lying on a part of Khao Luang Mountain Range in Phipun District, Nakhon Si Thammarat Province. The intention of the designed framework was to ensure that the prediction could be done under limited information conditions. The study established an image-based GIS through process of research design, data collection, and software development. It also developed a knowledge-based system through similar processes (designing, knowledge acquisition, and software developing). The study had engineered those two systems so they could be integrated perfectly. Four methods of landslide hazard prediction were investigated in the study: (1) the method using knowledge of experts, (2) the method using infinite slope analysis, (3) the method using a logistic model, and (4) the method using knowledge elicited from the GIS. Results of the investigation showed that the integration of an image-based geographic information system and a knowledge-based system was a useful approach for predicting landslide hazard zones.

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 were Grade IV to VI for the soil thickness of 1 to 2 meters, with the slope greater than 26 degrees. Moreover, sandy and cohesion less of clayey soil was 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 kilometer and the percentage of total land area in each basin, sub-basin, and the Tapi plain foothills as indicators of debris flows susceptibility. He found that hillslope areas in tropical regions underlain by granite were more susceptible to debris flows than those underlain by clastic sedimentary or metamorphic rocks. The most frequent mode of land use in which debris flows occurred was rubber tree plantation.

The National Economic and Social Development Board (1997) conducted the study of natural hazard management in southern region of Thailand. The study consisted of 6 sub-topics as follows: (1) types of natural hazards and the effected areas, (2) flood hazard and risk assessment, (3) landslide hazard and risk assessment, (4) soil erosion hazard and risk assessment, and (5) recommendation for natural hazard management in the southern region of Thailand. Geographic information system was also applied to manipulate, analyze and present in the study.

Pattanakanok (2001) proposed the landslide hazard monitoring in Nam Ko area using (1) analysis of Landsat TM (4R 5G 3B) to classify land use by Maximum Likelihood Classification, (2) creating 3D digital terrain model from 20 meter contour intervals, (3) creating slope in 5 degree interval, (4) analysis the levels of the landslide hazard zonation by using 3 major groups: land use, soil and geological properties, as well as slope and 3D digital terrain model. It was noted that the factors related to the landslide occurrence used in this analysis were only those 3 major groups.

Thassanapak (2001) investigated the landslide assessment of Phuket Province using the influencing parameters of geology, landform, surface drainage zone, land use and land cover, soil characteristics, and rainfall intensity. The relationship between these parameters and the spatial data were evaluated using the proposed weight-rating technique. The findings of this study revealed that most of the potential areas to be affected by very high and high susceptibility to landslide included the famous tourist resorts.

Petchprayoon (2002) developed the prediction models of flash floods caused by dam failure and overflow through a spillway case study at Tha Dan Dam, Nakhon Nayok Province. The study used the technique on the integration of software MIKE 11, remote sensing and geographic information system for conducting this prediction. The study consisted of 5 main steps: (1) studying general characteristics of dam-location and of watercourse in downstream area with remote sensing technique, (2) modeling dam-failure with mathematic model, (3) estimating of damaged areas using geographic information system, (4) mapping the flooding in various degrees of severity , and (5) testing the assumption.

Yumuang (2006) using GIS and remote sensing to identify the potential source area, run-out area, depositional area, and determine the evidences of the potential for hazard of debris flow and debris flood in Nam Ko area, Phetchabun Province, Central Thailand. The study conclude that the landslide occurred in Nam Ko Yai sub-catchment was not only the work of the unusually heavy rainfall alone but it was the work of combined parameters including the terrain characteristics with specific land cover, underlain-material geotechnical properties, and time-delay for accumulation of plant debris and sediments.

In the present Nan study area, there are many preliminary studies that had been done such as Environmental Geology Division, Department of Mineral Resources (DMR) (2004) conducted a project of hazard zonation mapping from landslide in the whole Thailand in a scale 1:250,000 for identify the specific target areas to mitigate, monitor, and improve. The areas of Nan Province were selected for this practical approach that had been applied landslide mathematical predictive model of Pantanahiran (1994) combine with lithological weighting to analyze the landslide hazard zonation. It was noted that the parameters that used in the model consisted of elevation, adjusted aspect, slope, water flow direction, water flow accumulation, vegetation index from Landsat TM, soil characteristic (brightness), wetness and lithology. Landslide hazard zonation had been divided into 4 probability level levels as very high, high, medium and low. The proposed landslide hazard maps from the study will be investigated the accuracy and reliability in the field survey to further improve this prototype model.

Local Government Office (2006) reported the general information of the existing risk areas from flooding and associated disasters in 9 Districts in Nan District. It noted that if there were continuing and heavily rainfall occurrence, the risk areas in Nan Province could be identified into two types: (1) the overbank flooded areas in the lower flood plain of Nan River and Nam Sa River, and (2) the flash flood areas in the areas of that lied on the canyon mouths of streams. The report also concluded that the major factors influencing flooding were as follows: a lot of sediments in the main rivers and canals, heavily rainfall, lack of enough water retentions and reservoirs, and the obstacle from the transportation routes, etc.