CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the definition and terminology given for landslide classification system, landslide hazard, knowledge types used in prediction of landslide hazard, and basic concepts and previous investigations on evaluation of the potential for debris-flows and related sediment-flows, are reviewed. Besides, use of the remote sensing and geographic information system (GIS) techniques in landslide hazard assessment are also briefly mentioned.

2.2 Definition and Terminology

A wide variety of terms have been used for the denudational process whereby soil or rock is displaced along the slope by mainly gravitational forces. The frequently used terms are slope movement, mass movement, mass wasting, and landslide.

Mass movement is defined as "the outward and downward gravitational movement of earth material without the aid of running water as a transporting agent" (Crozier, 1986), or "the movement of a mass of rock, debris or earth down a slope" (Cruden, 1991). These are the most widely used definitions of the phenomenon. Although they are slightly different from each other when considering beyond the scope of inclusion of water, both definitions point to a mass transportation down slope in which a hazardous activity for humans may occur.

In the last few decades, landslide is a term being the most used, though in the narrow sense of the word (sensu strictu), it only indicates a specific type of slope movement with the specific composition, form and speed.

2.3 Landslide classification systems

The following factors can be used and have been used to classify landslides:

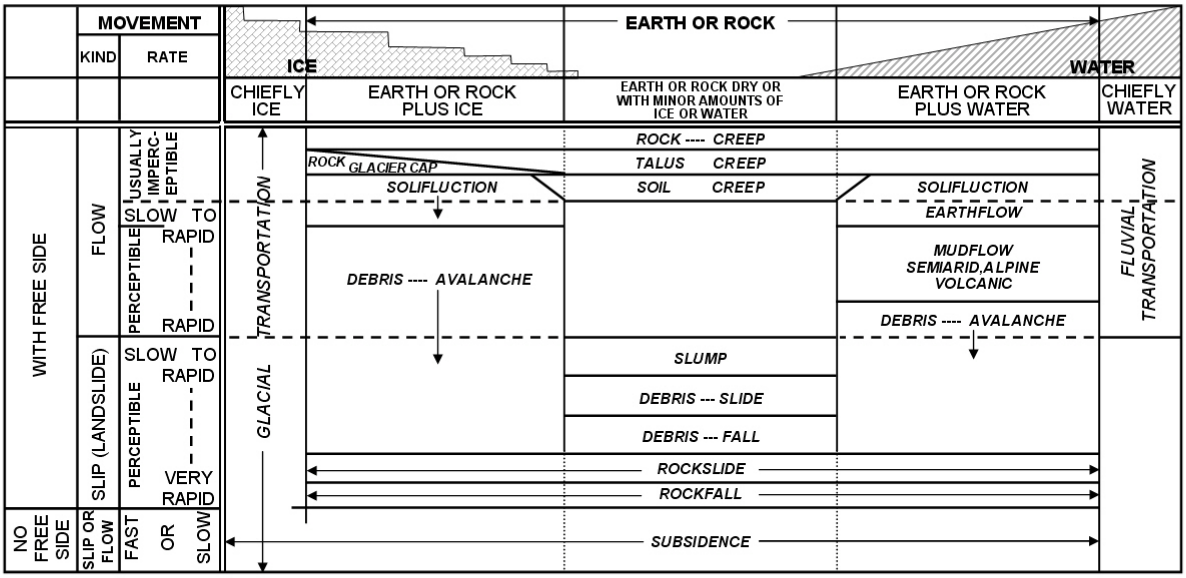
- Material (rock, soil, lithology, structure, geotechnical properties);
- Geomorphic attributes (weathering, slope form);
- Geometry of landslide body (depth, length, height etc.);
- Type of movement (fall, slide, flow etc.);
- Climate (tropical, temperate, periglacial etc.);
- Water (dry, wet, saturated);
- Speed of movement (very slow, slow etc.);
- Triggering mechanism (earthquake, rainfall etc.).

Therefore, numerous approaches to classification of slope movements have been made, those concerning the type of movement, material, velocity, morphometric parameters, amount of water involved, velocity, climate, etc. The most common classifications are discussed briefly below.

Sharpe (1938) gave a classification based on the type of movement (slip and flow), kind of material (earth or rock) and the role of water/ice as main factors, while the speed of the movement is a secondary parameter (Table 2-1).

The continuum of slope movements to the transportation of solids mainly by water (fluvial transportation) or by ice (glacial transportation) is clearly shown in the setup of the classification. Hutchinson (1988) used type of movement and morphology, which enables for a classification based only on field observation or the evaluation of landslides by means of on aerial photography. A practical classification also was that of Crozier's (1986). He used the threshold values of morphometric criteria (width, depth, length, dilatation, etc.) to define the different types of landslides (Table 2-2).

Table 2-1 Landslide classification system by Sharpe (1938).



Varnes (1978) proposed a classification based on the type of movement and material type as shown in Table 2-3. This classification nominated primarily types of movement and types of material (as bed rock and engineering soils) as main factors.

Rather than dealing with the types, activities and definitions, as they are defined by the I AEG Commission on Landslides in the 1990's, a more relational approach was given by Soeters and Van Westen (1996) as "Slope instability processes are the product of local geomorphic, hydrologic and geologic conditions; the modification of these by geodynamic processes, vegetation, land use practices and human activities; and the frequency and intensity of precipitation and seismicity".

Table 2-2 Landslide classification according to Hutchinson (1988).

Rebound	When ground is unloaded, either artificially by excavation or naturally by erosion, the unloaded area responds, initially elastically and subsequently by slow swelling
Creep	Any extremely slow movements which are imperceptible except through long-period measurement
Sagging of mountain slopes	A general term for these deep-seated deformations of mountain slopes, which, in their present state of development, do not justify classification as landslides.
Landslide	Relatively rapid downslope movements of soil and rock, which take place characteristically on one or more discrete bounding slip surfaces which divine the moving mass.
Debris movement of flow like form	Term covering five types of movement of flow-like form, which differ markedly in mechanism: non-periglacial mudslides, periglacial mudslides, flow slides, debris flows and sturzstroms.
Topple	A movement that occurs when the vector of resultant applied forces falls through, or outside a pivot point in the base of the affected block.
Fall	The more or less free and extremely rapid descent of masses of soil or rock of any size from steep slopes or cliffs.
Complex slope movement	The combination of two or more of the types of movements described above.

Table 2-3 Landslide classification system by Varnes (1978).

Type of Movement			*Type of Material*		
			Bedrock	Engineering Soils	
				Predominantly Coarse	Predominantly Fine
Falls			Rock Fall	Debris Fall	Earth Fall
Topples			Rock Topple	Debris Topple	Earth Topple
Slides	Rotational	Few Units	Rock Slump	Debris Slump	Earth Slump
	Translational		Rock Block Slide	Debris Block Slide	Earth Block Slide
		Many Units	Rock Slide	Debris Slide	Earth Slide
Lateral Spreads			Rock Spread	Debris Spread	Earth Spread
Flows			Rock Flow	Debris Flow	Earth Flow
			(Deep Creep)	(Soil Creep)	
Complex – Combination of Two or More Principal Types of Movement					

2.4 Landslide hazard

Mass movement, or slope instability or landsliding are the same natural denudational and degradational processes, unless they threaten human life. Their interference with ongoing human activities in the terrain marks a landslide hazard. The general accepted terminology explained below is that's of Varnes's (1984) and is illustrated in a form of formula:

$$Rs=H*V$$

Where

Natural hazard (H): The probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area (Figure 2-1).

Vulnerability (V): The degree of loss of a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. Scale is 0 (no change) to 1 (total loss).

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

The total risk could also be expressed in another formula:

$$Rt=E*Rs$$

Where

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

Total Risk (Rt): The expected number of lives lost, persons injured, damage to property or disruption of economic activity due to a particular natural phenomenon.

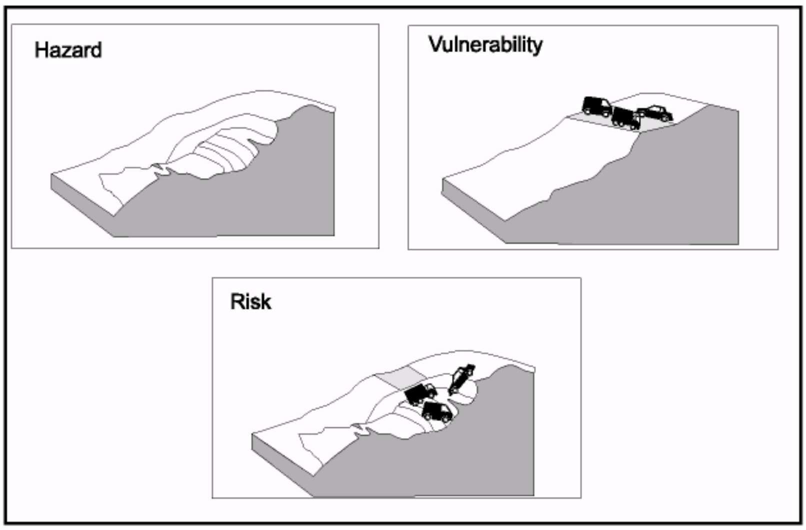


Figure 2-1 Graphical representation of hazard, vulnerability and risk (Varnes, 1984).

Based on the above definitions, hazard and risk information are generally represented as discrete maps. The discrete classes represent equal probability classes, which are in turn equal hazard or risk classes. The differentiation of hazard classes and their groupings are called "zonation". The formal definition given by Varnes (1984) is "The term zonation refers to the division of land into homogenous areas or user defined domains and the ranking of these areas according to their degrees of actual or potential natural hazards".

The natural hazard zoning/mapping constitutes the first and major task of the earth scientists in natural hazard analysis. The zoning of a natural hazard is the vital part of the study strategy in which the whole strategy will be based on. The zonation activities are mutually dependent on some factors as shown in Figure 2-2.

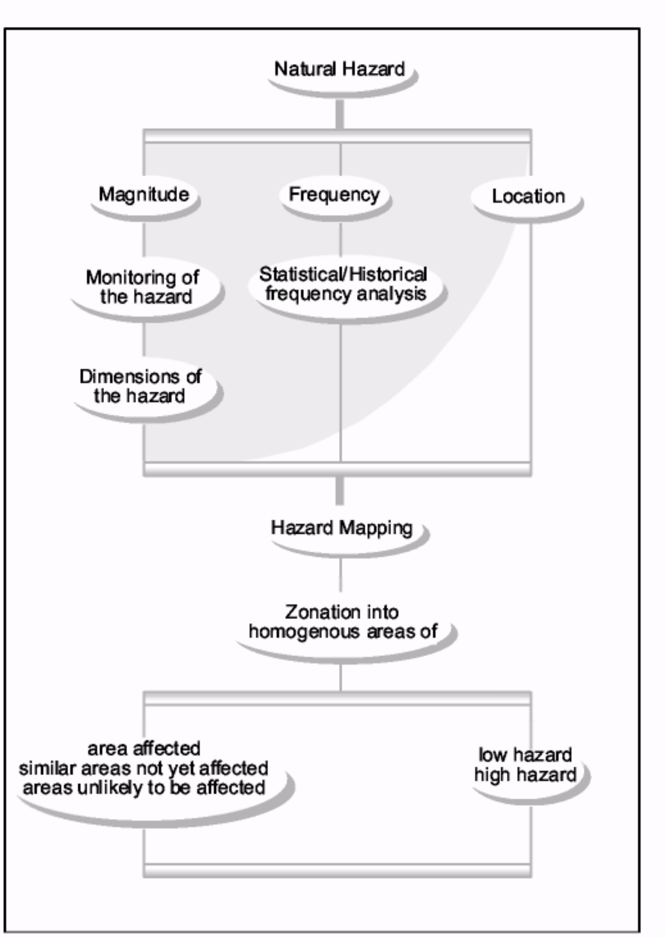


Figure 2-2 Overview of landslide hazard zonation activities (Varnes, 1984).

These factors can be grouped into magnitude properties of the hazard, frequency of the hazard and the spatial location of the hazard. The next step in hazard mapping is to show the mapped hazard and to classify the hazard map into some homogenous areas regarding the equal attributes of the hazard map.

The natural hazard zoning is controlled mainly by two factors, such as: the scale of the zoning or mapping and the knowledge type used in the hazard zoning.

2.4.1 Scale factor in analysis

Before starting any data collection, an earth scientist working on a hazard analysis project should have to answer a number of interrelated questions below.

- What is the aim of the study?
- What scale and with what degree of precision must the result be presented?
- What are the available resources in the form of money, data and manpower?

As the aim of the study would be previously defined, the scale and the precision are the first parameters to be defined prior to the start of the project. Hence, the scale factor must be determined at the first glance as it controls the type of the input data, nature of the analysis, and the output data of the study. The outcome precision also depends on the scale chosen; however is independent parameter regarding the nature of the project. The necessary adjustments should be made with the scale until the output precision and the desired precision fulfills the project conditions. The resource analysis will be conducted after the aim and scale is fixed.

The following scales of analysis, which were presented in the International Association of Engineering Geologists (IAEG) Monograph on engineering geological mapping (IAEG, 1976) can also be distinguished in general natural hazard zonation (Figure 2-3).

a. National Scale (<1/1,000,000)

The national scale analysis is used only to outline the problem, give an idea about the hazard types and affected hazard prone areas. They are prepared generally for the entire country and the required map detail is very low, even in the best case giving only data based on records in the form of an inventory. The degree of the hazard is assumed to be uniform. These kinds of maps are generally prepared for agencies dealing with regional (agricultural, urban or infrastructure) planning or national disaster prevention / hazard assessment agencies.

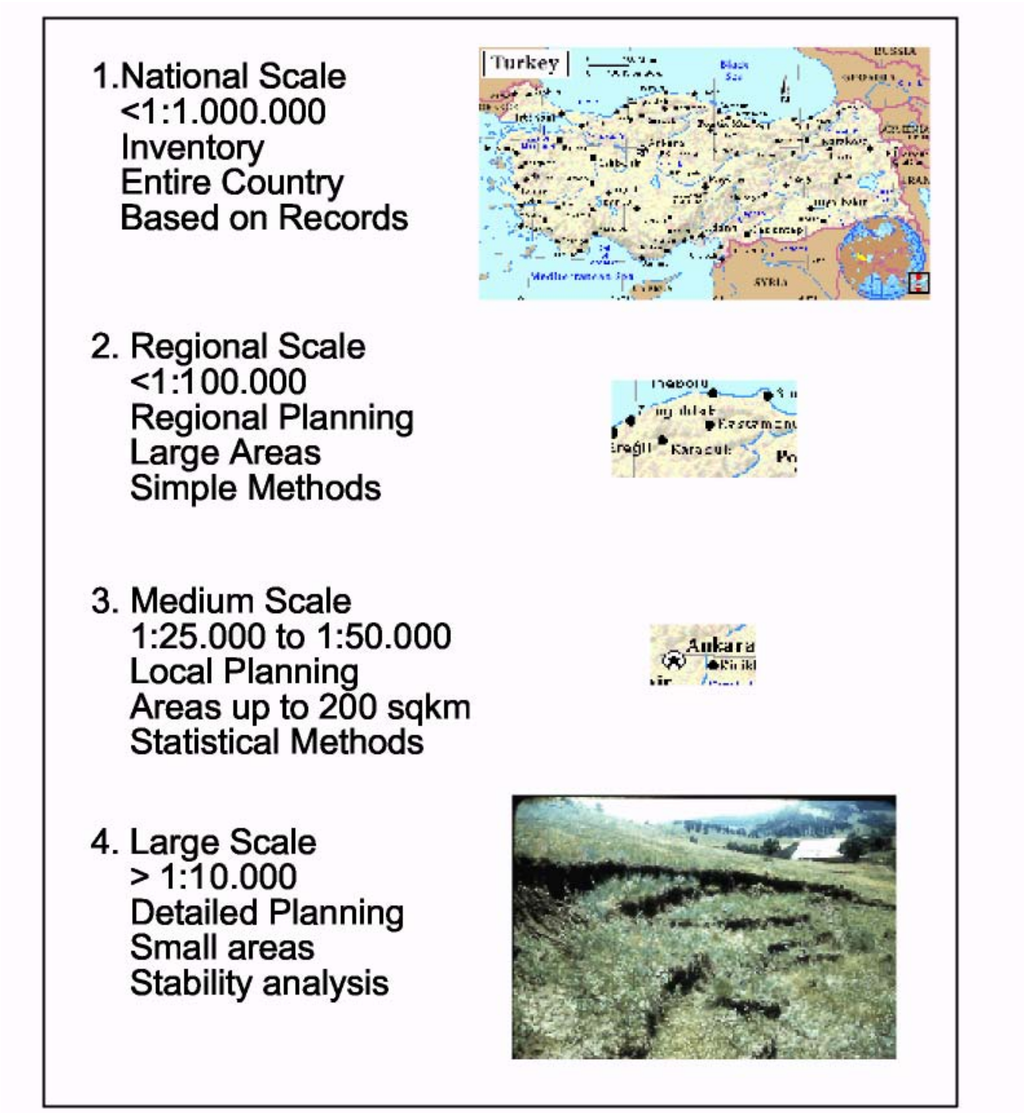


Figure 2-3 Scales of analysis and minor details (Sgzen, 2002).

b. Regional/Synoptic Scale (< 1/100,000)

The scale is still so small to be used in any quantitative method, but these maps are for regional planning and in early stages of appropriate region planning activities. The areas to be investigated are still too large, in an order of thousands of square kilometers, and the map detail is also low. Only simple methods are used with qualitative data combination and the zoning is primarily based on regional geomorphological Terrain Mapping Units / Complexes (TMU) or dependent on regional geological units.

c. Medium Scale (1/25,000 -1/50,000)

These hazard maps are made mainly for agencies dealing with inter municipal planning or companies dealing with feasibility studies for large engineering works. The areas to be investigated will be of several hundreds square kilometers. At this map scale, considerably more detail is required than at the regional scale. These maps do serve especially the choice of corridors for infrastructure construction or zones for urban development. Statistical techniques are dominantly used in this scale.

d. Large Scale (> 1/10,000)

These hazard maps are produced generally for authorities dealing with detailed planning of infrastructure, housing or industrial projects or with evaluation of risk within a city or within a specified project area. They cover very small areas hence the deterministic hazard analyses become available to be used. The detail level of the maps is set into a maximum. They are based on physical numerical models that require extensive data collection in the field and laboratory surveys.

2.4.2 Knowledge types used in prediction of landslide hazard

Prediction of landslide hazard for areas not currently subject to landslide hazard is based on the assumption that hazardous phenomena that have occurred in the past can provide useful information for prediction of future occurrences. Unlike general educational geological phrases in this case, "Present is not a key to the past but present and past are the keys to future", of which the real value of engineering and its futuristic approaches are represented. Therefore, mapping these phenomena and the factors thought to be of influence is very important in hazard zonation. In relation to the analysis of the terrain conditions leading to slope instability, two basic methodologies can be recognized (Van Westen, 1993) as below.

The first mapping methodology is an experience-driven applied-geomorphic approach, by which the earth scientist evaluates direct relationships between landslides and their geomorphic and geologic settings by employing direct observations during a survey of as many existing landslide sites as possible. This is also known as direct mapping technology.

Contrarily to this experience based- or heuristic approach is the indirect mapping methodology, which consists of mapping of a large number of parameters considered to potentially affect landsliding and subsequently analyzing (statistically) all these possible contributing factors with respect to the occurrence of slope instability phenomena. In this way the relationships between the terrain conditions and the occurrence of the landslides may be identified. On the basis of the result of this analysis, statements are made regarding the conditions under which slope failures occur.

Another division of techniques for assessment of slope instability hazard was given by Hartlen and Viberg (1988), who differentiated between relative and absolute hazard assessment techniques. Relative hazard assessment techniques differentiate the likelihood of occurrence of mass movements for different areas on the map without giving exact values. While absolute hazard maps display an absolute value for the hazard such as a factor of safety or a probability of occurrence.

Furthermore the hazard assessment techniques can also be divided into three broad classes based on use of statistical methods (Carrara, 1983; Hartlen and Viberg, 1988; Soeters and Van Westen, 1996) as follow.

- White box models: based on physical models (slope stability and hydrologic models), also referred to as deterministic models;
- Black box models: not based on physical models but strictly on statistical analysis; and
- Gray box models: partly based on physical models and factual data and partly on statistics.

2.5 Disaster management

A way of dealing with natural hazards is to ignore them. In many parts of the world, neither the population nor the authorities choose to take the danger of natural hazards seriously, for various reasons namely socio-economic, political, cultural, religious, etc. To effectively mitigate disasters, a complete strategy for disaster management is required, which is also referred to as the disaster management cycle.

Disaster management consists of two phases that take place before a disaster occurs, disaster prevention and disaster preparedness (both phases together are also referred to as disaster mitigation), and three phases after the occurrence of a disaster: disaster relief, rehabilitation and reconstruction.

Unfortunately, the emphasis in most countries has always been on the phase of disaster relief, and most disaster management organizations in developing countries have been established only for this purpose. Recently, the emphasis is being changed to disaster mitigation, and especially to vulnerability reduction.

Investment companies, (international) donor agencies, banks, and governments are increasingly requiring precise data on the risk due to hazards that may hamper the investment or reduce the return of their investment. Insurance and reinsurance companies similarly are demanding the more detailed risk evaluations to be able to set the insurance premiums for projects. Standard procedure will also be (or going to be) the development of risk scenarios that minimize the adverse consequences for the project and financial losses. Projects can be: civil engineering works, housing projects, mining, agricultural and forest developments, etc. (Van Westen, 1994).

Table 2-4 Key elements of disaster management (Van Westen, 1994).

Pre-disaster phases				Post-disaster phases	
Risk Identification	Mitigation	Risk Transfer	Preparedness	Emergency response	Rehabilitation and Reconstruction
Hazard Assessment	Physical structural mitigation works	Insurance/ reinsurance of public infrastructure and private assets	Early warning systems. Communication systems	Humanitarian assistance / rescue	Rehabilitation/ reconstruction of damaged critical infrastructure
Vulnerability assessment	Land-use planning and building codes	Financial market instruments	Monitoring and forecasting	Clean-up, temporary repairs and restoration of services	Macroeconomic and budget management
Risk Assessment	Economic incentives	Privatization of public services with safety regulations	Shelter facilities Emergency planning	Damage assessment	Revitalization of affected sectors
GIS mapping and scenario building	Education, training and awareness	Calamity funds (national or local level)	Contingency planning (utility companies / public services)	Mobilization of recovery resources	Incorporation of disaster mitigation components in reconstruction

(Note: The green colored blocks indicate those activities for which remote sensing and GIS are most useful)

2.5.1 Geo-spatial requirements

Mitigation of natural disasters will be successful only when detailed knowledge is obtained, including the expected frequency, characteristics, and magnitude of hazardous events in an area, as well as the vulnerability of the people, buildings, infrastructure and economic activities in the potentially dangerous area. Many types of information that are needed in natural disaster management have both an important spatial as well as temporal component.

Remote sensing and GIS provide a historical database, from which hazard maps may be prepared, to indicate which areas are potentially dangerous. Remote sensing data should be linked with other types of data, derived from mapping, measurement networks or sampling points, to derive parameters useful in the study of disasters. GIS may give models for various hazard and risk scenarios of an area to be developed in the future.

The spatial modeling of hazards is a complex task, in which many factors play a role, and which only experts can execute. It also involves a large number of uncertainties, which have to be taken into account. The zonation of hazard must be the basis for any disaster management project and should supply planners and decision-makers with adequate and understandable information.

Remote sensing data derived from satellites are excellent tools in the mapping of the spatial distribution of disaster related data within a short period of time. Many different satellite based systems exist nowadays, with different characteristics related to their spatial-, temporal- and spectral resolution. As many types of disasters, such as floods, drought, cyclones, volcanic eruptions, etc., will have certain precursors. Real time and near-real time satellite remote sensing may detect the early stages of these events as anomalies in a time series.

When a disaster is about to occur, the speed of information collection from air- and space borne platforms and the possibility of information dissemination with a corresponding swiftness make it possible to monitor the chance of disaster. Simultaneously, GIS analysis may be used to plan evacuation routes, design centers for emergency operations, and integration satellite data with other relevant data.

In the disaster relief phase, GIS is extremely useful in combination with Global Positioning Systems (GPS) for search and rescue operations. Remote sensing and GIS can assist in damage assessment and aftermath monitoring, providing a quantitative base for relief operations.

In the disaster rehabilitation phase, GIS can organize the damage information and the post-disaster census information, as well as sites for reconstruction. Remote sensing updates databases used for the reconstruction of an area.

Disaster management is a multidisciplinary activity requiring spatial and temporal information and expertise from many different specialization fields (Van Westen, 1994), such as:

- Expertise on techniques for the collection of geo-information, generation of data bases, and design of disaster management information systems.
- Expertise on the analysis of disastrous phenomena, their location, frequency, magnitude, etc.
- Expertise on hazard zonation and mapping the environment in which the disastrous events might take place: namely topography, geology, geomorphology, soils, hydrology, land use, vegetation, etc.
- Expertise on the inventory of elements that might be destroyed if the event takes place: infrastructure, settlements, population, socio-economic data, emergency relief resources, such as hospitals, fire brigades, police stations, warehouses, etc.
- Expertise on cost-benefit analysis, spatial decision support systems, conflict management, and the implementation of disaster management in organizations in developing countries.

2.5.2 Risk assessment as central theme

Much of the effort in disaster management is on the policy and social side. However, the decision-makers must be supplied with reliable, up-to-date, and well-interpreted information on the nature and geographical distribution of hazard and risk, and the possible risk scenarios. Risk assessment is considered as the central and most important aspect within disaster management. Risk is defined as "the expected number of lives lost, people injured, or economic losses due to potentially damaging phenomena within a given period of time " by Van Westen (1994).

In order to obtain quantitative risk maps, the first essential requirement is to carry out a quantitative hazard assessment. Most hazard maps still are of a qualitative nature and do not express the probability of occurrence of potentially damaging phenomena with a certain magnitude within a given period of time. In many developing countries, qualitative hazard maps are the only possibility, due to the scarcity of input data for quantitative analysis. There is an important role for data collection using remote sensing and the design of data bases for hazard assessment, as well as the use of various types of modeling techniques depending on the available data and the scale of analysis. Emphasis should be given to the development of quantitative hazard maps, derived by earth scientists, based on probabilistic or deterministic modeling. In data-scarce situation qualitative techniques should be applied, based on terrain analysis.

Another aspect which needs to be worked out in more detail is the quantification of vulnerability, which is achieved by making an inventory of the elements at risk (population, building stock, essential facilities, transportation and lifeline utilities, high potential loss facilities, economic activities) and an assessment of the degree of damage that may result from the occurrence of a potentially damaging phenomena. Emphasis should be given to techniques for rapid inventory of elements at risk in densely populated areas (urban and rural), using high resolution images., and the generation of elements at risk databases, which should be designed for multi-purposes, on the basis of cadastral databases. Furthermore, an aspect for modeling of vulnerability, using vulnerability curves in GIS is as well essential. Also input from partners is needed in order to include the economic aspects, in order to come to quantitative loss estimation.

The combined information of hazard and vulnerability is used to derive at quantitative risk analysis, including the total losses due to different hazards with different return periods and magnitudes. Methodology for data handling and quantification of risks in a large area is yet to be developed.

One of the large challenges is the implementation of these risk maps into risk scenarios, and the development of spatial decision support systems for disaster management, to be used in:

- Anticipating the possible nature and scope of the emergency response needed to cope with disaster,
- Developing plans for recovery and reconstruction following a disaster, and
- Mitigating the possible consequences of disasters

(Van Westen, 1994).

2.6 Use of remote sensing in landslide hazard assessment

Remote Sensing can be defined as the instrumentation, techniques and methods to observe the Earth's surface at a distance and to interpret the images or numerical values obtained in order to acquire meaningful information of particular objects on earth.

Three definitions of remote sensing are given below:

- Remote sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter.(Sabins, 1997)
- Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. (Lillesand and Kiefer, 1994)
- The term remote sensing means the sensing of the Earth’s surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment. (Van Westen, 1994)

The process of Remote Sensing is schematically shown in Figure 2-4.

The phenomenon, landslide, is affecting the earth's surface, hence it also falls in to the research and application areas of both aerial and space born remote sensing. The nature of this phenomenon as it is occurring at the surface of earth allows the earth scientists to exploit this fact using remotely sensed data. On the other hand, the nature of this phenomenon again limits the applications, as being dynamic and sometimes being quite small in terms of conservative remote sensing language. Furthermore they reveal very small information when they are observed in planar two-dimension, however, they contain large amounts of data when explored in three-dimension. Basing on this fact the use of stereo-remote sensing products seems to be indispensable, which reveals the true morphodynamical features of the landslides. These information are providing the diagnostic information regarding the type of the movement (Crozier, 1973). The general application fields of remote sensing in landslide business are monitoring the change of landslide activities through time (change detection) and mapping out where the hazard occurs.

Plenty of researchers have tested the usage of remote sensing products during the last 30 years. Two major groupings could be made upon the investigation of this research. These are aerial photography and space-born sensor images.

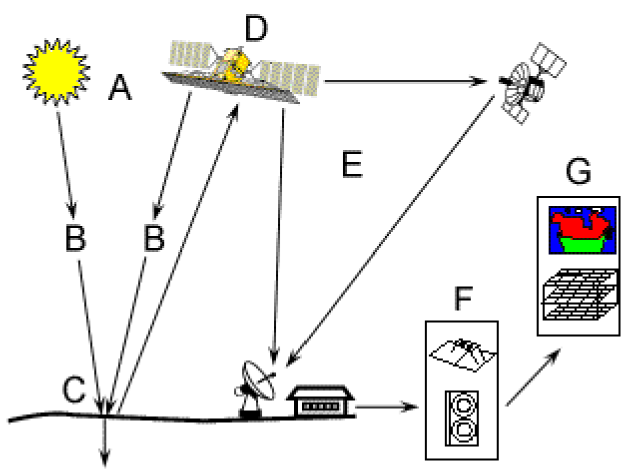


Figure 2-4 Process of Remote Sensing (Van Westen, 1994).

Note: A) Energy source to illuminate the target; B) Interaction of the radiation with the earth's atmosphere; C) Radiation-target interactions; D) Data reception; E) Data transmision; F) Data processing; G) Data application)

Numerous applications have been carried out which generally define the landslide areas. Chandler and Moore (1989), Chandler and Brunsden (1995) and Fookes and others (1991) gave excellent applications for photogrammetry. For single landslide within a smaller area, a monitoring scheme is best applicable with this technique with good accuracy. However, the application of this technique in a larger area of interest is limited as such larger areas could be easily accomplished by classical aerial photographical studies.

The landslide information extracted in the remotely sensing studies normally shows a relationship with the morphology, vegetation and the hydrological conditions of the slope. The slope morphology can be examined with stereographical coverages. Generally the identification of the slope instabilities is an indirect method. The failures are identified by associated elements with slope instability process. The advantages of aerial photographs can be listed as follows:

- They provide quite older coverages before digital world starts.
- The flight coverages are adjustable for new missions.
- The spatial and temporal resolutions are very high.
- Stereoscopic coverage provides access to slope identification.
- Most of the geoscientist are familiar to them.
- Every country have at least one full coverage of their land due to military reasons.

The disadvantages are as follows:

- Low spectral resolution
- The nature of photograph as hardcopy, hence not very handy
- Presence of distortions in parts of the images
- Orthorectification is needed to remove distortion and add coordinate information

- Absence of coordinate information
- The resultant map is dependent to the experience of interpreter

The applications with space born images are quite new compared to the others. Furthermore, they are generally defining the landslides indirectly by mapping out other parameters such as land cover. Gagon (1975); Mc Donalds and Grubbs (1975); Sauchyn and Trench (1978); Stephens (1988); Huang and Chen (1991); and many more workers could give discussion on this topic.

In comparison to the aerial photographs, the advantages of satellite images are as follow:

- Bigger coverage picture
- Larger spectral range
- Easily accessible
- No significant distortion
- Only georeference is needed to mark the geographic coordinates

The disadvantages are as follow:

- Low spatial resolution
- More expensive than aerial photographs of the same resolution
- Limited stereo graphic capability
- Limited number of geoscientists who are familiar with them

2.7 Geographical Information Systems (GIS) and landslide hazard assessment

Geographic data have previously been presented in the form of hard-copy maps. But the recent rapid development of computer hard- and software help introducing them in a digital form which is more applicable. Many organizations now spend so much money on establishing Geographic Information Systems (GIS) and the geographic data bases. The demand for the storage, analysis and display of complex and voluminous environmental data has led, in recent years, to the use of computer for data handling and the creation of sophisticated information systems. Effective use of large spatial volumes depends on the existence of efficient systems that can transform these data into usable information. Geographic Information Systems (GIS) becomes an essential tool for analyzing and graphically transferring knowledge.

GIS is a "powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for particular set of purposes" (Burrough, 1986). A more specific definition is given by Bonham-Carter (1996) as

"A geographic information system, or simply GIS, is a computer system for managing spatial data. The word geographic implies that the locations of the data items are known, or can be calculated, in terms of geographical coordinates. The word information implies that the data in GIS are organized to yield useful knowledge, often as colored maps and images, but as also statistical graphics, tables and various on-screen responses to interactive queries. The word system implies that a GIS is made up from several interrelated and linked components with different functions. Thus, GIS has functional capabilities for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output."

These internationally valid definitions of GIS are certainly contradicted to the belief that GIS is only a Computer Aided Drawing (CAD) software or only a drawing tool. Generally, CAD can only constitute a small portion of the whole integrated system, whereas an ideal GIS and its possible integrated components are as shown in Figure 2-5 and 2-6. GIS, if based on the right components should answer several questions as shown in Figure 2-7.

More over the products of mapping and inventory are being stored in data banks for their ultimate retrieval or combination with data from other sources. Often they are incorporated GIS or LIS (Land Information Systems) which serves as a base for programmable data manipulation and selective information extraction for planning and project assessment.

The development of GIS and LIS is of considerable interest in the context of satellite surveying, change detection, and monitoring. The flexibility of digital data processing, combined with quick input of new data (possible from updating on the basis of satellite remote sensing records) offers new possibilities to the surveyor, cartographer and planner.

It is clear that in a rapidly developing society, change detection is of great importance. In modern society, mapping suffers from high rate of change, such as, change in land use in rural and urban areas, change in requirements for maps and inventories, change in concepts in the various disciplines of earth and social sciences, leading to different interpretations of the same data, and change in the economical and technical factors on which mapping methods were based.

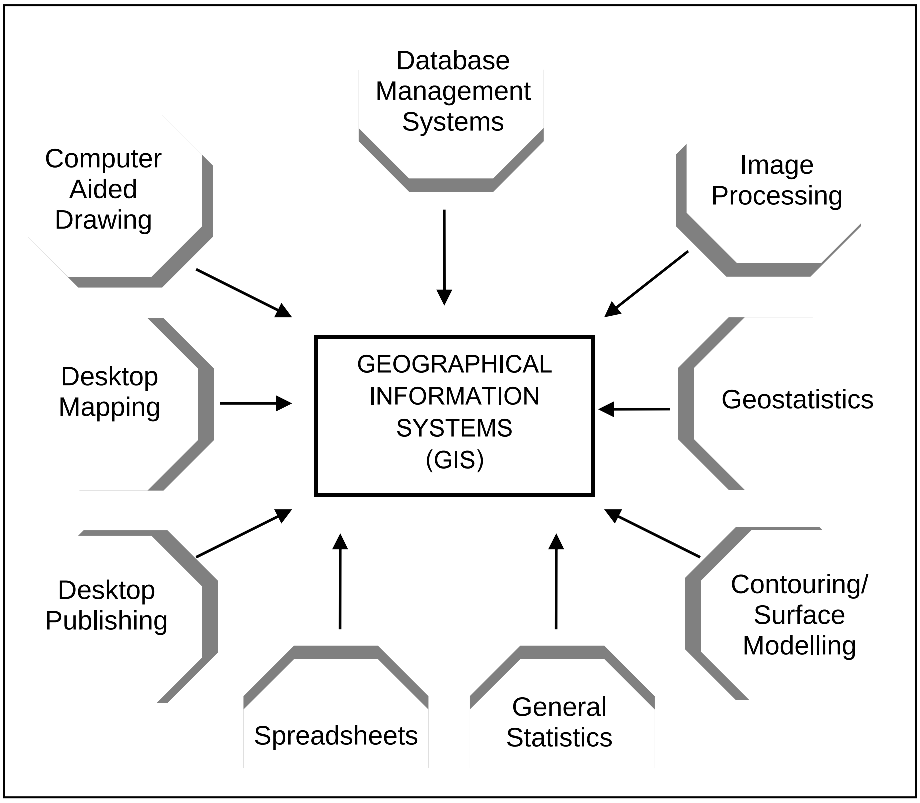


Figure 2-5 GIS and its related software systems as components of GIS (Sgzen, 2002).

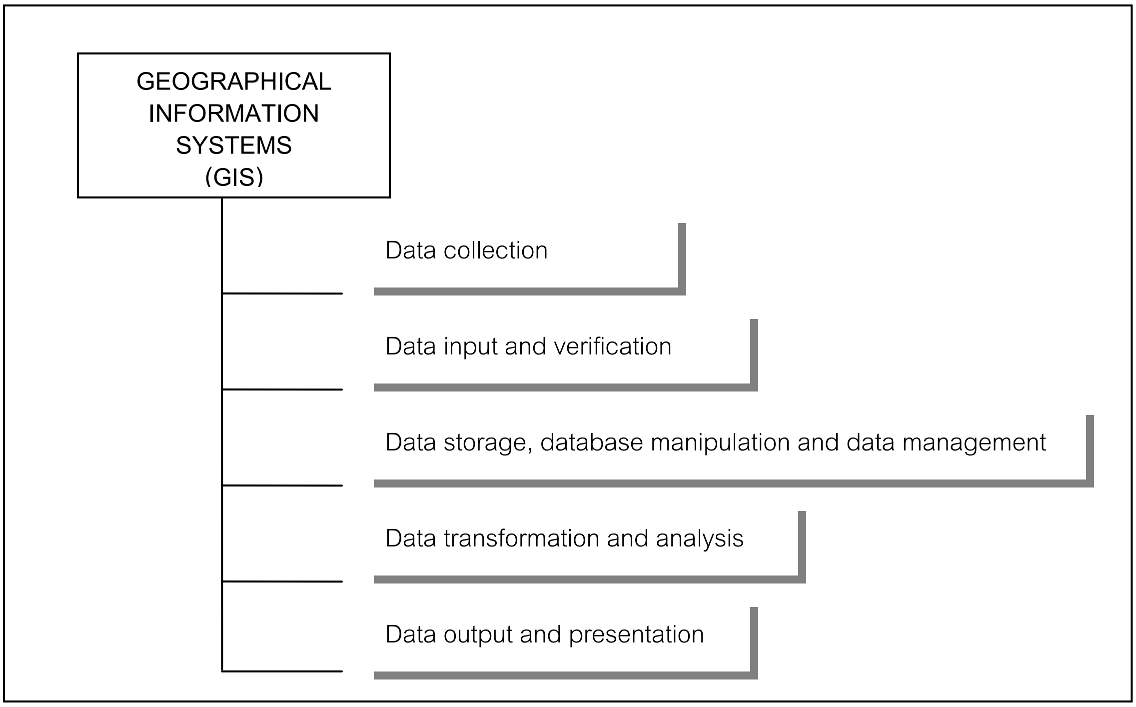


Figure 2-6 Phases of a GIS (Sgzen, 2002).

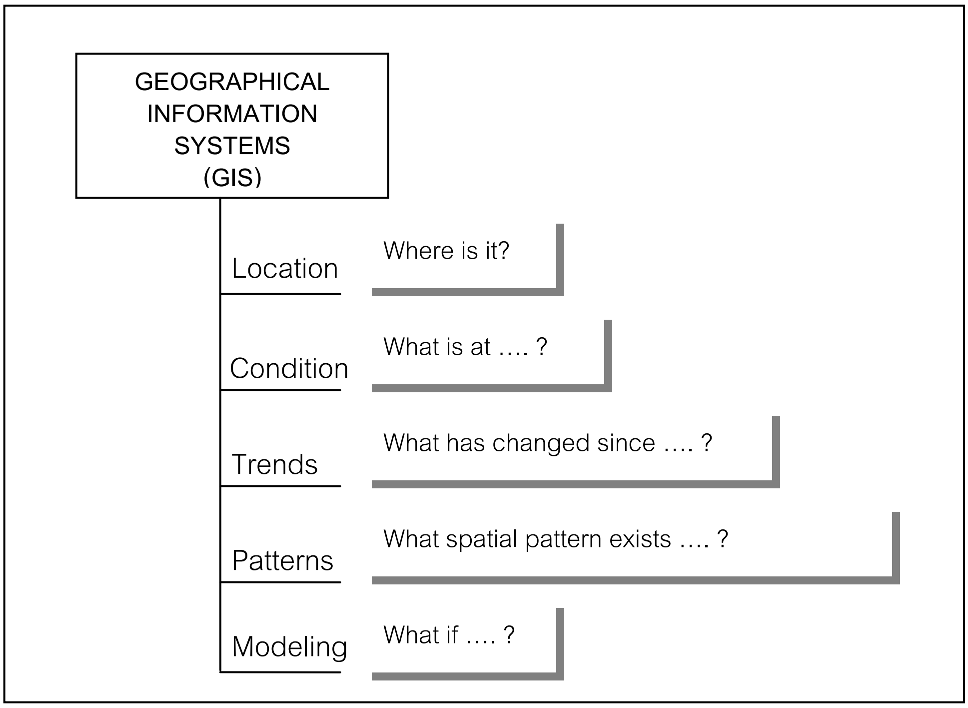


Figure 2-7 Questions which a well-built GIS should answer (Sgzen, 2002).

In order to refine the discussion around landslide hazard, one can say that the occurrence of slope failure depends generally on the complex interactions among a large number of partially interrelated factors. Analysis of landslide hazard requires evaluation of the relationships between various terrain conditions and landslide occurrence. An experienced earth scientist has the capability of mind to assess the overall slope conditions and to extract the critical parameters. However, an objective procedure is often desired to quantitatively support the slope instability assessment. This procedure requires the evaluation of the spatially varying terrain conditions as well as the spatial representation of landslides. GIS is allowed for the storage and manipulation of information concerning the different terrain factors as distinct data layers, and thus provides an excellent tool for slope stability hazard zonation.

The advantages of the use of GIS for assessing landslide hazard as compared to conventional techniques are treated extensively by several previous workers including Burrough (1986) and Aronoff (1989). The advantages of GIS for assessing landslide hazard include the follow.

1. The much larger variety of hazard analysis techniques that becomes attainable. Due to the speed of calculation, complex techniques requiring a large number of map overlaying and table calculations become feasible.
2. The possibility to improve models, by evaluating their results and adjusting the input variables. The users can achieve the best results in a process of trial and error, by running the models several times, whereas it is difficult to use these models even once in a conventional manner. Therefore more accurate results can be expected.
3. In the course of a landslide hazard assessment project, the input maps derived from field observations can be updated rapidly when new data are added. Also after the completion of the project the data can be used by the others in any other effective manner.

The disadvantages of GIS for assessing landslide hazard include the follow.

1. The large amount of time needed for data entry. Digitizing is very time-consuming.
2. The danger of placing too much emphasis on the data analysis as such, at the expense of data collection and manipulation based on professional experience. It is possible to use many different techniques of analysis, but often the necessary data are missing. In other words, the tools are available but cannot be used due to the lack, or uncertainty, of input data.

2.8 Basic concepts on evaluation of the potential for debris-flows and related sediment-flows

Basic concepts on evaluation of the potential for debris-flows and related sediment-flows are briefly reviewed from the related literatures below.

The term landslide includes a wide variety of processes that result in the downward and outward movement of slope-forming materials. The mass may move by any types of five principle types of motion: falling, toppling, sliding, spreading, or flowing, or combinations of these (Varnes, 1978). As both the kind of involved material and the movements are of importance in all phases of landslide investigation--from recognition to mitigation—these two factors, namely, type of movement and type of material, are generally used to identify types of landslide. Each region has its distinctive suite of problems that are determined by the characteristics of geology, topography, climate, and other aerial factors. Moreover, each kind of landslide process required its own kind of response directed toward recognition, avoidance, or mitigation.

With these basic ideas in mind, the goals of the landslide process and prediction segment can be summarized as follow:

- To determine the inherent geologic, topographic, and hydrologic conditions that set the stage for slope failures,

- To determine the factures, either natural, such as storms and earthquakes, or man-induced that lead to change slope stability,
- To analyze the time, physical setting, mechanism, rate, and extent of past failures in order to develop capacity to predict future failures,
- To acquire new knowledge of slope failure processes that is applicable to method for avoiding, preventing, or mitigation damage, and
- To present conclusions regarding hazardous slope processes in forms suitable to devise methods to map and assess the degree of hazard in large or small areas.

The several steps that are necessary to reach these goals are as follow:

1) Identify those slope processes that are hazardous,
2) Determine the relative degree of hazard and risk presented by the various processes of slope failure,
3) Identify gaps in knowledge regarding below topics
    a) Methods for recognition of unstable areas,
    b) Prediction of place, extent, time, and potential damage of failures, and
    c) Devise techniques to avoid, prevent, or mitigate landslide hazards and damage.

U.S. Geological Survey (1982) explained that the relation of debris flows to weather-related triggering events presents problems in predicting time and place that involves not only the geologic and topographic setting but also regional and local meteorological conditions. To improve their predictive capability a coordinated combination of field, laboratory, analytical, and statistic studies should be undertaken by the following specific tasks:

- Construct analytical, numerical, and laboratory physical models to help understand the generation and mechanical behavior of debris flows,
- Undertake geotechnical investigations to characterize hillside soils in potential debris-flow source areas to determine which soil types are most

susceptible to oversaturation and mobilization under heavy precipitation, snow-melt, or thawing of frozen ground,

- Provide instrumentation at field locations to monitor precipitation, groundwater levels, and movements in potential debris flow source areas,
- Augment existing data bases and construct statistical models relating debris flow to mapable parameters such as bedrock lithology, soil type, slope, vegetation, and precipitation,
- Determine the effect of denudation of vegetation (due to forest fires, timber clear-cutting, and so forth) on subsequent erosion and downstream sedimentation patterns as related to debris flow,
- Reconstruct a history of climatic variation in the recent geological record of a climate area,
- Devise and improve techniques to find date of the recent geologic features for determining the timing and frequency of debris flows,
- Conduct statistic studies of recent rainfall histories of selected mapping areas to investigate effects of rainfall variations during drought-wet cycles, and
- Organize teams of scientists and engineers to investigate major debris-flow events during and immediately after they occur.

Ikeya (1974) proposed three main causes for debris flows as follow: (1) sediments produced by breaking up hill slopes mix with water and flow down, (2) collapsed sediments dam up a river and dam outbursts, and (3) riverbed deposit experiences strong scouring action.

Takei (1980) provided a more detailed list of causes for debris flows as follow:

- High rainfall intensity in a short period of time after a period of continuous rainfall.
- High rainfall intensity in a short period of time in an area with new volcanic sediments.

- Unstable sediments on steep torrent beds (>20°) become saturated; liquefaction occurs as a result of the impact of surface runoff.
- Collapsed materials flow down carrying water and sediment from the torrent bed.
- Collapsed sediments block a torrent stream to form natural dam then break allowing the collapsed sediments and water to form a debris flow
- Landslide materials turn into a debris flow as a result of liquefaction.
- Earthquakes or vibrations from volcanic eruptions cause parts of slopes to break off and the flowing torrent bed sediment liquefies.
- Other causes e.g. pyroclastic flow (volcanic eruption), and rapid melting snow.

Wieczorek and others (1983) summarized that abundant coarse-grained sediment can be transported and deposited by two processes, debris flow and debris flood. Both processes commonly occur during periods of rapid accumulation of water to the landscape, either by rainfall or snowmelt. In debris flow, water and soil materials including rocks combine to form muddy slurry much like very wet concrete, considerably more viscous than flowing water that moves down-canyon with a front armored of coarse-grained materials such as boulders. Debris flows may leave levees along the edges of the flow that indicate lateral and vertical dimensions of the flow front. In debris flood, soil materials with a greater relative proportion of water are transported by fast-moving flood waters. Deposits formed by debris flood can be distinguished from those of debris flow by greater degree of sorting those general characterized water-borne deposits. Debris flow deposits, in contrast, are characteristically poorly sorted, showing that rock fragments suspended randomly in poorly sorted matrix typically consisting of silty sand with a small but significant content of clay. Debris flow and debris flood may well form a continuum. As water content of a debris flow is increased, its plastic strength decreased abruptly and its viscosity approaches that of flowing water with entrained sediment.

The careful evaluation of potential for debris flows and debris floods should address the following questions (Wieczorek and others, 1983):

1) Relations between rainfall (or snowmelt), ground-water levels, and landslide movement,
2) Stability of the partly-detached landslides,
3) Process of transformation from landslide to debris flow,
4) Incorporation of channel materials by debris flow,
5) Transition from debris flow to debris flood,
6) Factors that control debris flow run-out, and
7) Recurrence of debris floods and debris flows at canyon mouths.

Varnes (1984) proposed that landslides are inherent parts of the environment that require control and management strategy. Hazards themselves are not disaster but rather a factor in causing a disaster. Hazards are natural agents that transform a vulnerable condition into a disaster. Terminology related to hazards and disasters has numerous definitions depending on the particular nature or special interest of the person or organization concerned. It should therefore be a great value if a more general and internationally accepted definition could be applied to these terms.

Varnes (1984) also specified that the parameters consider for assessment of the landslide hazard, vulnerability and risks included a landslide map (both of recent and old landslides), major land use/cover categories, topographic factors, etc. Synthesizing from the assessment of the landslide hazard, vulnerability and risks mentioned above, the landslide hazard management tool would be conducted to aid in the identification of the occurrence of landslides, of the degree of loss as a factor of vulnerability, and would ultimately allow the assessment of risk from landslides. Therefore, risk assessments are a combination of hazard and vulnerability measurements that will assist with predicting locations where landslide events might cause damage in each study area.

Hansen (1984) presented that mass movements in mountainous terrain were of the natural degradational processes. Most of the terrain in mountainous areas has been subjected to slope failure at least once, under the influence of a variety of casual factors, and triggered by events such as earthquakes or extreme rainfall. Mass movements become problem when they interfere human activity. The frequency and the magnitude of slope failures may increase due to some human activities, such as deforestation or urban expansion. In developing countries, this problem is especially great due to rapid non-sustainable development of natural resources. Losses due to mass movements are estimated to be one quarter of the total losses caused by natural hazards.

Innes (1985) reported that the frequency of debris flow events from individual source areas was controlled by the rate of accumulation in hollows or channels, and by the recurrence of climatic triggering events. Because the rate of accumulated debris was limited, there must be an upper limit to the magnitude-frequency of debris flows.

Crozier (1986) proposed that mitigation of landslide disasters could be successful only when detailed knowledge was obtained about the expected frequency, character, and magnitude of mass movement in an area. The zonation of landslide hazard must be the basis for any landslide mitigation project and should supply planners and decision-makers with adequate and understandable information. Analysis of landslide hazard was a complex task, as many factors could play a role in the occurrence of mass movements.

Osterkamp and Hupp (1987) reported that radiocarbon dating, lichenometry and dendrochronology had proved to be very useful techniques in estimating debris flow recurrence.

Hutchinson (1988) concluded that some landslides moved slowly and cause damage gradually, whereas others moved so rapidly that they could destroy property and took lives suddenly and unexpectedly. Debris flows were common types of fast-moving landslides or flows. They were potentially a very destructive from of mass movement in mountainous areas, where sudden access of water, usually from heavy rainfall or melting snow, could mobilize debris mantling the slopes and incorporated it into a debris flow. Debris flows from many different sources could combine in channels where their destructive power might be greatly increased. They continued flowing down hills and through channels, growing in volume with the addition of water, sand, mud, boulders, trees, and other materials.

Van Westen (1993) summarized that a wide variety of names had been used for the denudational process whereby soil or rock was displaced along the slope by mainly gravitational forces. The names most frequently used are slope movement, mass movement, mass wasting, and landslide. In the last decades landslide was the term most used, though in the narrow sense of the word (sensu strictu) it only indicates a specific type of slope movement with a specific composition, form and speed.

Van Westen (1994) also proposed that landslide disasters could have been prevented or mitigated if there were proper precautions. The precautions could be either to stabilize the slide-prone slopes or to avoid the slide-prone areas. In either approach, landslide-related information of the area must be known. He also concluded that the information required for analyzing landslide hazards should include that in the following categories.

- geomorphology: terrain mapping units, geomorphologic units, geomorphologic subunits, landslide (recent), landslide (older period)
- topography: digital terrain model (DTM), slope map, slope direction map, breaks of slope, concavities/convexities
- engineering geology: lithology, material sequences, sample points, fault & lineaments, seismic events
- land use: (recent) infrastructure, (older) infrastructure, (recent) land use, (older) land use, cadastral blocks; and
- hydrological data: drainage, catchment areas, meteorological data, water table.

According to the increasing availability of remote sensing technology and geographic information systems (GIS) during the last decades has created opportunities for a more detailed and rapid analysis of landslide hazard in large areas. Westen (1994) also applied these technologies in the analysis of landslide hazard that requires a large number of input parameters. The techniques of analysis might be very costly and time-consuming, however.

Corominas and others (1996) defined a debris flow as a rapid mass movement of a mixture of fine and coarse material, with a variable quantity of water, that formed muddy slurry which moved downslope, usually in surges induced by gravity and the sudden collapse of river bank material. Three distinctive elements involved in a debris flow were the source area, the main tract, and the depositional toe. The flows commonly followed pre-existing drainage ways. The tracts had a V-shape or rectangular cross-section. Some of the coarse debris might be heaped up along the sides of the track forming lateral ridges. Debris flow deposits were left where the channel gradient decreased or at the toe of mountain fronts. Successive surges might build up into a debris fan. Some debris flows had high energy, their deposits could travel long distances beyond the source area. The deposits of these low viscosity debris flows spreaded out in areas of decreased confinement to form alluvial fans. Corominas and others (1996) also described that the socio-economic impact and the loss of life, property and agriculture could be catastrophic in the case of large debris flows through populated areas. However, smaller debris flows might also cause serious damage, especially in upland watersheds of mountainous regions (e.g. destroying houses, roads, railways and bridges). The deposits were also responsible for severe indirect damage and hazards such as damming of rivers or sudden debris supply to river systems. It was essential that the potential source areas and run-out zones were correctly assessed and mitigation measures adopted using modern mapping and monitoring techniques.

U.S. National Research Council (1996) reported that debris flows could result from the existence of a large percentage (up to 70-90% of flow by weight) of fine sediment such as silt and clay in steeply-flowing floodwaters. This enabled the muddy flow to transport sand, gravel, boulders, and dislodged timber and brush from the mountain watershed onto a fan surface. Conditions favoring the formation of debris flows are: available unconsolidated silt, clay and larger rock in the basin watershed (due to minimal vegetation), heavy or sustained rainfall in the basin, and the presence of steep basin and fan slopes. Fans which had been formed from repeated debris flow activity were called debris fans, and were composed of deposits of rock, soil and vegetation from the upstream watershed. Alluvial fans, and flooding on alluvial fans, showed a great diversity because of variations in climate, fan history, rates and styles of tectonism, source area lithology, vegetation, and land use. Acknowledging this diversity, the U.S. National Research Council's document provided an approach that considered site-specific conditions in the identification and mapping of flood hazards on alluvial fans. Investigation and analysis of the site-specific conditions might require knowledge in various disciplines such as geomorphology, soil science, hydrology, and hydraulic engineering. Although the scope of study might constrain the degree of site-specific consideration undertaken, it was essential that field inspections of the alluvial fan should be conducted.

U.S. National Research Council (1996) further provided guidance for the identification and mapping of flood hazards occurring on alluvial fans, irrespective of the level of fan forming activity. The term alluvial fan flooding encompasses what would later be described as active alluvial fan flooding and inactive alluvial fan flooding. In general, the criteria used to assess whether or not an area was subject to alluvial fan flooding, and defining the spatial extent of such flooding, could be divided into three stages: namely

1) Recognizing and characterizing alluvial fan landforms,
2) Defining the alluvial fan environment and identifying active and inactive components of the fans; and
3) Defining and characterizing areas of the fan affected by the 100-year flood.

Miyajima (2001) defined debris flows as a mixture of loose soil, rocks, organic material, and water that moved rapidly downhill destroying everything in its path. In order to mitigate the damages caused by the flows, it was necessary to have a good understanding of their mechanisms. He concluded that data collection is an important first step in study of debris flow. He also summarized some characteristics (velocity and unit weight, causes, and types) of debris flows and outlined the type of data that needed to be collected in survey.

Giraud (2002) also revealed that the character of past debris-flow deposits provided a basis for determining the nature of future debris-flow deposition and the associated hazards due to impact, inundation, and burial. The findings of this study revealed that the drainage basin slopes and channels supplied sediment to alluvial fans, and the sediment-supply conditions governed the volume and frequency of future debris flows. Historical records indicated that 80 to 90 percent of debris-flow volume was bulked from drainage-basin channels. Therefore, evaluation of the drainage basin focused on determining the volume of channel sediment available for sediment bulking. The inventory of sediment supply provided information on the character, size, gradation, and volume of sediment available for incorporation into future flows. The flow volume determined from sediment-bulking estimates provided an independent check for flow volumes determined in the fan evaluation.

Giraud (2005) further proposed the guidelines for the geologic evaluation of debris-flow hazards on alluvial fans by the evaluation of debris-flow hazards on alluvial fans that was necessarily for safe and appropriate land use to prevent loss of life and property damage. These guidelines outline techniques to address debris-flow hazards by evaluating: the past flows on alluvial fans, and the drainage basin and channel sediment-supply conditions. Understanding the processes that governed debris-flow initiation, transport in the drainage basin, sediment bulking, and deposition on the alluvial fan were vital to hazard evaluation. The geologic evaluation of past flows on alluvial fans followed a two-step procedure consisting of an initial delineation of the active (generally Holocene) depositional area, and a subsequent detailed, site-specific analysis of the hazard within the active depositional area. In the detailed fan evaluation, flow-type, frequency, volume, and run-out data were collected to characterize the hazard based on the past debris-flow deposits. Surficial geologic mapping, dating methods, and subsurface exploration were used to investigate and describe the geomorphology, sedimentology, and stratigraphy of alluvial-fan deposits. Dynamic analysis of debris flows-floods using hydrologic, hydraulic, and other engineering methods to design site-specific risk-reduction measures should also be addressed in these guidelines.

2.9 Previous investigations on evaluation of the potential for debris-flows and related sediment-flows

The previous investigations on evaluation of the potential for debris-flows and related sediment-flows 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.

Owen and others (1995) conducted the study of mass movement induced both by shaking during 20 October 1991 Grahwal earthquake and by heavy rainfalls during the 1992 monsoon season in the Bhagirathi and Jumna catchment areas, Garhwal Himalaya to assess their role as natural hazards. Avalanching was the major mass movement process that occurred during the earthquake and during the heavy monsoonal rains, and was the greatest in the lower reaches of the valleys where the rivers were actively eroded steep rocks and debris slopes and where road construction had cut into slopes. Inventories of both the earthquake and rainfall-induced mass movements were used to characterize the different types and distribution of mass movements. The extent and type of damage, ground conditions, geology and geomorphology were mapped in order to produce hazard map for the region and to identify areas of the greatest risk.

Cannon (1997) investigated the potential of significant debris- and hyperconcentrated-flow activity in Capulin Canyon that was evaluated through 1) a systematic consideration of geologic and geomorphic factors that characterized the condition of the hillslope materials and channels following the fire, 2) examination of sedimentary evidence for past debris-flow activity in the canyon, and 3) evaluation of the response of the watershed through the 1996 summer monsoon season. His findings revealed that the factors, namely lack of accumulations of dry-ravel material on the hillslopes or in channels, absence of a continuous hydrophobic layer, relatively intact condition of the riparian vegetation and of the fibrous root mat on the hillslopes, and lack of evidence of widespread past debris- and hyperconcentrated-flow activity, even with evidence of past fires, indicated a low potential for debris-flow activity in Capulin

Canyon. In addition, thunderstorms during the summer monsoon of 1996 had resulted in abundant surface overland flow on the hillslopes which transported low-density pumice, charcoal, ash and some mineral soils downslope as small-scale and non-erosive debris flows. In some places cobble- and boulder-sized material was moved short distances. A moderate potential for debris- and hyperconcentrated-flow activity was identified for the two major tributary canyons to Capulin Canyon based on evidence of both summer of 1996 and possible historic significant debris-flow activity.

Morgan and others (1997) reported an analysis of areas susceptible to debris flows including an examination of source areas, channels and areas of deposition. The analysis was used to develop a methodology for identifying areas subject to debris flow hazards in Medison Country, Virginia, United States. The preliminary carbon-14 dated from the older deposits of fossil soils, grey horizons with abundant organic remains in the deposits of prehistoric debris flows was used to interpret the recurrence interval for the debris flow events. The stratigraphy was also studied to compare with those recurrent interval interpreted from carbon-14 dating of the prehistoric debris flows. The report concluded with a discussion of strategies for reducing debris-flow hazards and the long term risk of these hazards in the study area as well as for similar areas along the eastern flank of the Blue Ridge mountain.

Singhroy (1998) reported on the use of Interferometric SAR, RADARSAT, and airborne SAR combined with Landsat TM images to identify diagnostic features of landslides and their slope characteristics in Canada that the landslide types were found in different physiographic regions and associated with certain kinds of soil and rock materials, geological structures and topographic settings. He concluded that Interferometric SAR images provided information on detail slope profiles of the large rock slides on steep slopes and along faults in the Canadian Cordillera. From this image, faults, rock slumps, block slides, slide scars, and debris slopes were identified. RADARSAT images with incident angles varied from 40-59 degrees, particular the fine mode images, were the most useful to identify landslide features in mountainous areas. An interpretation of retrogressive slope failures on the shale banks of the Saskatchawan river was conducted using a combined Landsat TM and SAR images. Flow slides on sensitive marine clays were identified on airborne SAR images in the Ottawa valley.

Taylor (1999) conducted a study of the production, transport, and storage of sediments in drainage basins by comparative geomorphic analysis of surficial deposits at three central Appalachian watersheds that was essential for understanding their evolution and geomorphic behaviors. The mechanisms for routing and storage of sediments in the Appalachian region were poorly understood. This study involved a comparative geomorphic analysis of three watersheds underlain by interbedded sandstones and shales of the Acadian clastic wedge. GIS-based analyses of surficial map units allowed first-order approximation of valley-bottom storage volumes. Volume estimates were examined in tandem with clast-size analysis and bedrock-channel distribution to make inferences regarding controls on sediment-transport efficiency in the central Appalachians.

Jishan and Tianchi (2001) reported the study in China, described the types, characteristics, dynamics, and fundamental mechanics of debris flows, as well as the type of damage they caused to roads and other structures, settlements, and farmland. Five different ways of classifying debris flows were done based on the viscosity, composition, triggering factors, origin, and scale. The differences between debris flows and other similar phenomena such as landslides and floods were also summarized.

In Thailand, the literatures on the landslide investigations and similar phenomena are also reviewed in chronological order as below.

Perhaps 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 Lorn Sak-Chum Phae highway between Kms. 18 to 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 huge 1988 landslide 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 depended on the size and characteristics of the area considered the socio-economic condition and the financial and political factors.

The event had been studied by many other workers as well. According to 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 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 Amphoe Phi Pun, Changwat Nakhon Si Thammarat.

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 terrain 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 20th-23rd 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 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 per cent; (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 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 could cause instability to soil slopes. From the event, the slope, between 10 to 40 degrees in gradient was where the most of landslides 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 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 included eight parameters namely, elevation, aspect of slope, TM 4 (Thematic Mapping Band-4), flow accumulation, brightness, wetness, slope and flow direction. This model was capable of classifying 82 per cent 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 Range in Amphoe Phipun, Changwat Nakhon Si Thammarat. 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 experts' knowledge, (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.

Elsewhere, 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.

Thassanapak (2001) investigated the landslide assessment of Changwat Phuket 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, Changwat Nakhon Nayok. 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.

In the present study area, there are many preliminary studies that had been done. 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.

The Secretariat Office of Government (2002) had formed a technical committee from the personnels of many disaster-related government organizations preliminary concluded and proposed the technical draft-report from the 2001 Nam Ko disaster in the following topics: (1) background of the area (geography, land use, geology and soil, and climate), (2) occurrence characteristics (rainfall and river-water quantity, areas that were damaged from the flood and landslide), and (3) causes of the disaster and mitigation concept. However, this draft-report had been done in very short time for the preliminary mitigation management in the Nam Ko and other similar areas in Thailand so the primary and actual data collected and related to the disaster in the area had not been systematically investigated in details.

Local Government Office (2002) reported the general information of the existing risk areas from flooding and associated disasters in 11 Amphoes in Changwat Phetchabun. It noted that if there were continuing and heavily rainfall occurrence, the risk areas in Amphoe Lom Sak could be identified into two types: (1) the overbank flooded areas in the lower flood plain of Pa Sak River and Nam Pung, and (2) the flash flood areas in the areas of that lied on the canyon mouths of Nam Ko Yai stream, Nam Chun stream, Thanthip stream, and Nam Duk stream that originating from Khao Kao and Nam Nauw mountain ranges. 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.

Research and Development Center of Soil Engineering and Foundation (2002) conducted a proposal report on sustainable solution for slope stabilization to mitigate the debris flow and flash flood at Nam Ko area, Amphoe Lom Sak, Changwat Phetchabun. The investigation had been examined to identify preliminary geotechnical engineering characteristics of landslide areas as follows: water and mud flow, land use, topography of river channels, landslide areas, river deposits, general geology, types of hazard in river channels, soil strength-test in the field, soil profiles, and permeability testing. The review of this event from local people was also conducted to receive the eye-witness evidences. In addition, the damage from this event was informally summarized as two categories: the severe damage in the community and agricultural areas, and the damage in Nam Ko Yai sub-catchment.

Environmental Geological Division (2003) 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 Nam Ko and Nam Chun in Amphoe Lom Sak, Changwat Phetchabun were selected for this practical approach that had been applied landslide mathematical predictive model of Pantanahiran (1994) 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), and wetness. 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.