

## LANDSLIDE SUSCEPTIBILITY IN MAI CHAU DISTRICT, HOA BINH PROVINCE, Viet Nam

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### ABSTRACT

Among natural hazards, landslides happen frequently and severely impact local people and environment in slope areas. The research objective was to determine landslide susceptibility triggered by the various factors in the high slope area. Analytic Hierarchy Process (AHP) and GIS methods were used to predict the landslide susceptibility in the whole Mai Chau district. Three categories of landslide susceptibility were defined as low, moderate and high susceptibility. The area of high susceptibility was evaluated as a significant help for land users and decision makers in the research district to correct unsuitable land use types. The results will be verified by an investigation of actual landslide happened in the previous period of time to specify the accuracy of the prediction.

Keywords: AHP, GIS, Landslide, landslide susceptibility.

### Nguy cơ lở đất tại huyện Mai Châu, tỉnh Hòa Bình, Việt Nam

#### TÓM TẮT

Trong những thảm họa tự nhiên, lở đất xảy ra thường xuyên và ảnh hưởng rất lớn đến người dân và môi trường tại các vùng đất dốc. Mục tiêu nghiên cứu là xác định nguy cơ lở đất gây ra bởi các yếu tố khác nhau tại vùng có độ dốc cao. Phương pháp phân tích đa mục tiêu (AHP) và hệ thống thông tin địa lý (GIS) được áp dụng để xác định nguy cơ lở đất trên địa bàn huyện Mai Châu. Ba mức đánh giá nguy cơ lở đất được xác định là nguy cơ thấp, nguy cơ trung bình và nguy cơ cao. Trong đó, nguy cơ cao được đánh giá là rất quan trọng giúp người sử dụng đất và các nhà hoạch định chính sách trong vùng điều chỉnh các loại hình sử dụng đất không thích hợp. Kết quả cũng sẽ được kiểm định bởi điều tra thực tế lở đất đã xảy ra tại địa phương để từ đó đánh giá được độ chính xác của dự báo về nguy cơ lở đất.

Từ khoá: AHP, GIS, lở đất, nguy cơ lở đất.

#### 1. INTRODUCTION

Natural hazards like landslides, avalanches, floods and debris flows can result in enormous property damage and human casualties in mountainous regions. The wide spectrum of landslide phenomena, the complexity and variability of its interactions with the environment (both natural and human) make the acceptance of a single definition of landslide hazard unsuitable (Guzzetti et al., 1999). Landslide is defined as the movement of soil-slip-debris triggered by intensive rainfalls,

which leads to extreme destruction of natural conditions and causing the casualties. A landslide, defined as the movement of a mass of rock, earth or debris down a slope (Cruden, 1991), is a geological process which includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows, which can occur in offshore, coastal and onshore environments. Additionally, each time a landslide occurs, the topographic, geological and hydrological settings of the slope change, often dramatically, giving rise to different conditions of instability.

Recently, landslides have been among the most hazardous natural disasters (Guzzetti et al., 1999). Many studies on landslides and their impacts were carried out in different countries with various methods, including GIS, remote sensing, AHP, and landslide inventory analysis (Chau et al., 2004; Domínguez-Cuesta et al., 2007; Komac, 2006; Lee et al., 2002; Lee and Dan, 2005; Neuhäuser and Terhorst, 2007). The damages of landslides on residential areas, infrastructures and even human casualties have been increasing worldwide (Singh et al., 2004 cited by Neuhäuser and Terhorst (2007)). The impacts of landslides on socio-economic development are potentially very large. Landslides can damage urban (Chau et al., 2004) or rural areas and they cause thousands of deaths and injuries.

Landslides are triggered by events, such as earthquakes, rainfall and rapid snowmelt. They are influenced by multiple factors: topography, the soil and rock types, geologic fractures, etc. (Guzzetti, 2000; Sidle and Ochiai, 2006); (Varnes, 1984). According to Guzzetti et al., (1999), landslides in a specific area do not only depend on the natural condition, but also on land-uses and other human activities. Neuhäuser and Terhorst (2007) stated that the landslide susceptibility assessment has become a major concern for authorities who are responsible for regional land use planning and environmental protection. To determine the damage of landslide, a growing research effort has been dealing with the creation of susceptibility or hazard maps which describe the actual or future threat from landslides. Landslide hazard maps are of great help to planners and engineers for choosing suitable development sites (Lee and Dan, 2005; Pradhan et al., 2008).

In Viet Nam, the economy has changed significantly from a bureaucratic and centralized planning economy to the market-oriented system after the opening of the country since 1986. The average annual GDP growth was high (7.3% from 1995 to 2005) (WB, 2008). The economic transition has resulted in profound changes in the organization of

different sectors of the Viet Nameese economy and current land use types. In addition, some climatic factors, such as temperature, rainfall, and humidity increasingly fluctuated significantly affecting the land use and human activities not only in Viet Nam, but also all over the world. Thus, association with a great contribution to economic development, current land-use practice in Viet Nam is still limited by the environmental assessment (SEMLA, 2009).

The research objective was to determine the landslide susceptibility in the district of Mai Chau using Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) methods. The results are meaningful for local land users, planners and natural resources management officials in risks management and land use in research area.

## 2. METHODS

### 2.1. Research area

Maichau District with its complicated terrain was selected for this study. Located in the mountainous and attractive region of the province of Hoa Binh with many beautiful landscapes and traditional customs, the district is considered as one of the most beautiful districts of the Province and the northwest region of Viet Nam. Moreover, the location of the district is also a crucial bridge between Ha Noi and other provinces in the northwest region of Viet Nam.

### 2.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a pair-wise comparison method in the field of multicriteria analysis (Saaty, 1980). AHP is a multicriteria decision making approach in which factors are arranged in a hierarchic structure. It has become a widely known method for solving discrete multiple criteria problems (Pekka and Jyrki, 2001). It was used in the research with the following steps:

**Defining the fundamental scale:** A fundamental scale is used in making the comparison (Saaty and Vargas, 2001; Saaty, 1990).

**Table 1. The fundamental scale**

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

The scale is defined as verbal judgments (intensity of importance) ranging from equal to extreme (equal, moderately more, strongly more, very strongly more, extremely more) corresponding to the numerical judgments (1, 3, 5, 7, 9) and compromises between these values. The definition and explanation of fundamental scale of 1-9 are given in Table 1 where number 1 and 9 indicates equal and highest priority, respectively, in comparison with other criteria.

**Comparison to calculate the weight of each criterion:** The criteria in each level are arranged in a reciprocal matrix (Ahn, 2000). According to Saaty (1990): Given n elements in a level of hierarchy, one may first make a pass through them by comparing one element with another, dropping it and picking another if that one is perceived to be larger and continuing the comparison. The largest element, therefore, is selected in n-1 such comparisons. The process is repeated for the remaining n-1 elements to identify the second largest element and so on.

In the end, the elements would be arranged in descending order.

A: Criteria (From 1 to n)

$W_i$ : Weight of criterion i (1 to n).

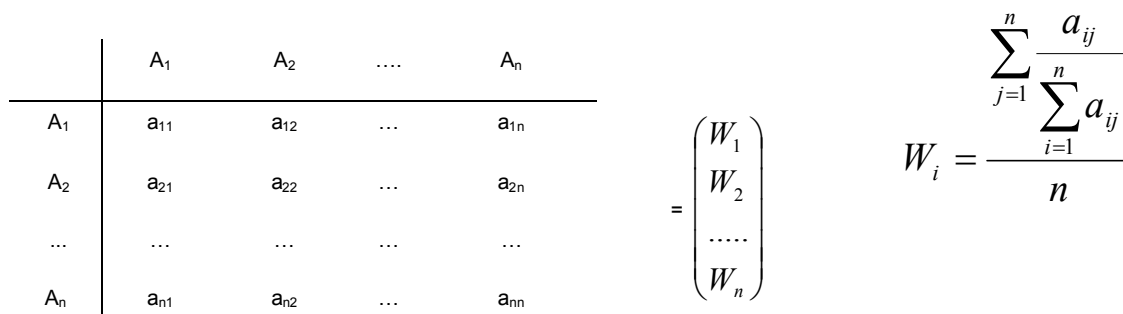
$a_{ij}$ : Fundamental scale of difference between criterion i and j (from 1-9).

**Determining the accuracy of the calculation:**

The Consistency Ratio (CR) is a measure of how much variation is allowed for reasonable results that is expected to be less than 10 percent for the reasonable result. CR calculation is described as in following formula from the matrix goal calculation,  $\lambda_{max}$  value can be gained and later it is used to count Consistency Ratio (CR) and  $W_i$  which becomes the priority vector. The formula of Consistency Ratio (CR) is derived from the Consistency Index (CI) as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad CR = \frac{CI}{RI}$$

Comparison matrix:



**Fig. 1. Reciprocal comparison matrix**

Where:

$\lambda_{\max}$ : The maximum eigen value

CI: Consistency Index

CR: Consistency Ratio

RI: Random Index

n: The numbers of criteria or sub-criteria in each pair-wise comparison matrix

The following steps of AHP were carried out in the field trip in the research area:

Determining the criteria to use in AHP method: Which criteria were meaningful with landslide susceptibility?

Arranging the criteria in the AHP matrix: How were criteria ranked in the hierarchy structure?

Discussing to find the fundamental scale between two criteria towards landslide susceptibility: Which fundamental scale was assigned in comparison matrix?

### 2.3. Geographic Information System

Geographic Information System (GIS) is considered as a powerful tool for collecting, storing, retrieving, transforming and displaying spatial data from the real world (Burrough, 1986). It can be used in resource assessment, land evaluation and land use planning. It provides tools for data visualization, data analysis and the evaluation of scenarios as well. GIS is an integrated technology that allows, encourages and expects users to bring together data from different sources through the unifying medium of geography. The typical application of GIS is in spatial modeling which can be described simply as combining information from several images to produce a single output image.

Additionally, GIS is basically understood as a computer-based system of storage and a manipulation of data which is organized by area or location. This location can be identified by a grid of cells (cell-based or raster systems), or information can be stored by means of the boundaries of mapped areas, e.g. land units or administrative units (polygon-based systems). GIS enables different kinds of information to be recalled and combined, for example, areas that

are both suitable for export crops and within a specified distance of an all-weather road could be overlain and mapped (FAO, 1993). Furthermore, GIS helps manage spatial data and visualize the results.

Actually, GIS was conducted in the research to build 5 thematic maps, including slope map, soil types, soil texture, soil depth and vegetation cover. After that, the method was used to overlap the 5 thematic maps together with their weight. Finally, landslide susceptibility map was determined by GIS with three categories: high susceptibility, moderate susceptibility and low susceptibility.

## 3. RESULTS

### 3.1. Criteria

Based on the characteristics of actual landslides, natural conditions of the research area and opinion of experts, five criteria were selected including slope, soil types, soil texture, soil depth and vegetation cover.

#### 3.1.1. Slope

Topography is one of the major factors in landslide hazard and risk analysis (Sidle and Ochiai, 2006: p55; Westen et al., 2006). The slope map was built from DEM (Digital Elevation Model) of Mai Chau district. The slope was divided into 4 categories (Table 2).

#### 3.1.2. Soil types

Mai Chau district has a high diversity of soil types. Based on the soil map developed by the Institute of Agricultural Planning and Projection in 1999, there were six soil types in the district (Table 3).

#### 3.1.3. Soil texture

Soil texture relates directly to soil cohesion. The smaller soil particles they are, the higher soil cohesive characteristic it is. Also based on the result of soil map of Mai Chau district made by the Institute of Agricultural Planning and Projection in 1999, the soil texture was divided into three categories including, sandy loam, silty loam and clay loam (Table 4).

**Table 2. Categories of slope in Mai Chau district - Hoa Binh province**

Slope category	Notation	Area (ha)	Proportion (%)
0 - 8°	SL <sub>1</sub>	8,970.74	16.33
8 - 15°	SL <sub>2</sub>	11,867.75	21.61
15 - 25°	SL <sub>3</sub>	19,677.92	35.82
> 25°	SL <sub>4</sub>	14,412.26	26.24
Total		54,928.67	100.00

**Table 3. Soil types in Mai Chau district - Hoa Binh province**

Soil types	Notation	Area (ha)	Proportion (%)
Dystric-Fluvisols	FLd	1,904.47	3.47
Calcic-Luvisols	Lvca	228.25	0.42
Rhodic-Ferralsols	FRr	24,287.69	44.21
Ferralic-Acrisols	Acf	19,636.36	35.75
Gleyic-Acrisols	Acg	707.03	1.29
Humic-Ferralsols	Frhu	8,165.87	14.87
Total		54,928.67	100.00

**Table 4. Categories of soil texture in Mai Chau district - Hoa Binh province**

Category of soil texture	Notation	Area (ha)	Proportion (%)
Sandy loam	L <sub>1</sub>	23,624.88	43.01
Silty loam	L <sub>2</sub>	7,017.10	12.77
Clay loam	L <sub>3</sub>	24,286.69	44.21
Total		54,928.67	100.00

### 3.1.4. Soil depth

Soil depth can cause the landslide because it relates to ability of storing water inside the land. As soil depth is one of the most crucial parameters in deterministic landslide hazard assessment, the use of shallow geophysics

should receive more attention (Sidle and Ochiai, 2006: p59-63; Westen et al., 2006). There were four categories of soil depth (Institute of Agricultural Planning and Projection, 1999) as follows: >100cm, 70cm - 100cm, 50cm - 70cm and < 50cm (Table 5).

**Table 5. Categories of soil depth in Mai Chau district - Hoa Binh province**

Categories of soil depth	Notation	Area (ha)	Proportion (%)
> 100cm	D <sub>1</sub>	3,414.62	6.22
70m - 100cm	D <sub>2</sub>	6,558.88	11.94
50m - 70cm	D <sub>3</sub>	22,741.44	41.44
< 50cm	D <sub>4</sub>	22,213.73	40.44
Total		54,928.67	100.00

### 3.1.5. Vegetation cover

According to Sidle and Ochiai (2006), land use activities and concentrated disturbances affect the magnitude, frequency and type of landslides that occur in many part of the world. In Viet Nam, land inventory is being carried out every 5 years, beginning in 1990, 1995, 2000, 2005, and 2010. It has been funded by the government and supported by different institutes, universities and specific companies.

Land inventory in Mai Chau district was carried out in the whole district from January to September in 2000. The results are shown in table 6.

### 3.2. Weight of criteria to determine landslide susceptibility

The hierarchy structure to determine landslide susceptibility in Mai Chau district was established. Level one had the main criteria: slope, soil type, soil texture, soil depth and vegetation cover. Level two had sub-criteria: 4 categories of slope, 6 categories of soil type, 3 categories of soil texture, 4 categories of soil depth and 4 categories of vegetation cover. Reciprocal matrix was used to compare two criteria in pair-wise comparison and it was repeated to the last criterion in the level one. For level two, sub-criteria in each main criterion were reciprocally compared to determine weight of each sub-criterion.

By the help of software Expert choice 11.5, the weight of each criterion was specified. The

results show the priority of each criterion with the respect to landslide susceptibility in Mai Chau district. The weights are shown in table 7.

At the level one, weight of slope was the highest with 0.376, followed by vegetation cover with 0.315, the lowest weight was soil depth (0.057). The higher weights in comparison with the lowest one were soil type and soil texture with 0.14 and 0.112, respectively. Similarly, in level two, sub-criteria were valuated with respect to landslide susceptibility. The higher weight of each sub-criterion reflects the greater role in causing the landslides in the district.

After valuating level one and level two, final weight ( $W_{fi}$ ) of each sub-criterion with respect to landslide susceptibility in comparison with all criteria integrating level one and level two was determined. The formula used to calculate the final weight of each criterion is:

$$W_{fi} = W_1 * W_2$$

Where:

$W_1$ : weight of level one;

$W_2$ : weight of level two.

The results show that sub-criterion of slope  $> 25^\circ$  had the highest weight (0.193, so it is the most important criterion possibly causing the landslide. After that, sub-criterion of shrubs and treeless hill was the second place with the weight of 0.162. The lowest weights were soil depth  $> 100\text{cm}$  and soil type Rhodic-Ferrasols with 0.004 and 0.006, respectively. Other weights ranged mostly from 0.087 to 0.011.

**Table 6. Categories of vegetation cover in Mai Chau district - Hoa Binh province**

Category of vegetation cover	Notation	Area (ha)	Proportion (%)
Forest	$V_1$	38,774.16	70.59
Perennial tree	$V_2$	2,084.85	3.80
Agriculture	$V_3$	4,341.47	7.90
Shrubs and treeless hill	$V_4$	9,728.19	17.71
Total		54,928.67	100.00

**Table 7. Weight of criteria to determine landslide susceptibility in Mai Chau district**

Level 1		Level 2		Final weight
Criteria	Weight	Sub-criteria	Weight	
1. Slope	0.376	1. SL <sub>1</sub> : 0-8°	0.074	0.028
		2. SL <sub>2</sub> : 8-15 °	0.138	0.052
		3. SL <sub>3</sub> : 15-25 °	0.275	0.103
		4. SL <sub>4</sub> : >25°	0.513	0.193
2. Soil types	0.14	1. S <sub>1</sub> : Dystric-Fluvisols (FLd)	0.293	0.041
		2. S <sub>2</sub> : Calcic- Luvisols (LVca)	0.135	0.019
		3. S <sub>3</sub> : Rhodic - Ferrasols (FRr)	0.041	0.006
		4. S <sub>4</sub> : Ferralic - Acrisols (ACf)	0.103	0.014
		5. S <sub>5</sub> : Gleyic - Acrisols (ACg)	0.351	0.049
		6. S <sub>6</sub> : Humic - Ferrasols (FRhu)	0.078	0.011
3. Soil texture	0.112	L <sub>1</sub> : Sandy loam	0.701	0.079
		L <sub>2</sub> : Silty loam	0.193	0.022
		L <sub>3</sub> : Clay loam	0.106	0.012
4. Soil depth	0.057	D <sub>1</sub> : >100cm	0.074	0.004
		D <sub>2</sub> : 70 - 100cm	0.138	0.008
		D <sub>3</sub> : 50 -70cm	0.275	0.016
		D <sub>4</sub> : < 50cm	0.513	0.029
5. Vegetation cover	0.315	V <sub>1</sub> : Forest	0.074	0.023
		V <sub>2</sub> : Perennial tree	0.138	0.043
		V <sub>3</sub> : Agriculture	0.275	0.087
		V <sub>4</sub> : Shrubs and treeless hill	0.513	0.162

**3.3. Zoning the landslide susceptibility**

The range weight is basically defined as a numerical range. It is used to determine that whether an assessed factor is in the range weight or not? The range weight of landslide susceptibility is understood as a susceptible range that a pixel of map could have. Actually, the range weight of each landslide susceptibility classification was determined by using the fundamental scales of AHP. Expert choice 11.5 was as well used to specify the range weight in the research area. The results are shown in table 8.

Total weight of each pixel was calculated basing on the formula:

$$W_{\text{pixel}} = \sum_{i=1}^n W_i$$

Where:

W<sub>pixel</sub>: Weight of each pixel

W<sub>i</sub>: Final weight of i<sup>th</sup> criterion.

n: Number of criterion.

GIS software (ArcGIS 9.3) was applied to overlap the thematic maps including soil map, slope map, soil texture, soil depth and vegetation cover to build the map of landslide susceptibility in Mai Chau district.

**3.4. Results of landslide susceptibility**

The overlapping different thematic maps, including soil type, slope, soil texture, soil depth, and vegetation cover maps, were made. Area of three categories of landslide susceptibility (low, moderate and high) shown Fig. 2 was calculated automatically by each pixel.

**Table 8. Landslide susceptibility classification**

Range weight	Classification	Explanation
> 0.250	Highly susceptible	Basically meet almost criteria set out for susceptibility
0.095 - 0.250	Moderately susceptible	Meet almost criteria set out for susceptibility, but some limits of some criteria
< 0.095	Lowly susceptible	Meet almost criteria set out, but some minor limits of some criteria

The data in fig.2 and fig.3 show that roughly 3% area of the total district was predicted as low susceptibility. Averagely, area of low susceptibility was divided into around 2-5% area of each commune. Area of moderate susceptibility occupied at about 62% of total district. The high susceptibility area accounted for roughly 35% and distributed not regularly in 22 communes and a town.

### 3.5. Actual landslides in Mai Chau district (2000 - 2010) and overlapping with landslide susceptibility

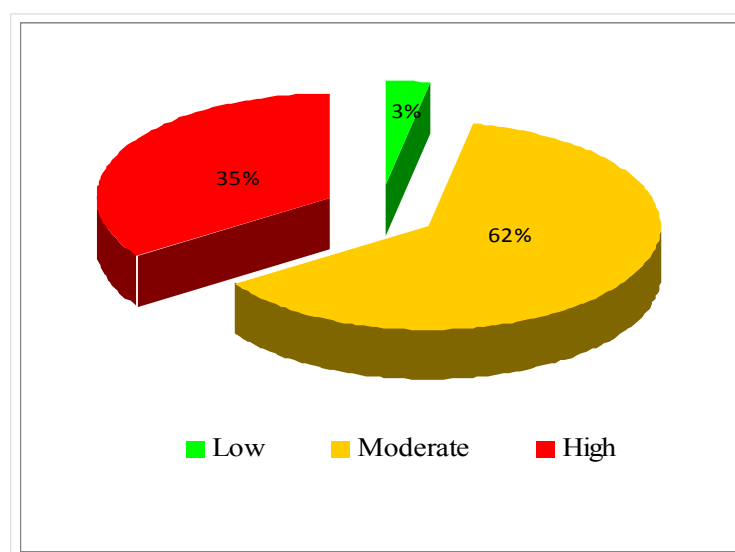
The investigation of actual landslide events were carried out at 22 communes and a town in Mai Chau district using a GPS and detailed maps of 1:5000 and 1:2000 scale. Actually, 122 landslide events happened from 2000 to 2010 in the district, an annual frequency of 12.2. The number of landslide events was nearly flat from 2000 to 2006 and hit the peak of 70 in 2007. The smallest numbers stood at 1 and 3 in 2004 and

2001, respectively. According to the investigation, 6 deaths caused by landslides were confirmed in the period which is a concern of local people to avoid or diminish the damages of landslides.

Total area affected by landslides was 114.10ha, including: agriculture (56.28ha), forest (55.48ha), residence (1.51ha), and road (0.83ha). This area fluctuated normally from 4.0ha to 6.0ha in a year and climbed the peak of nearly 78ha in 2007.

Overlapping actual landslides from 2000 to 2010 and landslide susceptibility are shown in table 8.

The results show that around 77% number of events and area of actual landslides actually happened on pixels classified as having a high level of landslide susceptibility. At the moderate level, nearly 23% of the area was affected. Notably, no landslide happened in the previous period of 10 years at the low level.

**Fig. 2. Categories of landslide susceptibility in Mai Chau**

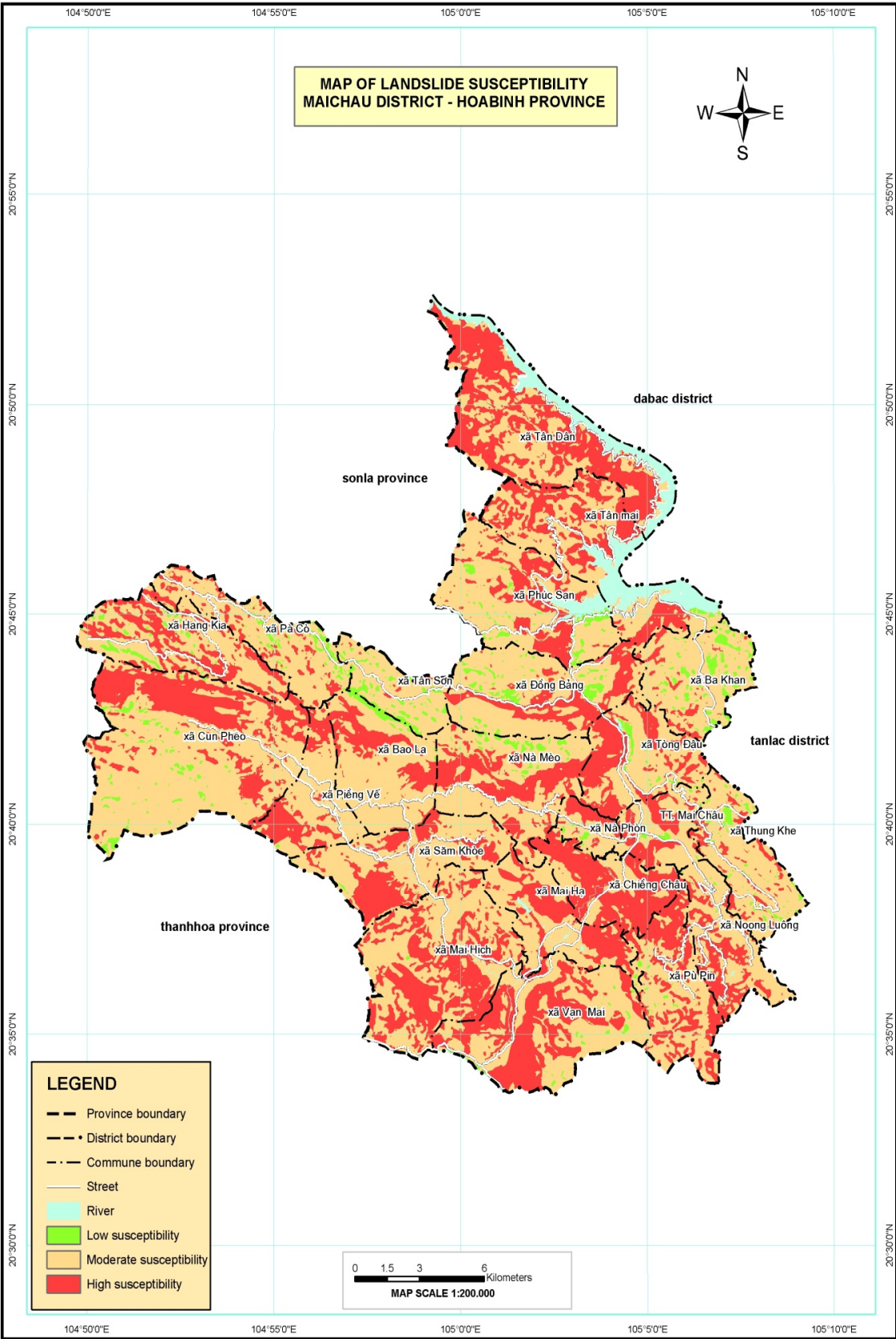


Fig. 3. Map of landslide susceptibility in Mai Chau district

**Table 8. Results of overlapping between actual landslides and landslide susceptibility**

Category of landslide susceptibility	Number of landslide events		Affected area (ha)					
	Number	(%)	Agriculture	Forest	Residence	Road	Total	(%)
High	94	77.05	43.70	43.18	0.84	0.61	88.33	77.41
Moderate	28	22.95	12.58	12.30	0.67	0.22	25.77	22.59
Low	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	122	100	56.28	55.48	1.51	0.83	114.10	100

#### 4. CONCLUSIONS AND DISCUSSIONS

AHP is regarded as a suitable method to determine landslide susceptibility and other analyses of environmental damage. However, AHP method usually needs to be confronted with the intuition for selecting the criteria and fundamental scale values between different criteria towards the relative overall goal. In this application of the AHP method own judgment is based not only on its own intuition but is supported by an extensive consultation process with national, regional and local experts.

The landslide susceptibility model indicates that roughly 35% area of the whole district is judged as having a high susceptibility. However, the prediction of triggered factors also can cause some concerns. Demounlin and Chung (2007) pointed out that the predicted features may have different direct or indirect causes, one should carefully avoid omitting triggering factors of the prediction. The prediction of triggered factors needs accumulated data of 10 years or longer because of extremely random factors like climatic conditions.

The 122 landslide events that happened from 2000-2010 in Mai Chau district impacted a total area of around 114ha, in which 56.3ha of farmland, 55.4ha of forest, 1.5ha of residence and 0.8ha of road. Roughly 77% of the landslide events and affected area occurred as predicted on high level of landslide susceptibility. Therefore, if the prediction of landslide susceptibility had been realized in 2000, 77% of landslide events and affected area would have

probably been anticipated on the high level of landslide susceptibility. Case study may continue to apply in other mountainous regions of Northern Viet Nam.

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