CHAPTER III

METHODOLOGY

A landslide hazard map was generated to identify areas with differing landslide hazard degree. The entire study area was divided into sub-areas based on the degree of a potential hazard from landslides using the method proposed by Greenbaum et al. (1995) and Lee (2004). The landslide hazard map is, therefore, produced by analysing the data represented by the maps of inventoried landslides and the factors determined to influence the landslide occurrences.

Generally, the factors related to landslides can be subdivided into 3 groups based on Van Westen et al. (2008), namely; triggering mechanism, human activities, environmental parameters. The methodology is the combination between probability method of bivariate analysis, and ranking and weighting of factor's important on landslide occurrence. The result is landslide hazard zonation map. Then, the result was validated with the past landslide events using probability method.

Assessing relative landslide hazard is the objective of the method described in this chapter. The research was carried out according to the methodology. The flow chart of thesis methodology is shown in Figure 3.1.

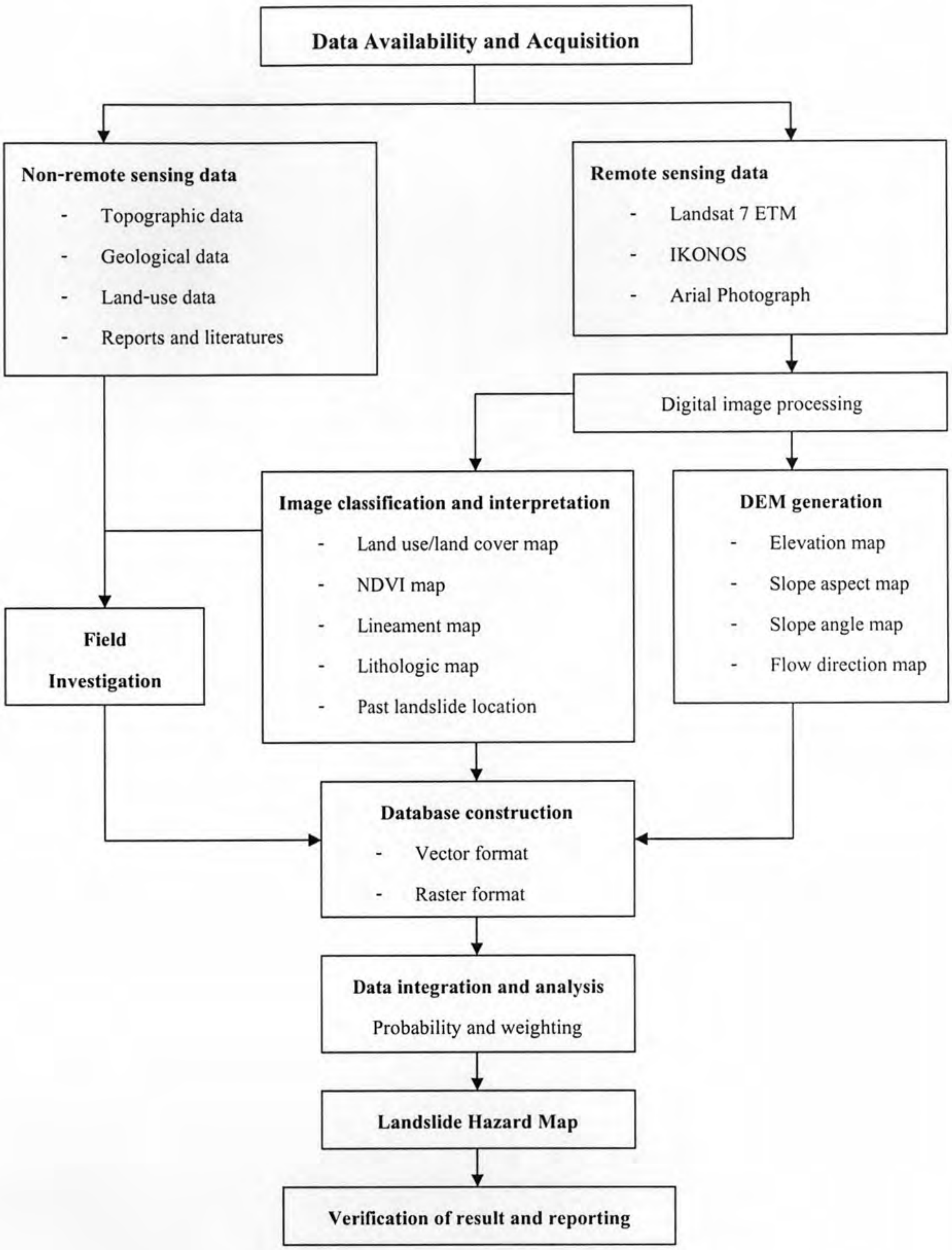


Figure 3.1 Flow chart of thesis methodology used in this research based on Greenbaum et al. (1995) and Lee (2004).

3.1 Data Acquired and used

The first task of this study includes collecting, storaging and selecting all data and information that is available and derived from remote sensing information as well as preliminary field investigation and necessary for this study. All kind of data and information are there collected, mapped and reformatted (if required) and stored in GIS as a database.

According to the data sources, data acquired and used for landslide hazard assessment can be divided into two groups, viz. remote sensing data and non-remote sensing data.

3.1.1 Remote Sensing Information

Remote sensing information is one of the most important data for landslide assessment. It is very useful in detecting and mapping landslide scars/landslide location, land use/land cover, forest, topographical, and geological conditions.

Several types of remote sensing data are used to integrate landslide hazard assessment. The satellite images are used widely as fundamental knowledge for land planning, land use mapping, geological investigation and landslide scar detection. The author applied data of the Landsat 7 ETM and IKONOS from Pointasia.com for analyzing and interpreting geological structures and landslide scar location in regional scale. The area under investigation lies within the latitude 17° 45' to 20° 00' N and longitudes 99° 50' to 101° 50' (see Figure 1.3). For the detailed work, one can use aerial photographs for landslide hazard mapping. However, in this study, aerial photograph are used when the IKONOS images are blurred. The aerial photographs are also used in more detailed study, particularly the contrast of landslide scar to fired land.

Table 3.1 Technical parameters of the satellite remote sensing systems used in this study.

List	Landsat 7 ETM	IKONOS
Operating Country	USA	USA
Year of Launch	1999 (failure in 2005)	1999
Orbit (km)	720	705
Repeatition Cycle (days)	16	3-5
Sensor	Scanner (7 bands multispectral, 1 Panchromatic)	Scanner (4 bands VNIR, 1 Panchromatic)
Spectral Bands (micrometer)	0.45-0.52 0.52-0.61 0.63-0.69 0.78-0.90 1.55-1.75 10.40-12.50 (TIR) 2.09-2.35 0.52-0.90 (Pan)	0.45-0.90 μm (PAN) 0.445-0.516 0.506-0.595 0.632-0.698 0.757-0.853
Ground Resolution (m)	30x30 60x60 (TIR) 15x15 (PAN)	4X4 1X1 (PAN)
Field of View (Km)	185x170	11x11

Source: GISTDA (2008) – http://www.gistda.org

Landsat 7 ETM Imagery: The Landsat 7 ETM satellite image scene (Figure 3.3) covers a land area approximately 185 kilometers (across-track) by 180 kilometers (along-track). The ETM system is designed to collect 8 spectral bands or channels of reflected electromagnetic radiation. Visible wavelength consists of bands 1-3, infrared wavelength consists of bands 4, 5 and 7. Band 6 is for thermal infrared wavelength, and band 8 is for panchromatic as shown in Table 3.2.

The Landsat 7 ETM images are used for this thesis supported by The Global Land Cover Facility (GLCF)'s website (http://glcf.umiacs.umd.edu). The study area covers Landsat 7 ETM scence for 6 scenes as shown in Table 3.3 and Figure 3.2.

Table 3.2 Spectral bands in Landsat 7 ETM imagery (after Alfoldi, 1996)

Band No.	Wavelength Interval (μm)	Spectral Response	Resolution (m)
1	0.45 – 0.52	Blue-Green	30
2	0.52 – 0.60	Green	30
3	0.63 – 0.69	Red	30
4	0.76 – 0.90	Near IR	30
5	1.55 – 1.75	Mid IR	30
6	10.40 – 12.50	Thermal IR	120
7	2.08 – 2.35	Mid IR	30
8	0.52 – 0.92	Panchromatic	15

Table 3.3 Landsat 7 ETM scenes used in this study (after GLCF, 2006)

No.	Path/Row	Data of Acquisition	Spectral Bands (no.)	Spatial Resolution (m)
1	129/46	2/11/2000	7	30m (MX), 60m (TI)
2	129/47	2/11/2000	7	30m (MX), 60m (TI)
3	129/48	2/11/2000	7	30m (MX), 60m (TI)
4	130/46	25/12/1999	7	30m (MX), 60m (TI)
5	130/47	25/12/1999	7	30m (MX), 60m (TI)
6	130/48	14/3/2000	7	30m (MX), 60m (TI)

IKONOS imagery: The IKONOS commercial remote sensing satellite images consist of panchromatic (gray-scale) image data of Earth's surface to one-meter resolution; and multi-spectral data (red, green, blue, and near infrared) to 4 meters resolution (Table 3.4). This powerful remote sensing system has changed the way the public and private industry worldwide view the Earth's surface and plan for its future. The images offer stunning new information to farmers, city planners, environmental planners, realtors, geologists, the media and others. IKONOS satellite image with the resolution of 1 x 1 meter (Figure 3.4) provided by The Map PointAsia's website (http://www.pointasia.com) for locating the landslide locations precisely.

Table 3.4 Spectral bands in IKONOS sattelite imagery (Geo-Eye, 2008)

Band No.	Band	1-m PAN	4-m MS & 1-m PS
1	1 (Blue)	0.45-0.90 μm	0.445-0.516 μm
2	2 (Green)	-	0.506-0.595 μm
3	3 (Red)	-	0.632-0.698 μm
4	4 (Near IR)	-	0.757-0.853 μm

Remarks: spatial resolution: 0.8 m for panchromatic (1-m PAN), 4 m for multispectral (4-m MS) and 1 m for pan-sharpened (1-m PS)

3.1.2 Non-Remote Sensing Data

Non-remote sensing data comprise all maps from available data sources and fieldwork, which are related to the study area. Import maps for this research are topographic maps, land use maps, geological maps, lineament maps (Table 3.5). Additionally, other relevant reports and documents collected from concerning organizations are also essential for the analysis.

Table 3.5 Overview of non-remote sensing data types and sources for the study.

Data types	Scale	Original of data format	Sources	Number of maps
Geologic map	1:50,000	Shape file of ArcView	Department of Mineral Resources	14
Land use map	1:250,000	Shape file of ArcView	Land Development Department	6
Topographic map	1:50,000	Hard copy	Royal Thai Survey Department	32

3.2 Methods of Remote Sensing Data Processing and Interpretation

The remote sensing system consists of the personal computer hardware and the ENVI 4.1 image processing software, both of which are used to process and classify satellite images in this study. All of the remote sensing data for the Nan Province area were provided in digital format. This original data was already corrected for systematic and radiometric errors and stored on CD in standard remote sensing formats. Further digital data processing was carried out in the framework of the research. Purpose of image processing is to derive enhanced imageries for data interpretation and mapping. The functional categories of image processing are shown in Figure 3.2 and described below.

3.2.1 Image Processing

In this study, digital image processing can be carried out for image registration, image enhancement and image classification. During the digital processing, new and altered digital images are created and they show information of interest in enhanced conditions. The processed image is interpreted, visually and/or digitally, to extract information about the target object, which was illuminated. It was aimed on the extraction of geological information, land use/cover, Normalized Difference Vegetation Index (NDVI) and Digital Elevation Model (DEM).

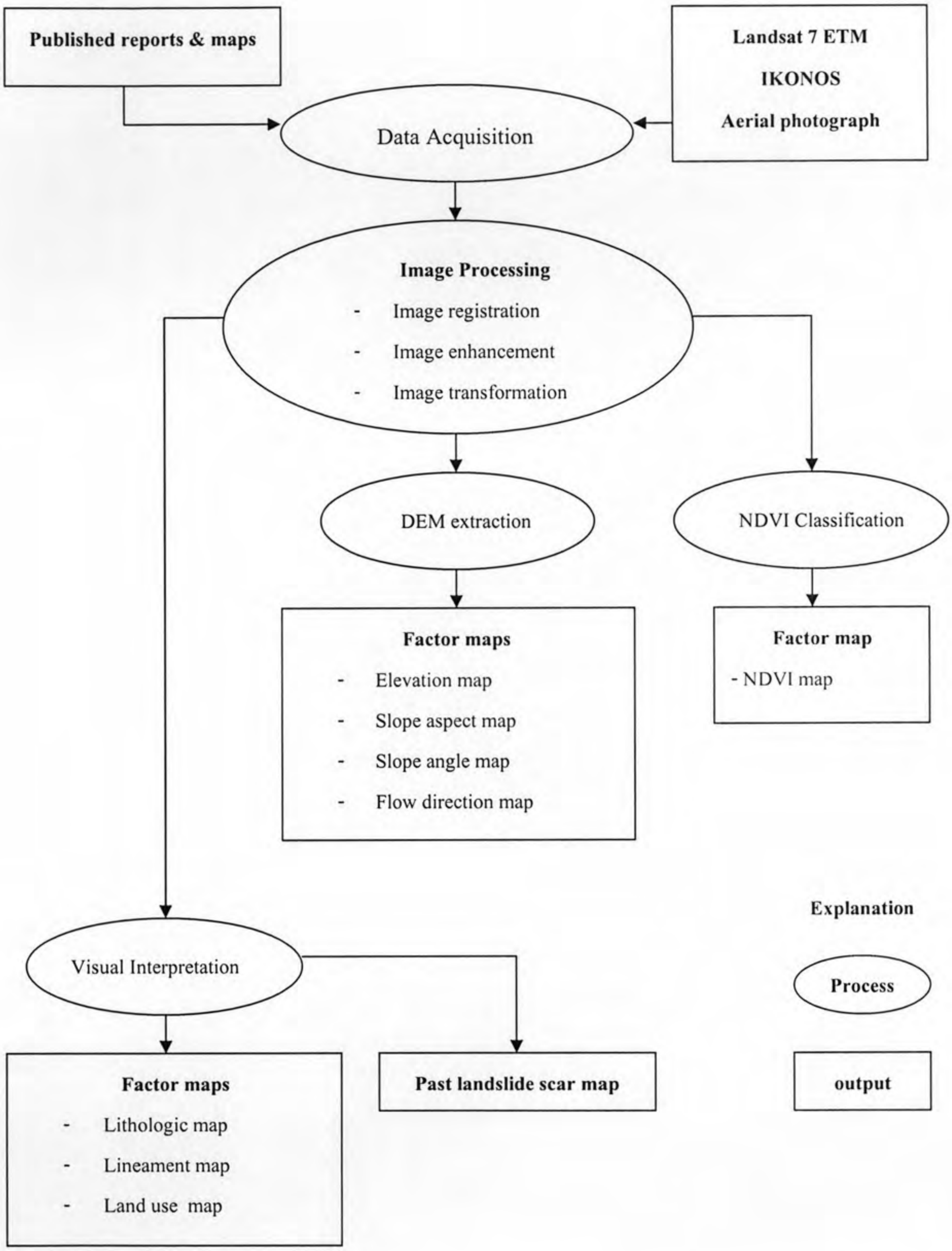


Figure 3.2 Flow chart showing sequences of methodology process and output maps applied for remote sensing analysis.

The categories of digital image processing are demonstrated with reference to Landsat 7 ETM satellite image data, but the techniques are equally applicable to other sets of digital image data.

Image registration: Generally, image registration is the process of superimposing an image over a map or another already registered data. The geometric registration process involves identifying the image coordinates (i.e. row, column) of several clearly discernible points, called Ground Control Points (GCPs), in the distorted image, and matching them to their true positions in ground coordinates (e.g. latitude, longitude). The true ground coordinates are measured from a map in hard copy of digital format or collected with GPS in the field. This is called image to map registration, which is used for registration all satellite image in this study. All satellite images are registered using the image to map geocoding-techniques with reference to the Thai-Vietnam Map Datum, UTM Map Grid Zone 47.

Image enhancement: The purpose of image enhancement is to make the images more interpretable for specific applications. Image enhancement is the modification of an image in order to alter its impact on the viewer. Generally, image enhancements change the original digital data values, and it should be carried out after geo-coding. Image enhancement is able to highlight features of thematic interest (lithology, lineaments, land use, etc.) and to suppress redundant information.

Contrast, RGB-color composite and spatial filtering enhancements are major tools applied on image enhancement in this study.

1) *Contrast enhancement* involves changing in the original brightness values, which is increased the contrast between target objects and their backgrounds. Nominally, an 8-bit image corresponds to a dynamic range of 256 grey tones. Original images usually occupy only small portions of the possible brightness range. Therefore, they appear dark and low contrast. Contrast enhancement is an image processing techniques that improves the contrast ratio of the image. The original narrow range of the digital values is expanded to utilize the full 8-bit dynamic range of available digital

values. It is also called contrast stretching (Sabins, 1997). In the case of 3-band Landsat 7 ETM False-Colored Composites (FCC), it is often necessary to stretch each of the single bands independently. This leads to balanced color tones allowing the maximum discrimination between certain targets at the ground surface.

The most frequently used contrast stretching types in this study is the linear expansion of the digital value range. Depending on the distribution of the digital values in the input image, and depending on the interpretation targets, selected portions or parts of an image (region of interest) of the data can be expanded. Apart from the standard linear stretching, Gaussian, equalization, special user defined approaches are used to test. The distribution of the digital values of the image before and after linear stretching is defined by the histogram.

Contrast enhancement is a quantitative operation. Therefore, it relies on the subjective judgment and experience of the operator who decides when an image has the right contrast and color balance for the final visualize and hard copy out put. For the Nan Province area, it was important to apply in a way that allowed the o ptimum discrimination of land use units, rock types, lineament and other targets of interests.

2) *The RGB-color composite image* is image, which was prepared by combining three individual images in blue, green and red. It is one of the simplest ways to enhance features of interest by digital image processing in the following steps:

(A) Selection of the 3 single spectral bands, which show the highest differences in the locations of the clusters characterizing the investigation targets (Gupta, 1991); and.

(B) Mixing of any of the three primary additive colors red, green and blue in various proportions is defined by the grayscale values of the pixels of three selected single bands of an n-dimensions multi-spectral data set.

The resulting colors of the colors composite image are defined by the RGB Color Diagrams (Gupta, 2002). Transformation is the most frequently used techniques in image processing. It is mostly combined with contrast stretching applied to any of the three selected bands. For Landsat 7 ETM, most common band combinations are Band4/Red, Band5/Green, and Band7/Blue for color composite images showing the clearly physiographic features and structures (Figure 3.3). Depending on the particular spectral response of targeted objects at the ground surface and the number and dimension of the spectral bands of the sensor controlled FCC images can be processed in order to highlight certain features at the ground surface.

3) *Edge enhancement* is an image processing technique that emphasizes the appearance of edges and lines in the image. Edge enhancement is achieved by spatial filtering or convolution using a box filter or the so-call kernel (in Figure 3.5). General goal of edge enhancement is to increase the brightness difference between each pixel (1 x 1 m) and its immediate neighbours. The filter kernel can be defined in different ways, so that high and low frequencies, as well as given directions can be emphasized or suppressed. A filter kernel procedure based on Yamakawa et al. (1998) involves moving a window of a few pixels in dimension (e.g. 3x3, 5x5, etc.) over each pixel in the image, applying a mathematical calculation using pixel values under that window, and replacing the central pixel with the new value (see an example in Figure 3.5). The window is moved along in both the row and column dimensions one pixel at a time. The calculation is repeated until the entire image has been filtered and a new image has been generated. In this way, "edge", i.e. abrupt changes in brightness within the image, such as lines or boundaries, appear emphasized and the overall image appear shaper (Figure 3.6). In this study, edge enhancement is a very useful tool for geological mapping, e.g. lineaments detection, and geological boundaries interpretation.

Figure 3.3 Enhanced Landsat 7 ETM by using the false-colored combination data of bands 4 (red), 5 (green), and 7 (blue) showing physiographic features of the Nan study area covering the eastern part of northern Thailand and western part of Lao PDR.

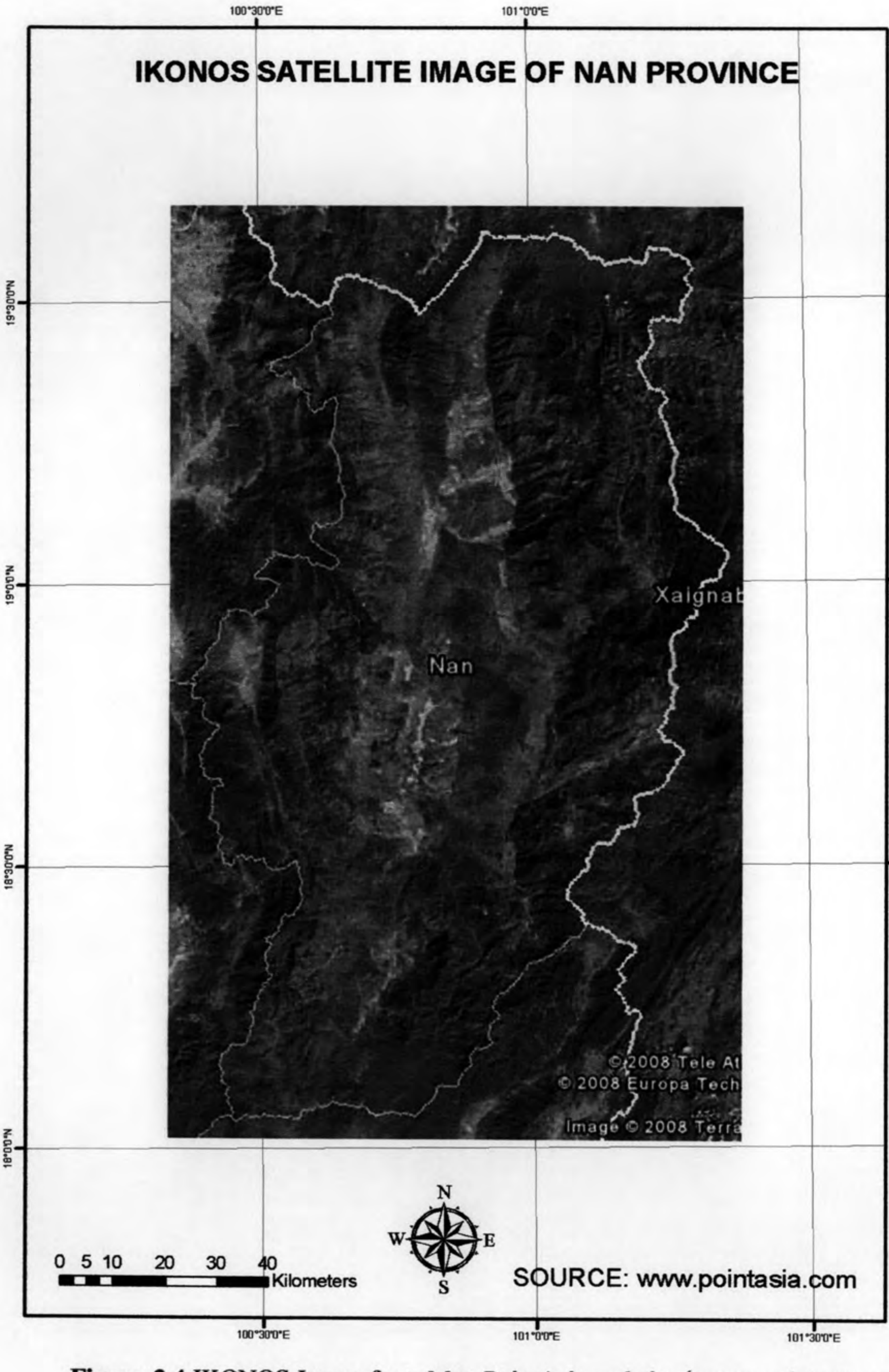
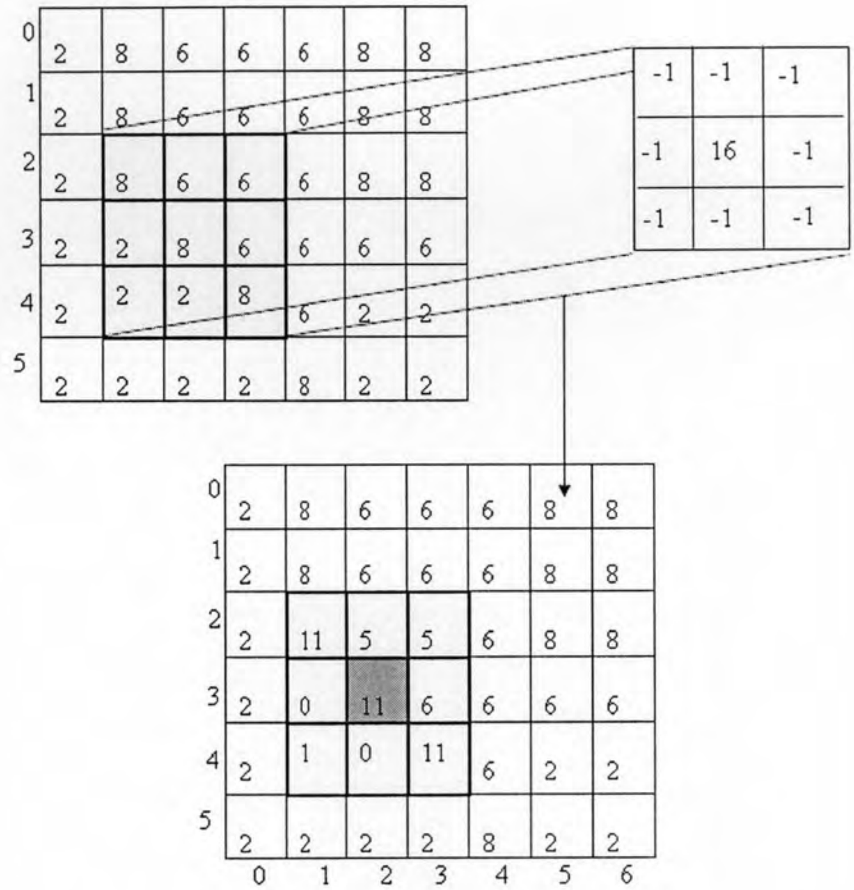


Figure 3.4 IKONOS Image from Map PointAsia website (www .pointasia.com) showing physiographic features of the Nan study area.



= integer{(-1x8)+(-1x6)+(-1x6)}+{(-1x2)+(16x8)+(-1x6)}+
{(-1x2)+(-1x2)+(-1x8)}/(-1+-1+-1+-1+16+-1+-1+-1+-1)

= int{(128-40)/(16-8)}

= int(88/8)

= int(11)

= 11

Figure 3.5 An example of a 3x3 convolution kernel being applied to a pixel in the third column, third row of sample data (the pixel that corresponds to the center of the kernel) (modified from Yamakawa et al., 1998).

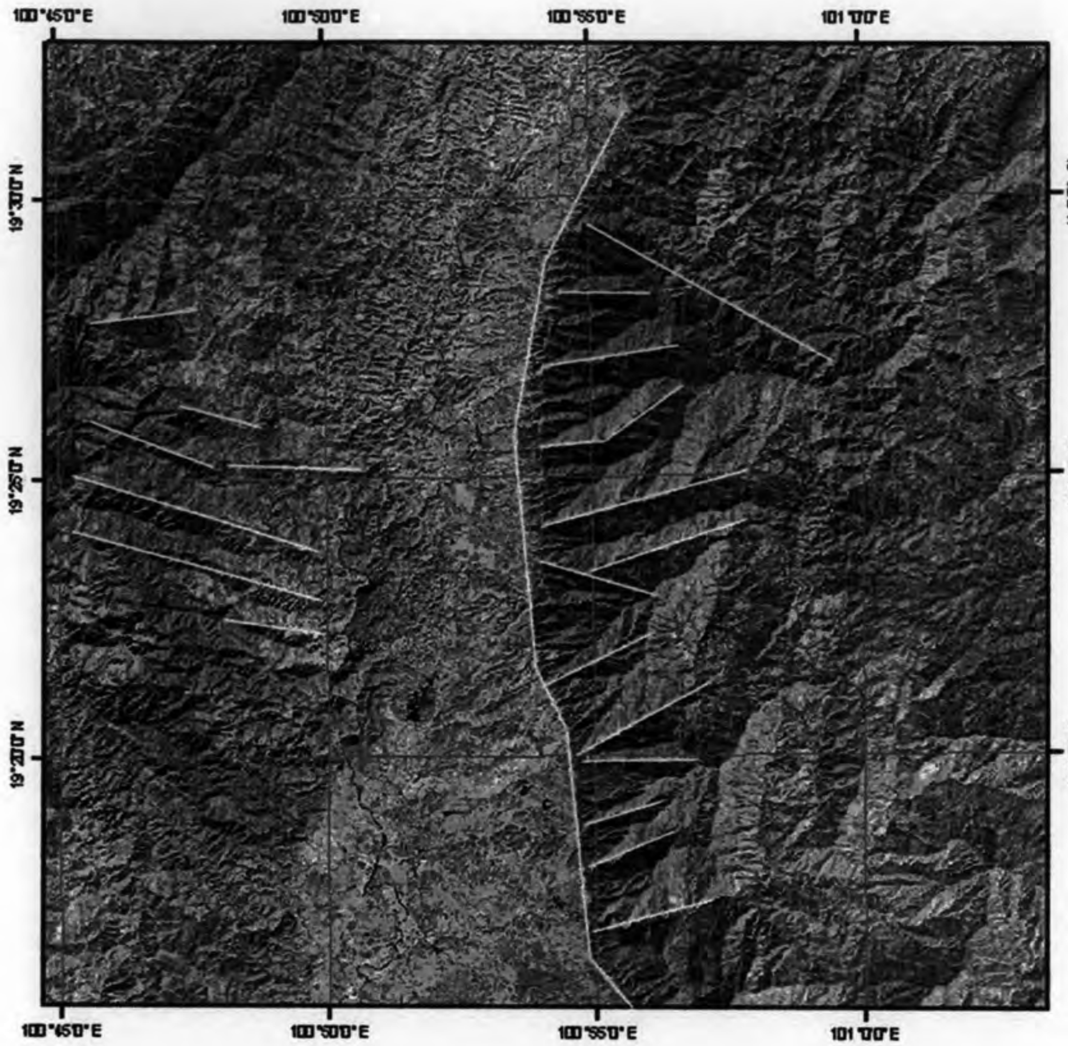


Figure 3.6 Edge-enhanced Landsat 7 ETM image as the result of 3 x 3 kernel high pass filtering and highlights linear arrangements of small topographic features interpreted as lineaments (white color lines). Note that the Landsat image of Path 129/Row 48 was taken on 2/11/2000.

Image transformation: Image transformations typically involve the manipulation of multiple bands of data, whether from a single multispectral image or from two or more images of the same area acquired at different times (i.e. multi-temporal image data). Image transformations generate new images from two or more sources, which highlight particular features or properties of interest, better than the original input images. Image division or band ratio and principal component analyses were used in this research.

1) Image division or band ratio serves to highlight subtle variations in the spectral responses of various surface covers. In this study, band ratio has been used in the version or the NDVI in order to characterize the land cover by assessing the degree of vegetation coverage. For example, the healthy vegetation reflects strongly in visible red. Other surface types, such as soil and water, show near equal reflectance in both near infrared and red portions. Thus, a ratio image of landsat 7 ETM Band 4 (Near Infrared) is divided by Band 3 (Red) would result in ratios much greater than 1.0 for vegetation, and ratio around 1.0 for soil and water. This is also used for land use/land cover interpretation. The normalized difference vegetation index or NDVI which is the ratio of Band4-Band3 to Band4+Band3 is used to detect vegetation conditions in the study area. The ranges of NDVI are from -1 to 1. When the land is free of vegetation, the NDVI value is assigned to zero, and when the land is covered with full vegetation, the NDVI approaches one.

2) The Principal Component (PC) transformation is used to compress the number of multispectral data sets by calculating a new image coordinate system. Gupta (1991) describes the theoretical background and the advantage of the principal component transformation as follows:

(A) Most of the variance of multispectral data set is compressed into the first three PC images;

(B) Noise is generally relegated to the less-correlated PC images; and

(C) Spectral differences between materials may be more apparent in PC images than individual bands.

The use of principle component analysis in this study, six bands of Landsat 7 data set may be transformed such that the first three principal components contain over 90 % of the information in the original six bands (Figure 3.7). These three bands can be used to improve visual interpretation of land use and landslide detection.

The image in Figure 3.8 shows that this technique can be used to map area affected by landslide (blue color) on hill slope. Landslide scar locations are classified by visual interpretation that will be mention in the next step.

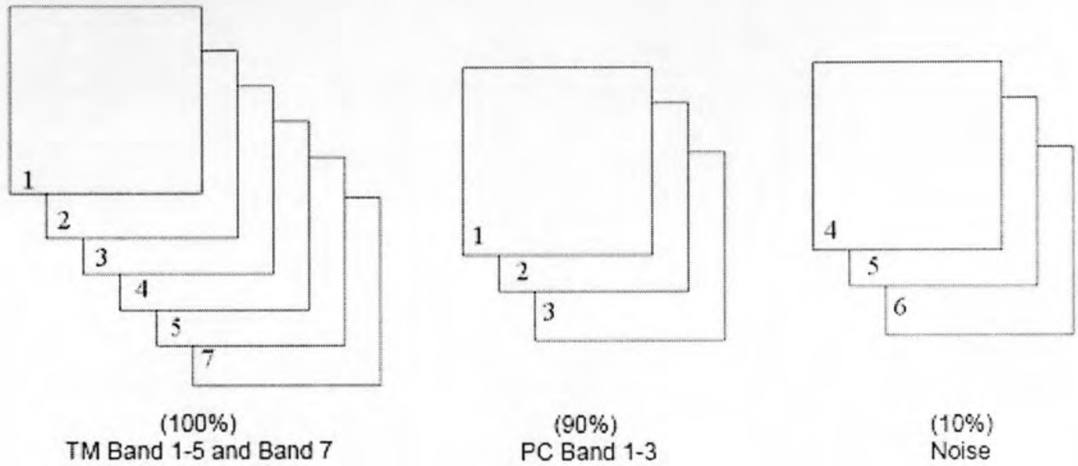


Figure 3.7 Example of the use of principal components analysis, a six-band Thematic Mapper (TM) data set was transformed such that the first three principal components contain over 90 percent of the information in the original six bands.

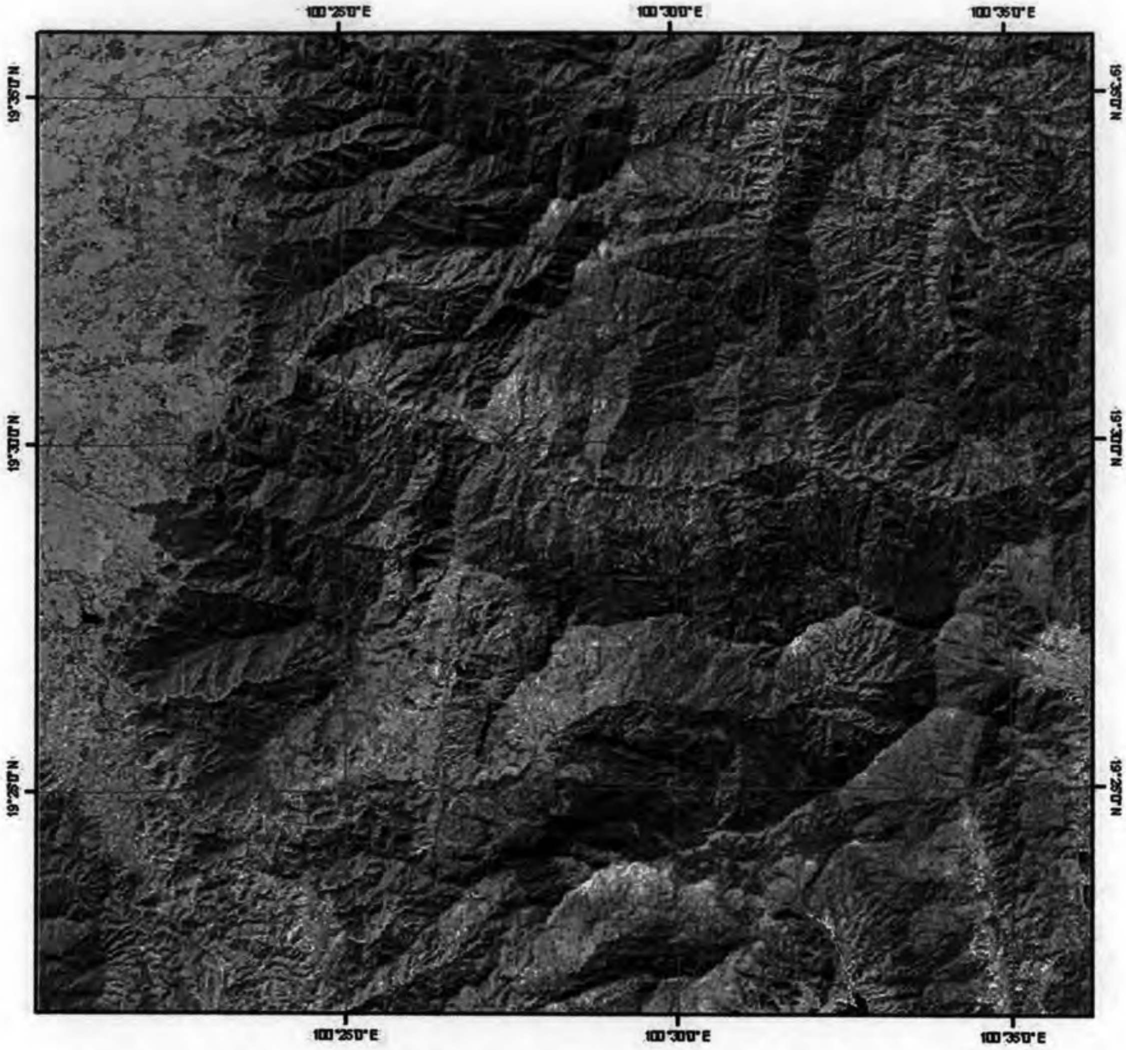


Figure 3.8 RGB colored composite based on PC4/Red, PC5/Green and PC7/Blue showing areas of landslide and alluvium deposits (blue color) easily separated from the other areas. Note that Landsat 7 ETM of Path 129/Row 46 was taken on 2/11/2000, in area of Tha Wang Pha District, Nan province.

3.2.2 Data Interpretation

Satellite imagery can provide information on previous and recent land use/cover, geo-hazards, geological structures (faults, fractures or lineaments), erosion and depositional processes in time and space and on other issues. Furthermore, items of infrastructures including the road net works and settlements can be mapped. In the present study, different types of satellite images were used in order to contribute to identifying the land use characterize, to mapping lineaments, to assessing the scope of landslide-hazard, to extract digital elevation model, to updating topographic maps and to acquiring other useful information relating to various developments and planning activities.

The method of data interpretation for gathering this information can be divided into visual interpretation and automatic interpretation. The two methods will be described as shown in Figure 3.2.

Visual interpretation: The visual interpretation uses hard copy plots of the digitally enhanced remote sensing data. Either the visually derived information such as traces of lineaments, features representing boundaries between rock and soil units, and land use categories, which can be annotated onto a transparency sheet overlaying the plotted-image or it can be directly digitized on the computer screen using geographic information systems.

In this study, the visual interpretation was used for the Landsat 7 ETM. False-Colored Composite images TM4/Red, TM5/Green, TM7/Blue of Landsat7 were processed and visualized on the computer screen as well as photographic hard copies in different scales. Lineament lines and categories of land use / land cover, such as the open forest, deforestation and teak plantations were identified and mapped by discrimination on the image processing display screen using ArcView-GIS and these data was also traced onto transparencies overlaying the geometrically rectified and geo-coded hard copy.

3.2.3 Digital Elevation Model Data Generation

In this study, Digital Elevation Model (DEM) data are provided by automatically generated from ASTER satellite data. DEM data are generated from Aster stereo pair (level 1B) of 1,980 pixels x 4,200 lines (75 x 63 km, band 3N and 3B) as shown in Figure 3.9.

DEM data are essential for landslide hazards investigation since they are base data to derive relevant topographic information such as slope angle, slope aspect, watershed boundary, and stream network.

3.3 Preliminary Field Investigation

In this study, fieldwork is an important part of the remote sensing data interpretation. It is crucial precondition for the provision of accurate and reliable interpretation results. Field checking (Figure 3.10) was carried out as follows:

1) Record and document location and nature of the landslide using GPS;
2) Spot-check and verify result of image interpretation result;
3) Collect relevant data and information for inputting in the automatic image classification for land use / land cover factor;
4) Collect ground truth information for the comparison with the processed satellite images and preliminary products;
5) Collect background information by interviewing local villages (on reasons of land use changes, past landslide events, etc.); and
6) Collect soil sample from landslide locations by using hand auger (Figure 3.11) for soil test of engineering properties in laboratory.

During the investigations, landslide locations recognized on remote sensing data will be verified. All types of slope failures were identified and classified. Other factors related to landslide (e.g., geological map and land use map) were updated by spot-check depending on accessibility.

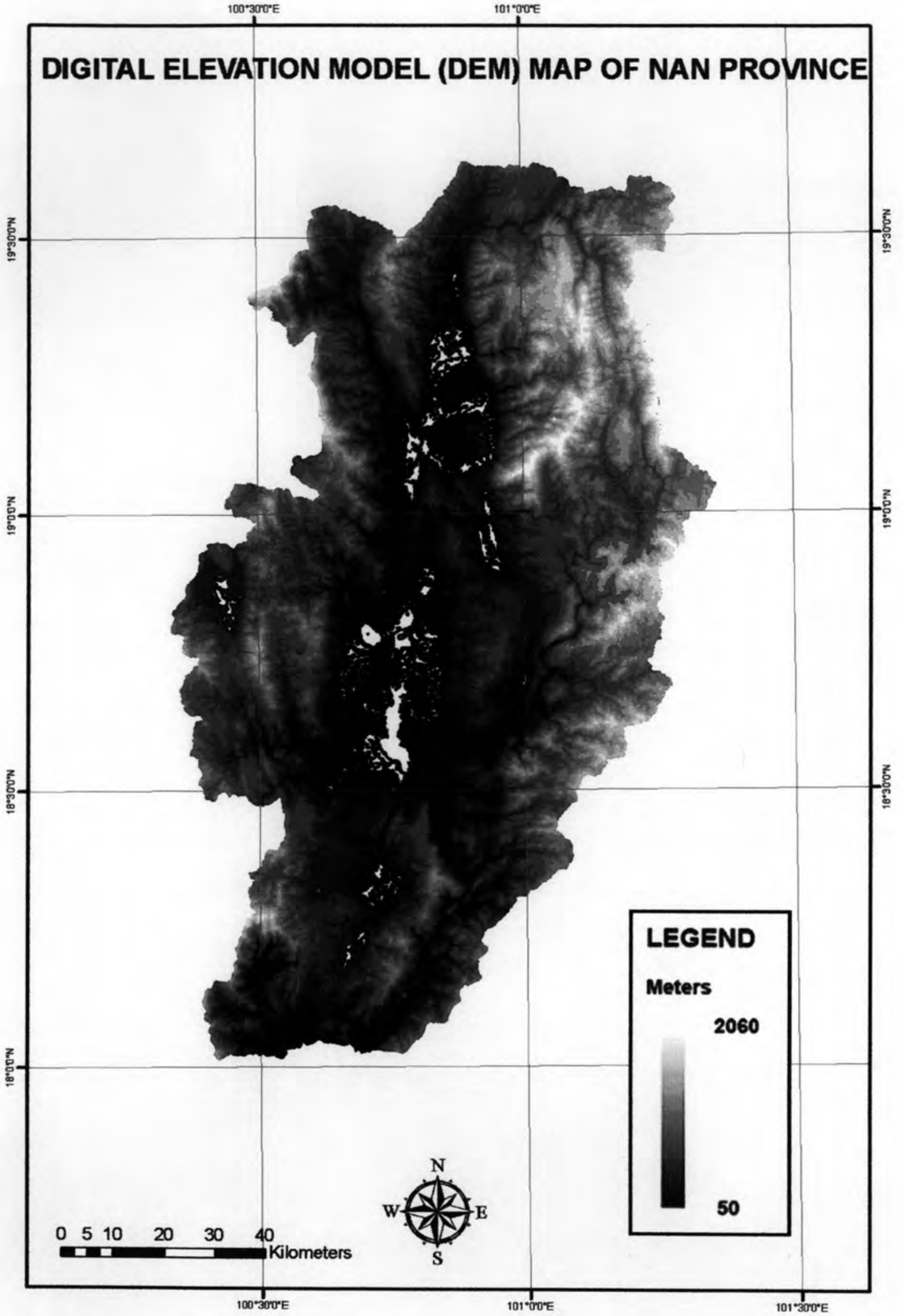


Figure 3.9 Digital elevation model (DEM) data of the Nan study area generated from Aster satellite data (bands 3N and 3B) taken on 2/11/2000. Note that white colour represents high elevation, black colour represents low elevation.

Figure 3.10 Landslide information are recorded at Sop Pun Village, Chalerm Phrakiat District, by using GPS and verified with the result from remote sensing interpretation (The author is to scale).

Figure 3.11 Soil samples are collected using hand auger nearby a landslide scar at Nam Phi Village, Thung Chang District, Nan Province for laboratory test.

3.4 GIS Data Preparation

This step describes the technique of GIS and database construction conducted in this study (Figure 3.12).

3.4.1 GIS Technique

In this study, map overlay functions and other functions of the ArcView are used to perform the database for the spatial analysis of landslide assessment. The functions that were used to construct the database map and to analyse the relationship between landslides occurrence and related factors, are shown in Figure 3.12.

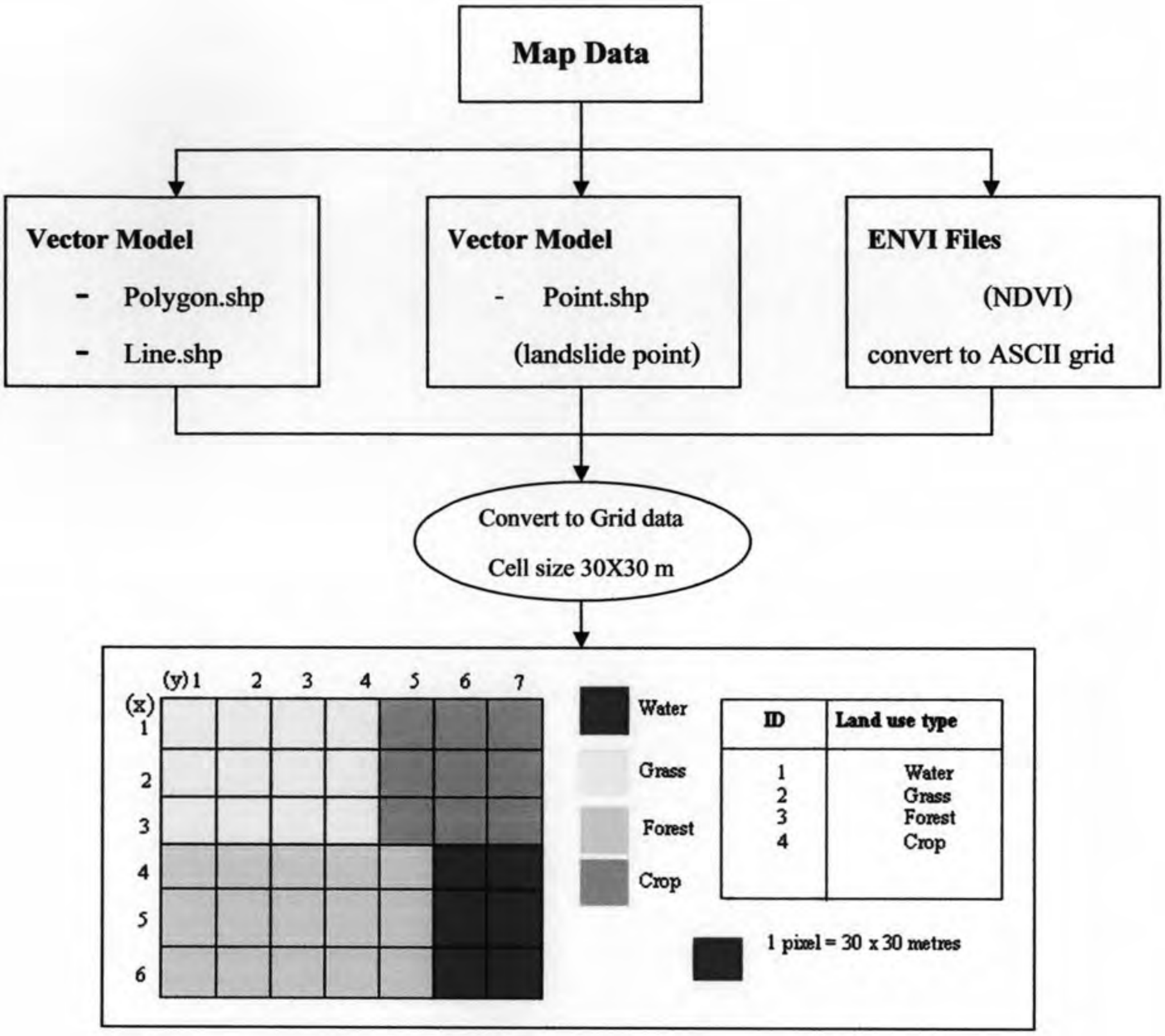


Figure 3.12 Flow chart of the database construction into GIS using ArcView GIS.

Buffer zone: Buffer command of ArcView is used to prepare the lineament buffer map, which has a distance of 100 metres, 200 metres, and 300 metres, 400 metres, 500 metres, 600 metres, 700 metres, 800 metres, 900 metres and 1000 metres from the lineament location, respectively. This map is used to analyse the relationship between landslide occurrence and lineament factor.

Cross-tabulated area: A cross-tabulated area of ArcView is used to sort out relationship of different thematic data maps. According to Alfoldi (2000), this technique combines two spatial data layers between landslide location map and individual factor maps to produce the landslide occurrences on each factor map. The principle concept of spatial cross-tabulated technique is to compare the characteristics of the same location on both data layers, and to produce a new characteristic for each location in the output data layer. For example, landslide locations are displayed onto the land use map (Figure 3.13).

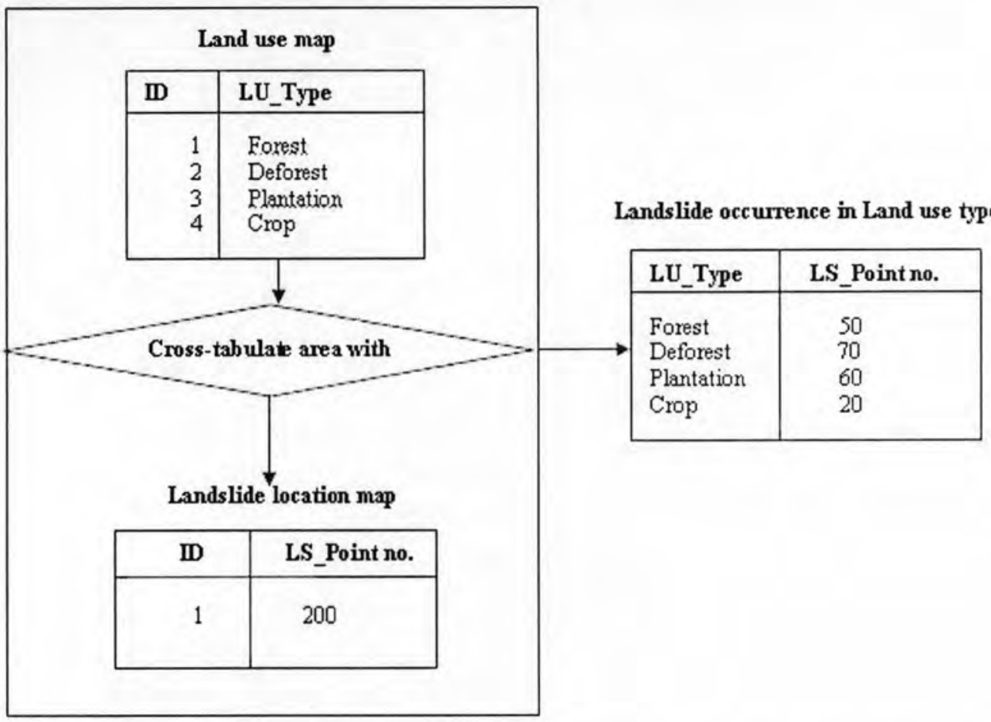


Figure 3.13 Concept of cross-tabulated area aggregation (modified from Alfoldi, 2000). It is show that, based on this concept the deforested area seems to have more landslide scars than the other land use types.

Data classification: The data classification tool of Arc View was used for creating new attribute data and new maps as well as for data visualization. Raster data reclassification is an important function in data exploration and data analysis. Creating a new raster model by classification is often referred to as reclassification, recording, or transforming through look-up table. Two methods of data classification are used in this study. The first method is "one-to-one change", meaning a cell value in the input grid is assigned a new value in the output grid. For instance, landslide occurrence in deforestation attribute of land use/land cover grid is assigned as a value of 1 in the output grid map. The second method assigns a new value to a range of cell values in the input grid that is called "value to range of cell values change". For example, grid cells with landslide hazard probability index between 0-25 in land use / land cover grid are assigned as a value of 1 in the output grid. The following applications of data classification were used in this study.

1) *Data isolation*: Data isolation classification is used to create a new grid that contains a unique category or value such as deforestation or a range of value such as slope of 10-20 degree (Figure 3.14).

2) *Data simplification*: Data simplification classification is used to group continuous slope values, for example, into a set of classes, for instance, 1 for slope of 0-10 degree, 2 for slope 10-20 degree, and so forth.

3) Data ranking: Data ranking classification is used to create a new grid that shows the result of the ranking of cell values in the input grid. For example, a reclassified grid shows the rank of 1 to 5 with 1 for the least suitable and 5 the most suitable.

Slope map

Unit	Slope
1	0-10
2	10-20
3	20-30
4	30-40
5	40-50

Reclassify Slope map

Unit	New slope value
1	0-15
2	15-30
3	30-45
4	45-60

Figure 3.14 Concept of reclassification function (modified from Alfoldi, 2000).

3.4.2 Data Base Construction

The data sets related to landslide occurrences in the study area were transformed to digital formats and stored as database of GIS. All data sets were built on a raster base (cell base) and assigned with an attributes database. Each pixel corresponds to a ground resolution cell of 30 metres by 30 metres, and contained the value (class number), symbol and class of data maps. The data maps and its attributes are constructed as a database into the GIS using ArcView software.

The factors affected on landsliding are primarily lithology, lineament, elevation, slope steepness, slope aspect, land use / land cover, normalized vegetation index, flow direction of a watershed, and past landslide location (Table 3.6). These can be divided into five groups of a factor map for this analysis as followings:

Geological factors: Lithological map and lineament map are grouped as a geological factor. These maps are modified from the geological map at the scale 1:50,000 and 1: 250,000, published by the Department of Mineral Resources (2004). Then the remote sensing interpretation and field checking are conducted to verify these maps. In this study, lithological map delineate bedrock and surficial units, based on rock type. Lineament map is represented by the bedrock structures, such as, fractures and faults.

Topographical and surficial material factors: The topographical factors represent surface units based on a number of terrain attributes, including surficial material genesis, surface expression and geomorphic process. These factors show the distribution of soil type, slope gradient, slope aspect, and elevation. Consequently, topographical factors database comprise soil map, slope angle map, slope aspect map, and elevation map.

Table 3.6 Factors map for landslide assessment of the Nan area of study.

Layer	Factor	*Value	Symbol	Class
1	Lithology	1	AS	Alluvial Sediments
		2	TS	Terrace Sediments
		3	SR	Semi-consolidated Rocks
		4	VCR	Very coarse-clastic Rocks
		5	CR	Coarse-clastic Rocks
		6	FR	Fine-clastic Rocks Shale
		7	LR	Limestone-dominated Rocks
		8	GR	Granitic Rocks
		9	VTR	Volcanic and Tuffaceous Rocks
		10	MUR	Metamorphic and Ultramafic Rocks
2	Lineament	1	-	0 m – 100 m
		2	-	100 m – 200 m
		3	-	200 m -300 m
		4	-	300 m – 400 m
		5	-	400 m – 500 m
		6	-	500 m – 600 m
		7	-	600 m – 700 m
		8	-	700 m – 800 m
		9	-	800 m – 900 m
		10	-	900 m – 1000 m
3	Land use / Land cover	1	-	Crop and Orchard
		2	-	Teak plantation
		3	-	Open Forest
		4	-	Wasteland
		5	-	Deforestation
		6	-	Reservior

Table 3.6 Factors map for landslide assessment of the Nan area of study (continued).

Layer	Factor	Value	Symbol	Class
4	Elevation	1	-	50 m – 100 m
		2	-	100 m – 200 m
		3	-	200 m – 300 m
		4	-	300 m – 400m
		5	-	400 m – 500 m
		6	-	500 m – 600 m
		7	-	600 m – 700 m
		8	-	700 m – 800 m
		9	-	800 m – 900 m
		10	-	900 m – 1,000 m
		11	-	1,000 m – 1,100 m
		12	-	1,100 m – 1,200 m
		13	-	1,200 m – 1,300 m
		14	-	1,300 m – 1,400 m
		15	-	1,400 m – 1,500 m
		16	-	1,500 m – 1,600 m
		17	-	1,600 m – 1,700 m
		18	-	1,700 m – 1,800 m
		19	-	1,800 m – 1,900 m
		20	-	1,900 m – 2,000 m
		21	-	2,000 m – 2,050 m
5	Slope angle	1	-	0°-10°
		2	-	10°-20°
		3	-	20°-30°
		4	-	30-°-40°
		5	-	40°-50°
		6	-	50°-60°
		7	-	60°-70°
		8	-	70°-80°
		9	-	80°-90°

Table 3.6 Factors map for landslide assessment of the Nan area of study (continued).

Layer	Factor	Value	Symbol	Class
6	Slope aspect	1	-	North
		2	-	Northeast
		3	-	East
		4	-	Southeast
		5	-	South
		6	-	Southwest
		7	-	West
		8	-	Northwest
7	Flow direction	1	-	North
		2	-	Northeast
		3	-	East
		4	-	Southeast
		5	-	South
		6	-	Southwest
		7	-	West
		8	-	Northwest
8	NDVI	1	-	-1.00 to -0.75
		2	-	-.075 to -0.50
		3	-	-0.75 to -0.25
		4	-	-0.25 to 0.00
		5	-	0.00 to 0.25
		6	-	0.25 to 0.50
		7	-	0.50 to 0.75
		8	-	0.75 to 1.00

*Value of class ID

Vegetation and Land use factors: The Normalized Difference Vegetation Index (NDVI) factors represent the density of vegetation on the surface and types of vegetation. The land use map describes a given area is being used for agriculture, settling, industry, national park and others. The land use map characterized their usage is based on the human activities on the land. For example, the land cover of an area may be evergreen forest, but the forest may be used for recreation or various combinations of activities. The land use factors are gathered from the Land Development Department (2004) and NDVI are derived from satellite image interpretation. These factor databases comprise land use map and NDVI map.

Hydrological factors: Watershed boundary and flow direction are used as hydrological factors. These factors affect the peak flow rate of a stream and transportation of debris flow. In this study, flow direction is entirely generated from the DEM data.

Landslide location map: A map of existing landslides serves as the basic data source for understanding conditions contributing to landslide occurrences. This map was prepared by visual interpretation of satellite remote sensing imagery and preliminary field examination of selected locations. The accurate detection of landslides location is very important for landslide susceptibility analysis.

3.5 Spatial Data Analysis and Data Integration

The spatial data analysis and integration or factor analysis following the work of Greenbaum et al. (1995) is a step-by-step approach used to prepare a landslide hazard zonation map of the Nan study area (Figure 3.15). Three consecutive steps involve for determining the factor analysis and to producing a hazard map as explained below.

3.5.1 Overlaying the Landslide Inventory Map on each Factor Map

The first step is to overlay the landslide distribution map with the factor map. This will identify which of the factor's attributes are associated with past landslides and which are not. Database of all factors from section 3.4 are used to prepare the maps that show the relationship between landslide occurrence and factors. The method applied is to cross-tabulate the past landslide location map with each factor map. Then, a landslide distribution table is developed and it indicates the total location of landslides occurring on each specific area of attribute of each factor.

3.5.2 Landslide Assessment Analysis

The second step is to group combinations of factors in order to classify and define the landslide hazard into five levels. This grouping is achieved by performing probability analysis, and ranking and weighting for assessing the factor's importance as described below.

A. ***Performing probability analysis***: Probability of landslide occurrence is the chance of landslide probability hazard to occur. It is represented as a real number between zero (0) and one (1). An impossible event has a probability of exactly 0, and a certain event has probability of 1, but the converses are not always true. Most probabilities that occur in practice are numbered between 0 and 1, indicating the event's position on the continuum between impossibility and certainty. The event's probability closer to 1 means the high possibility of landslides to occur.

The methodology used for landslide hazard assessment in this study is the "Probability Bivariate Analysis". The probability of landslide occurrence is usually a spatial distribution. In this method, a statistical correlation between the probability of landslide occurrence and several factor's classes was carried out as follows:

The first step is to measure the percentage of the total number of landslide location, and the total area for every classes of every factor in the study area Then the total percentage of landslide location associated with each class of individual factors is divided by the total percentage area of the same classes of factors found in the study area (equation 3.1). This result represents the probability of landslide occurrence in each class of each factor.

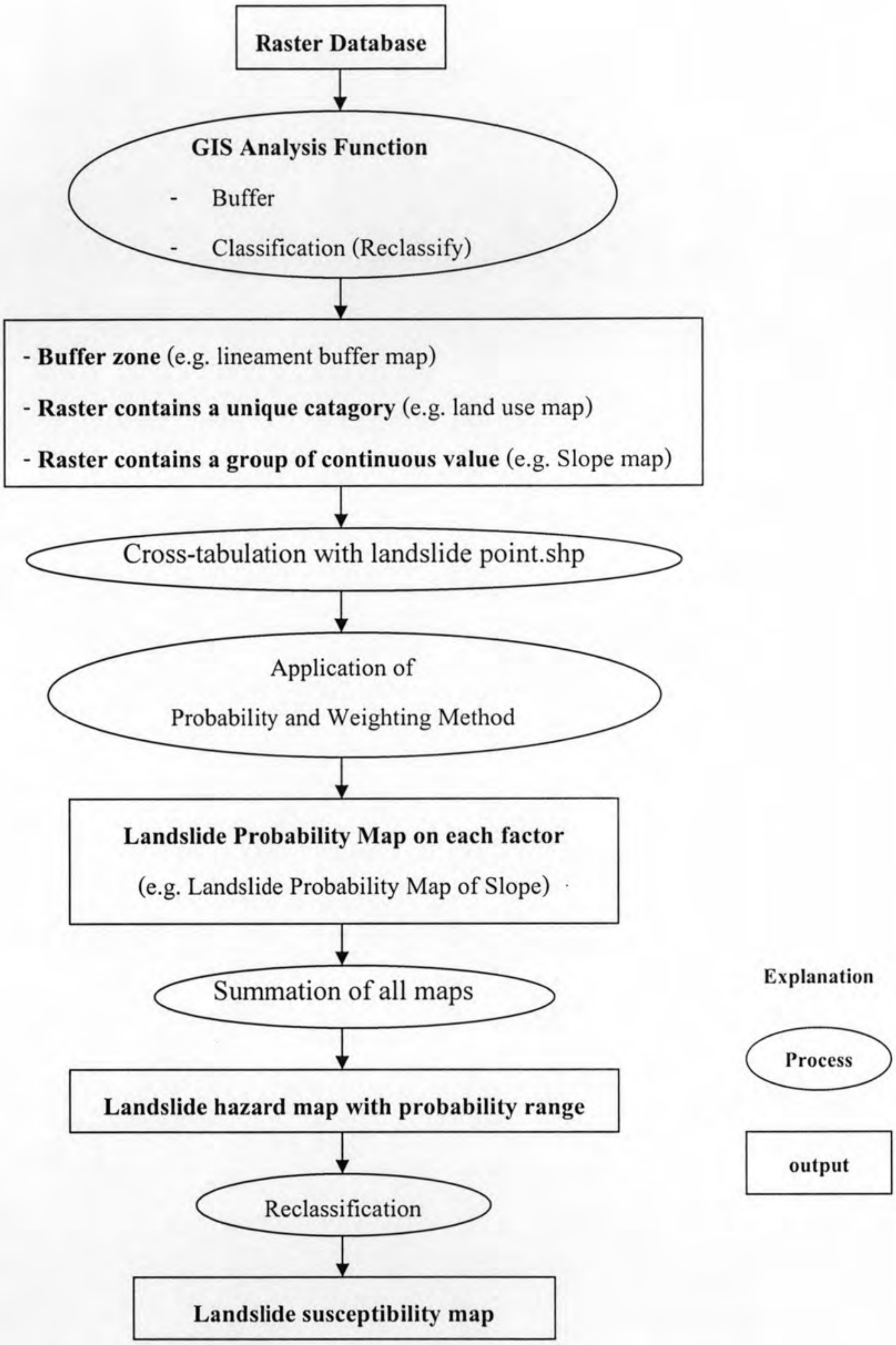


Figure 3.15 Flow chart showing procedures and products of spatial data analysis and integration for landslide hazard assessment (after Greenbaum et al., 1995).

$$\text{Probability of Landslide on each factor's class} = \frac{\text{\% total landslide number in factor's class}}{\text{\% total area comprising in the same class}} \quad \text{.....................(3.1)}$$

For example, in the case of landslide occurrence on slope angle 10°-20° (class 2) of slope angle factor. The landslide occurrence probability on this class can be calculated following equation (3.1) as:

$$\frac{\text{\% total landslide number in slope class 2}}{\text{\% total area of class 2}} = 36.11/29.77 = 1.21$$

This means that 36.11% (0.3611x100) of landslides occur on the area with slope angle 10°-20° (class 2) and it is divided by percent of the total area of the same class (29.77%). Then, probability of landslide at slope 10°-20° area equals 1.21.

The second step, involving the probability of landslide occurrence for the whole area was calculated from percent total landslide number in the whole area divided by percent total of the whole area (equation 3.2).

$$\text{Probability of landslide for the whole area} = \frac{\text{\% Total landslide points}}{\text{\% Total area of study area}} = \frac{100}{100} = 1 \quad \text{.....................(3.2)}$$

Then, the probability of landslide occurrence on each factor's class was compared with the probability of landslide occurrence for the whole area (equation 3.3). This result represents the probability ratio of landslide occurrence in each class of each factor compared with the probability of landslide for the whole area, as shown in equation (3.3).

$$\text{Probability ratio of landslide on each factor's class} = \frac{\text{Probability of Landslide on each factor's class}}{\text{Probability of landslide for the whole area}} \quad \text{..........(3.3)}$$

For example, the landslide occurrence probability on slope angle of 10°-20° is 1.21 and it is compared with the probability of landslide occurrence for the whole area.

$$\text{Probability ratio of landslide on slope angle } 10^\circ\text{-}20^\circ = \frac{\text{Probability of Landslide on slope angle } 10^\circ\text{-}20^\circ}{\text{Probability of landslide for the whole area}} = 1.21/1 = 1.21$$

This means that the incidence of landsliding on slope angle 19° -20° is 1.21 times greater than the probability of landsliding for the whole area. Considering as a measure of prediction, this slope category is 1.21 times more likely to occur than the whole area. Thus, the probability of landslide occurrence for the whole area is the mean value of landslide incidence for the study area and it is called "**the regional average incidence of landslides**". This can be explained that if the probability ratio of landslide occurring in each class of each factor is greater than 1, it means a higher likelihood and if it's lower than 1 it means a lower likelihood of landslide hazard occurrence.

B. ***Ranking and weighting for assessing the importance of factor***: The identification of potential landslide areas requires that the factors are considered to be combined in accordance with their relative importance to landslide occurrence. The importance of factors, as a predictor of landsliding, can be considered based on reliability probability method.

The reliability probability (RP) was calculated by the percentage area of factors corresponding to landslides. It was computed for each factor as shown in equation (3.4).

$$RP = \frac{\sum \text{\%Landslide point in classes having a probability ratio} \geq 1}{\sum \text{\%Landslide \& non-landslide area in the same classes}} \qquad (3.4)$$

According to the step of performing probability analysis, probability ratio of factor's classes less than 1 indicates a lower likelihood of landslide incidence, and probability ratio of factor's classes higher than 1 indicates a higher likelihood of landslides incidence. Therefore, in both performance measures, only probability values of attributes $\geq$ 1 (i.e. mean and above mean values of landslide incidence) are considered. The mean landslide incidence value means the probability of landslide occurrence for the whole area (equation 3.2). The results of RP of each factor were used to ranking and weighting the relative importance of each factor on landslide occurrence.

The relative importance of factors to landslide occurrence can be achieved by developing a ranking scheme to factors. The straight ranking (the most important=1, second important=2, etc.) is used in this study. Once the ranking is established for a set of factor, the numerical weights from ranking values are generated. In this study, the weights were calculated according to the formula shown in equation (3.5).

$$w_i = (n_j - r_i) + 1 \qquad (3.5)$$

where: n_j is the number of factor under consideration; j = 1,2,3,...;

r_i is the rank position of each single factor considered; $1 \leq i \leq n$; and

w_i is the weight of each single factor considered; $1 \leq i \leq n$.

Before the weights can be combined, they need to be normalized. Each factor is weighted as $(n_j - ri) + 1$ and then normalized by the sum of all weights, that is, $\sum (n_j - ri) + 1$ as shown in equation (3.6) follow.

$$w(n_j) = \frac{(n_j - ri) + 1}{\sum (n_j - ri) + 1} = \frac{w_i}{\sum w_i} \qquad (3.6)$$

where: $w(n_j)$ is the normalized weight of each single factor; and

$\sum w_i$ is the sum of all factor's weights.

The normalized weights of individual factors represent the relative importance of each factor. Then the probability ratio of landslide occurrence of each factor is multiplied by these weights in order to get a landslide hazard index of each factor. The example below shows that the slope factor is multiplied by its important weight, and the result is a landslide hazard index map (Figure 3.16).

0.1	0.1	0.3	0.3	0.8	0.8
0.1	0.1	0.3	0.3	0.8	0.8
0.1	0.1	0.3	1.0	1.0	0.8
0.1	0.1	0.4	1.0	0.8	0.8
0.4	0.4	1.0	1.0	1.0	0.8
0.4	0.4	1.0	1.0	0.8	0.8

Slope map with probability ratio of landslide x 2 (2 = weight of slope factor)

0.2	0.2	0.6	0.6	1.6	1.6
0.2	0.2	0.6	0.6	1.6	1.6
0.2	0.2	0.6	2.0	2.0	1.6
0.8	0.2	0.8	2.0	1.6	1.6
0.8	0.8	2.0	2.0	2.0	1.6
0.8	0.8	2.0	2.0	1.6	1.6

Figure 3.16 An example of landslide hazard index map showing that the slope factor contained probability ratio of landslide occurrence multiplied by its importance weight

3.5.3 Producing Landslide Hazard Map

The third step involves the group combination to produce landslide hazard zone. The numerical data layers representing weight values of the factor attributes as the information of attribute were generated from the thematic data layers for data integration and spatial analysis in the GIS. The input data layers were multiplied by their corresponding weight and were added up to obtain the Landslide Probability Index (LPI) for each 30 by 30 m cell as the equation 3.7.

$$LPI = \sum_{1\,1}^{j\,i} (F\,W) = F_1 W_1 + F_2 W_2 + \ldots\ldots\ldots + F_j W_i \qquad (3.7)$$

where:

F_j is the factor map, which is contained probability ratio of landslide occurrence;

and

W_i is the weight for factor j.

The landslide potential index map is used herein to produce landslide hazard zonation map. A judicious way for the landslide hazard zonation is to use the relative interval to separate the landslide potential index into landslide susceptibility class level. The level of landslide hazard is measured on the ordinal scale based on the equal interval values. Landslide potential index can be divided into 5 hazard levels, viz. ***very high***, ***high***, ***moderate***, ***low***, and **very low** of hazard levels in one single map as prediction image. It is important to note that the group of proportions with the larger values toward the end of the range represents combinations defining very high landslide hazard. The group of proportion with the smallest values represents very low landslide hazard. Landslide hazard map is, therefore, useful for the development project planning for the areas, which should be avoided.