Mapping Risk of Landslide at A Luoi District, Thua Thien Hue Province, Vietnam by GIS-based Multi-Criteria Evaluation

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ABSTRACT

The study was conducted to determine the weight of factors influencing landslides through the algorithm Analytical Hierarchy Process (AHP). These factors were used as inputs for establishing a landslide susceptibility map based on the geographic information technologies (GIS) at A Luoi District, Thua Thien Hue province. Results of the study showed that landslide risk could be divided into five levels: very low risk of landslide covered 17,638.22 ha (14%), low risk areas accounted for 41,036.20 ha (34%), medium risk of landslide covered an area of 22,380.84 ha (18%), high risk area was 27,176.99 ha (22.19%), and very high risk area was about 14,231 ha (12%). The results of this study could be used to support the implementation of land use planning, which could help reduce adverse impact of landslides on people and property.

Keywords: AHP, GIS, landslide, A Luoi
JEL Classification: Q15

INTRODUCTION

Worldwide, areas that are at high risk to landslide cover about 820,000 km^2 and could bring damage to 66 million people (Dilley et al. 2005). Landslides have been a growing concern in recent years because of their enormous damage on the economy and society. Vietnam is not an exception, especially the central region, which has a complex geological structure, strongly differentiated topography, and frequent storms.

Several studies on landslides have been conducted in central Vietnam, covering various topics such as geological hazards in the central coastal provinces from Quang Binh to Phu Yen (Van et al. 2002); studying and mapping environmental hazards in the natural territory of Vietnam (Yem 2003); geological hazards at Thua Thien Hue Region by integrating remote sensing and geographic information system (Hue 2008); and warning systems for landslide risk in mountainous districts of Quang Ngai (Hung and Dung 2013). These studies applied remote sensing and Geographic Information System (GIS) technologies. GIS tools are utilized to evaluate the relationships between factors causing landslides and to make a map of landslide susceptibility or risk for landslides. Recent studies showed the importance of determining weighted factors of landslide risk by the analytical hierarchy process (AHP) approach, which was mainly based on the intention of the experts (Minh et al. 2011; Tuan and Nguyen 2012; Tham, Do, and Kanh 2012). Therefore, this study was conducted based on a statistical analysis of landslide risk and results of interviews with local people living in a landslide-prone region, to ensure objectivity in identifying the factors causing landslides.

A Luoi is a mountainous district, west of Thua Thien Hue province, 70 km away from Hue City, and covers an area of 1,224.64 km^2. As a bordered district with 84 km national border, A Luoi is an important place adjacent to many different territories. In recent years, the covered vegetation at A Luoi district has shown signs of decline in both scale and quality. Meanwhile, the terrain is mainly mountainous with elevations from 680 m to 1,150 m, which is divided by multiple stream systems, between high mountains and steep passes. In particular, A Luoi is well known as the heavy rain center of Thua Thien Hue province. These features put A Luoi areas under high risk of landslides. Therefore, the assessment on landslide susceptibility is extremely urgent, which could help local authorities obtain a scientific basis for socio-economic development planning to minimize the harmful effects of landslides on the lives of people in the study area.

DATA AND METHODS

Data

Spatial data were collected from the Department of Natural Resources and Environment at A Luoi district, including soil type map, topographic map, and land use map. Additionally, remote satellite images (Landsat 8) acquired from 2005 to 2014 were also downloaded from the United States Geological Survey (USGS) website. These images were used to identify vegetation covering the study area.

Sources of attribute data include data associated with collected spatial data and other data such as weather conditions (precipitation collected at meteorological stations for each month), climate and geographic location, statistics about the situation of socio-economic development of the district, and information on landslide risks in the study area.

Methods

Field survey methods

In this research, the authors implemented various surveys in the study area to locate the slip points and slide marks from the past to present, and to record and measure the characteristics and properties of the sliding blocks, sliding points, and sliding tracks.

Remote sensing method

Landsat 8 satellite image with a resolution of 30 m was interpreted by ENVI software for mapping vegetation cover in A Luoi district and in identifying slip points in the past. In addition, it was used to conduct field surveys.

Analytic hierarchy process (AHP) methods

There are many factors affecting landslide risk, and the weight of each factor *(Wj),* which would allow researchers to express their views on proposed solutions, was determined. In this manner, the selection of weights was seriously considered before applying any model (Anderson and Holcombe 2013; Schuster 1996; Anh 2015). In this study, the analytic hierarchy process (AHP) model was employed in quantifying the weight of selected factors that cause landslides.

AHP, a semi-quantitative method, was used to build a system of comparison matrixes between the different elements to determine their importance (Table 1). In this method, the eigenvector principle was used to calculate the weights of components by dividing the values of each column by the total value of each column to set the new matrix, in which the average value of the rows is the weight for each factor (Schuster 1996; Anh 2015).

According to Panizza, Marchetti, and Patrono (1996), the landslide sensitive index is calculated based on the formula:

$$LSI = \sum_{j=1}^{n} W_j X_{ij} \quad (1)$$

in which *LSI* is the Landslide Susceptibility Index, W_j is the weight of the j factor, and X_{ij} is the i^{th} grade score of the slip factor j.

Table 1. The fundamental scale of absolute numbers

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

Source: Saaty (2008)

Integrating AHP in GIS for mapping of landslide risk

Geographic information systems (GIS) are important for this research because these allow the construction of a geo-database, and the management and analysis of thematic maps necessary in landslide risk assessment. In addition, GIS usually provides various spatial interpolation analysis and overlay tools, which are used to create the basic map for the identification risk of landslide. After classification and evaluation, the weight of selected factors was synthesized on layers (Saaty 1980). In this research, ArcGIS 10.2.2 was utilized to integrate the component layers, including: slope, aspect, soil, rainfall, roads, rivers, land cover as formula (1) to build a landslide risk map for A Luoi district. The landslide map was created under the assumption that future slip cases will occur given the same conditions in the past (Guzzetti et al. 1999). These factors were conducted as layers under raster format with pixel size of 30 m × 30 m. The process of mapping landslide risk in using GIS, remote sensing, and AHP is indicated in Figure 1.

RESULTS AND DISCUSSION

Status of Landslide Occurrence in A Luoi District

According to statistical publications and the research of Son and Hang (2010), landslides have occurred frequently in A Luoi district because of heavy rains and flash floods, resulting in damages. Specifically, the number of landslides was divided into two phases: Phase I (from 2005 to 2009) and Phase II (from 2011 to 2014).

As seen in Table 2, the number of landslides during Phase I varied. The year 2009 had the highest number of landslides at 293 (accounting for 57% of the total occurrences for the first period), followed by 2006 and 2005 with 24 percent and 10 percent of the total occurrences, respectively. Accordingly, the amount of landslide in 2009 was the highest at 137,034.3 m^3. The density of landslide in 2009 was also quite high at 3.02 point/km^2.

Compared to Phase I, the occurrence of landslides in Phase II was lower.

Figure 1. Process of mapping landslide risk using GIS, remote sensing, and AHP

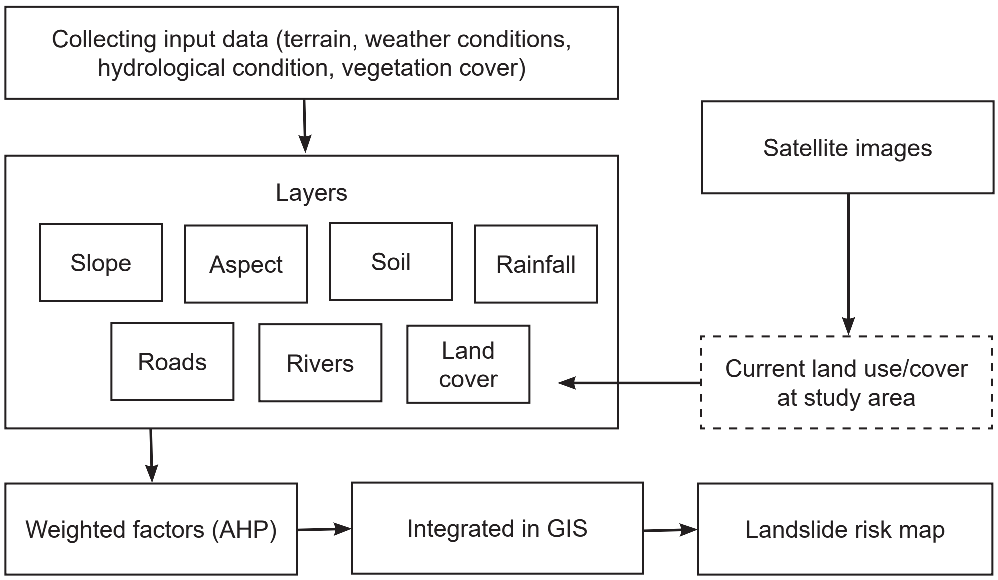


Table 2. Landslide occurences during Phase I (2005–2009)

Year	Landslide Point	Amount of Landslide (m³)	Density of Landslide Point (point/km²)
2005	53	7,922.10	0.60
2006	125	20,639.90	1.30
2007	39	35,163.50	0.40
2008	6	4,625.20	0.06
2009	293	137,034.30	3.02
Total	516	205,385.00	5.38

Source: Son et al. (2010)

The total number of landslides in the four years in Phase II was only about one-tenth of the total number of landslides in Phase I. Table 3 shows that the highest number of landslides occurred in 2013 (22 or 42 percent of the total occurrences for the second period), followed by 2014 and 2011 with occurrences of 33 percent and 19 percent, respectively. However, the year 2014 had the highest amount of landslide in cubic meters (53% of total landslide amount).

As seen in Figure 2, the landslide in A Luoi district occurred mainly in the Ho Chi Minh Trail that crosses in A Luoi district at different phases. At the initial phase (2005–2009), there were 516 landslide points with total amount of landslide at 205,385 m^3, whereas there were only 52 points of landslide in Phase II with around 7,064 m^3 as landslide amount. In both phases, the year 2009 had the highest amount of soil loss and damages due to heavy rains and storms, especially at Hong Thuy commune. The construction of the Ho Chi Minh road could be seen as one of the dominant factors that affected the frequency of landslides in the area as the number of landslides decreased when the road was finished.

Weight of Factors Affecting Landslide Risk

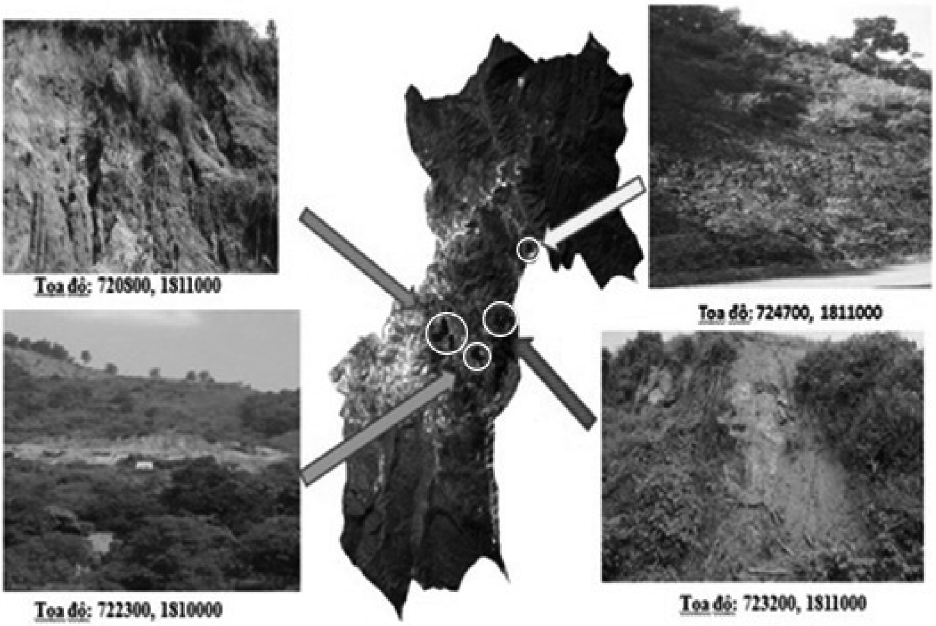
There are many factors that affect landslides, but their roles are not quite the same. Schuster (1996) asserted that based on researches on landslides, at least 20 factors affecting landslides can be identified depending on the landslide level. From the specific conditions of the territory, results of field surveys, the available data, and related literature (Anh 2015; Tan and Nguyen 2014; Minh et al.

Table 3. Landslide occurences during Phase II (2011–2014)

Year	Landslide Point	Amount of Landslide (m³)	Density of Landslide Point (point/km²)
2011	10	1,070.55	0.04
2012	3	112.00	0.03
2013	22	2,137.80	0.09
2014	17	3,743.70	0.05
Total	52	7,064.05	0.21

Source: Department of Natural Resources and Environment (yearbooks from various years)

Figure 2. The landslide points in Hong Thuy commune, A Luoi District



2011), seven prerequisite factors were selected to evaluate the sensitivity to landslide, including slope, aspect, average annual rainfall, land use/cover, type of soil, road density, and river density. To get the relative importance of each factor in relation to landslides, experts were interviewed including the Land Administration Officer of Communes and the heads of the following agencies: Road Management Division, Forest Protection Unit, and Natural Resources and Environment Division of A Luoi district (Table 4).

The AHP method was used to identify the importance of each element by calculating the weight of each factor. Table 5 shows that rainfall is the greatest factor affecting landslides, with the weight at about 42 percent. Due to the direct impact of rain fall on vegetation cover and topographic area, the more rainfall at sparse cover with a steep slope, the higher the risk of a landslide. The slope, road density, river network density, and aspect had weights of 22 percent, 11 percent, 10 percent, and 5 percent, respectively. Also at 5 percent weight were the land cover and the type of soil.

Because the consistency ratio (CR) is less than 0.1, the weights were accepted for building thematic maps. However, the risk of landslide is also affected by sub-factors; it is necessary to determine the weight of each specific sub-factor affecting landslide. Similarly, weights of sub-factors affecting landslide in the study area were determined first based on the interviewed experts, then calculated by AHP methods. Results showed that the CR indices of all sub-factors were lower than 0.1, which were accepted and used for building component maps.

The results show that rainfall was the main factor causing landslides in mountainous areas at A Luoi district with the highest weight at 0.417. Other factors causing landslides were slope, road density, river density, and aspect with weights of 0.217, 0.107, 0.104, and 0.053, respectively. The factors causing landslides with the lowest weights in the mountainous

Table 4. Importance intensity of landslide factors

Factor	Importance Intensity
Rainfall	9
Slope	8
Road density	7
River density	7
Aspect	6
Land cover	6

Table 5. The impact of factors causing landslides

Factor	Rainfall	Slope	Road Density	River Density	Aspect	Land Cover	Type of Soil	Weight	No.
Rainfall	1	3	5	5	6	6	6	0.417	1
Slope	1/3	1	2	2	5	5	5	0.217	2
Road Density	1/5	1/2	1	1	2	2	3	0.107	3
River Density	1/5	1/2	1	1	2	3	2	0.104	4
Aspect	1/6	1/5	1/2	1/2	1	1	1	0.053	5
Land Cover	1/6	1/5	1/2	1/3	1	1	1	0.050	6
Type of Soil	1/6	1/5	1/3	1/2	1	1	1	0.050	6
λmax=7,135			CI = 0.023 CR = 0.017						∑=1

area at A Luoi district were land cover and soil type (both at 0.050). Similarly, the weights of each sub-factor were also calculated to show sensitivity to landslide. Results are presented in Table 6.

Thematic Maps on Landslide Factors

Rainfall

The assessment results showed that landslide risk at medium level had the highest risk (Table 7). It covered an area of 40,532.49 ha, accounting for about 33 percent. The area where average annual rainfall was less than 2,400 mm had the lowest landslide risk at 3 percent. The very high landslide risk (more than 2,900 mm) accounted for 17 percent in the total area of the district. The survey indicated that high intensity rains usually lasted for about 3 to 5 days. The rainfall map in the district is presented in Figure 3.

Slope

Results from Table 8 show that the highest risk of landslide at A Luoi district distributed mainly at mountain peaks, where slope is over 25° accounting to only 4 percent, a very small percentage of the total area. Similarly, the high landslide risk regions having slopes from 20° to 25° were found in 8 percent of the total area (9,929.43 ha). The areas with low (5°–15°) and medium (15°–20°) risk of landslide covered 27 percent and 13 percent of the district, respectively. Meanwhile, very low risk of landslide had the largest percentage of total area at 48 percent. Figure 4 presents the slope map in the district.

Table 6. Weight of factors causing landslides

Main Factor	Main Weight	Sub-factor	Sub-weight	Sum
Rainfall	0.417	<2,400mm	0.026	0.0108
		2,400 mm–2,600 mm	0.038	0.0158
		2,600 mm–2,750mm	0.083	0.0346
		2,750 mm–2,900mm	0.215	0.0897
		>2,900mm	0.638	0.2660
Slope	0.217	<5°	0.017	0.0037
		5°–10°	0.028	0.0061
		10°–15°	0.053	0.0110
		15°–20°	0.108	0.0234
		20°–25°	0.238	0.0516
		>25°	0.557	0.1209
Road density	0.107	<1 km/km^2	0.026	0.0028
		1 km/km^2–1.5 km/km^2	0.038	0.0041
		1.5km/km^2–2.7 km/km^2	0.083	0.0089
		2.7km/km^2–4.1 km/km^2	0.215	0.0230
		>4.1 km/km^2	0.638	0.0683
River density	0.104	<1.2km/km^2	0.026	0.0027
		1.2km/km^2–1.9km/km^2	0.038	0.0040
		1.9km/km^2–2.7km/km^2	0.083	0.0086
		2.7km/km^2–3.5km/km^2	0.215	0.0224
		>3.5km/km^2	0.638	0.0664
Aspect	0.053	North	0.068	0.0036
		Northeast	0.237	0.0126
		East	0.478	0.0253
		Southeast	0.123	0.0065
		South	0.024	0.0013
		Southwest	0.013	0.0007
		West	0.017	0.0009
		Northwest	0.039	0.0021
Land cover	0.050	Lake and river network, unused land, road network, aquacultural land (L1)	0.638	0.0319
		Cemetery land, annual crop land, other agricultural land (L2)	0.215	0.0108
		Built-up land, irrigation land (L3)	0.083	0.0042
		Perennial fruit tree land, industrial plant land (L4)	0.038	0.0019
		Natural forest land, plantation land (L5)	0.026	0.0013
Type of soil	0.050	Acrivi-Humic Ferralsols (FRu-a)	0.513	0.0257
		Humic Ferralsols (FRu)	0.239	0.0120
		Lixi-Ferralic Acrisols (ACf-l)	0.117	0.0059
		Lixic Ferralsols (FRl)	0.061	0.0031
		Acrivic Ferralsols (FRac)	0.034	0.0017
		Arsenic Ferralsols (FRa)	0.021	0.0011
		Fluvic Ferralsols (FRf)	0.015	0.0008

Table 7. Landslide risk levels by average annual rainfall

Level	Rainfall (mm)	Landslide Risk Level	Area (ha)	Percentage (%)
1	<2,400	Very low	3,562.47	2.91
2	2,400–2,600	Low	30,874.34	25.21
3	2,600–2,750	Medium	40,532.49	33.10
4	2,750–2,900	High	26,988.36	22.04
5	>2,900	Very high	20,505.94	16.74
		Total	122,463.60	100.00

Figure 3. Rainfall map in A Luoi district

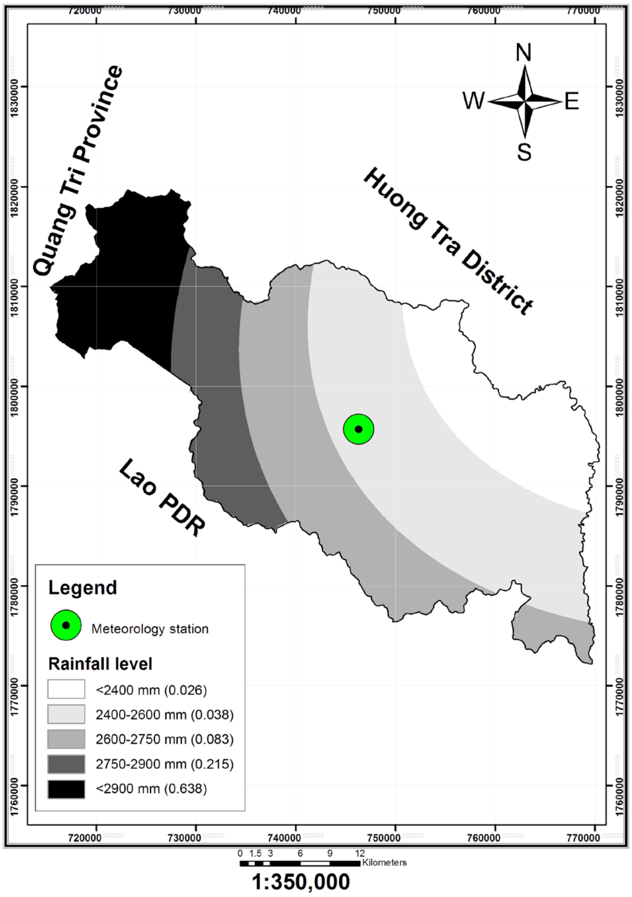
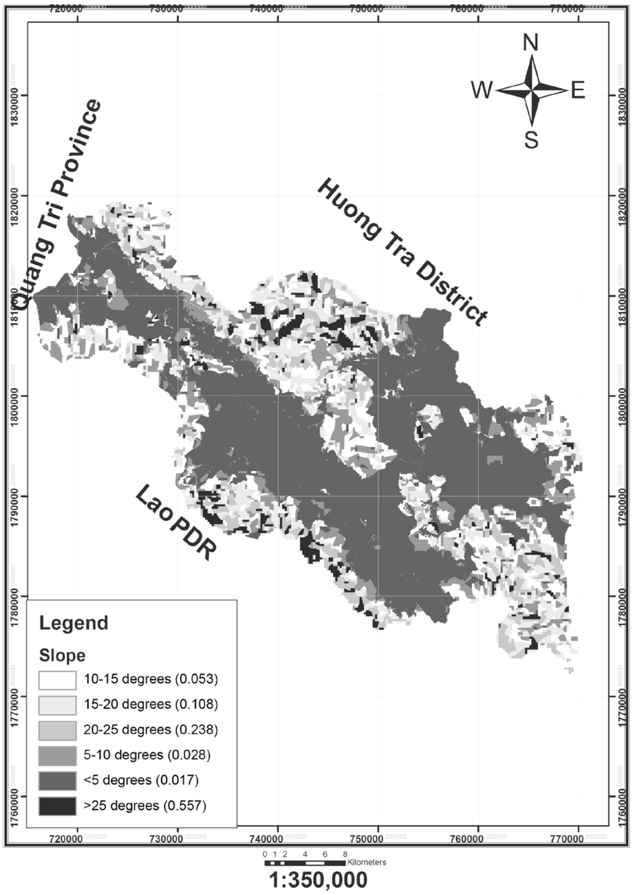


Table 8. Landslide risk levels by slope

Level	Slope (°)	Landslide Risk Level	Area(ha)	Percentage (%)
1	<5°	Very low	59,211.25	48.35
2	5°–15°	Low	33,188.11	27.10
3	15°–20°	Medium	15,340.03	12.53
4	20°–25°	High	9,929.43	8.11
5	>25°	Very high	4,794.78	3.92
		Total	122,463.60	100.00

Figure 4. Slope map of A Luoi District



River density

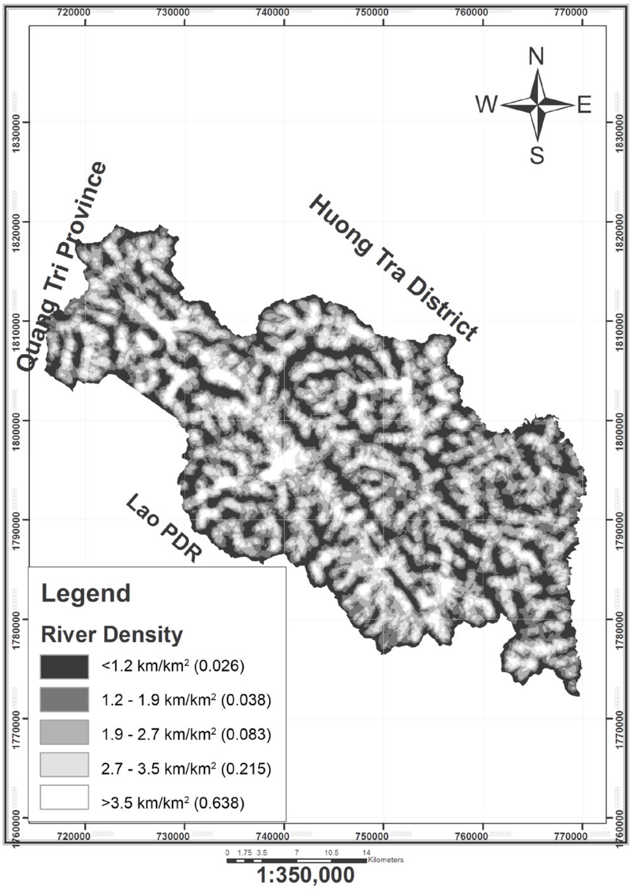
The survey results showed that the rivers occupied a large area in the region, which widely affected the riverbanks. The landslide risk rates were obtained based on the river density map (Figure 5). These are reported in Table 9.

As seen in the river density map (Figure 5), the highest risk of landslide appeared where river density was over 3.5 km/km^2, accounting for 17 percent of the total area of the district (20,505.94 ha). Similarly, the lowest risk of landslide appeared where river density was less than 1.2 km/km^2, accounting for about 15 percent (18,807.75 ha). The results also showed that landslide risk mainly appeared in the area where river density was from 2.7 to 3.5 km/km^2 (high level), accounting for about 28 percent (34,792.36 ha).

Table 9. Landslide risk levels by river density

Level	River density (km/km^2)	Landslide Risk Level	Area (ha)	Percentage (%)
1	<1.2	Very low	18,807.75	15.36
2	1.2–1.9	Low	26,398.43	21.56
3	1.9–2.7	Medium	21,959.12	17.93
4	2.7–3.5	High	34,792.36	28.41
5	>3.5	Very high	20,505.94	16.74
		Total	122,463.60	100.00

Figure 5. River density map of A Luoi District



Road density

Based on the survey results, landslides along the Ho Chi Minh Road happened mainly in September, October, and November every year. As can be seen from the road density map (Figure 6), Ho Chi Minh Road is the main road running through almost all communes. These roads were built on various geographical features, which defined different landslide risk levels. Table 10 shows that landslide risk rates fluctuated from 26 percent to 29 percent at very low (less than 1 km/km^2), medium (1.5–2.7 km/km^2), and high (2.7–4.1 km/km^2) levels, whereas only two percent of the road density had very high landslide risk level (more than 4.1 km/km^2).

Aspect

According to the aspect map in A Luoi district (Figure 7), the slope on the east had very high landslide risk, which accounted for 7 percent of the total area (Table 11). The northeast and southeast areas, on the other hand, had high landslide risk at 12 percent. A Roang commune at A Luoi district had the most frequent landslide occurences. The medium rate of landslide risk was 18 percent, mainly in the north area. Meanwhile, the low rate of landslide risk was 25 percent, distributed in the south, northwest, and southwest regions. The lowest landslide risk was concentrated in the west and accounted for 39 percent (47,341.20 ha).

Figure 6. Road density map of A Luoi District

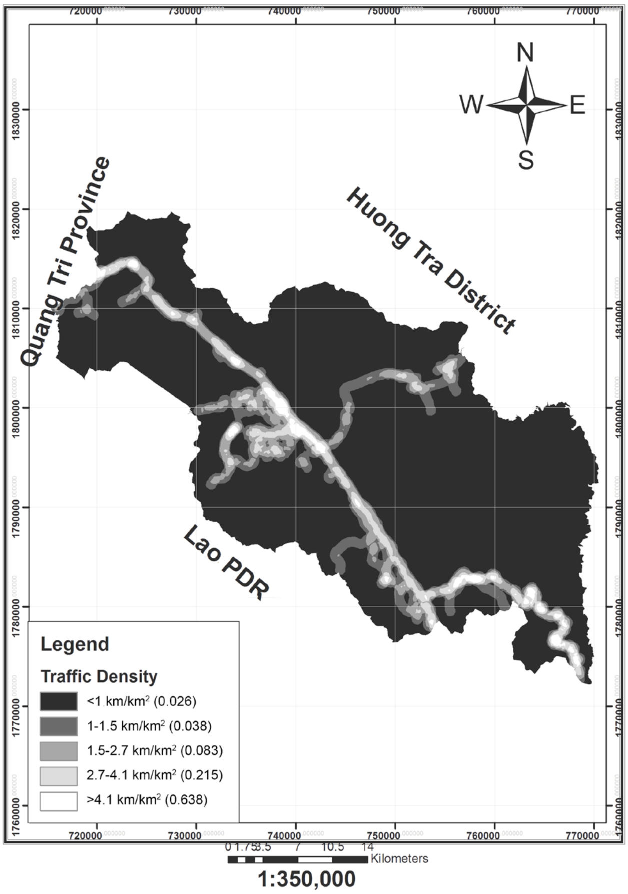


Table 10. Landslide risk levels by road density

Level	Road (km/ km^2)	Landslide Risk Level	Area (ha)	Percentage(%)
1	<1	Very low	34,352.84	28.05
2	1–1.5	Low	17,845.45	14.57
3	1.5–2.7	Medium	31,727.57	25.91
4	2.7–4.1	High	35,684.62	29.14
5	>4.1	Very high	2,853.12	2.33
		Total	122,463.60	100.00

Figure 7. Aspect map of A Luoi District

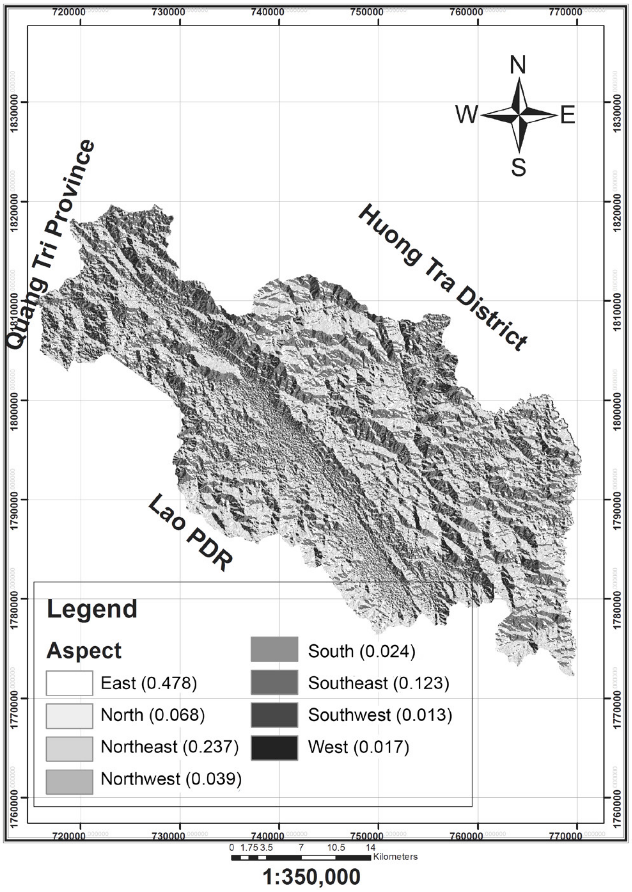


Table 11. Landslide risk levels by aspect

Level	Slope Direction	Landslide Risk Level	Area (ha)	Percentage (%)
1	West	Very low	47,341.20	38.66
2	South, Northwest, Southwest	Low	30,287.23	24.73
3	North	Medium	21,584.92	17.63
4	Northeast, Southeast	High	14,119.04	11.53
5	East	Very high	9,131.20	7.46
		Total	122,463.60	100.00

Land cover

As seen from the land use map (Figure 8), the dominant cover at A Luoi district was forest (88% of the total area) (Table 12). Because of their soil conservation capacity, the areas covered by forests had the lowest risk of landslide in the region. Conversely, areas with low plant cover and high rainfall had high landslide risk. Fortunately, the rates of landslide risk in A Luoi district from low to very high levels varied from 1 percent to 6 percent only and were mainly concentrated on special land cover, i.e., river and lake system, unused land, road, and aquaculture land.

Soil type

The analytical results showed that the yellow-red soil on metamorphic clay and yellow-red loam on metamorphic clay had high risk of landslides and accounted for 53 percent of the total area in A Luoi district (Table 13). The yellow-red soil on metamorphic clay was mainly concentrated in the southeast edge of the district. Soil depth in this type was about 1.5 m, while soil texture was from medium to heavy and porous on topsoil. Humus content was fair, total nitrogen was moderate, but other nutritive contents such as phosphorus and potassium were poor. Specifically, soil layers were very smooth and thin. The slope in this area was rather high, whereas, the humidity was low. Therefore, the landslide risk in this area was high.

The areas that contained yellow-red humus on acid igneous had high risk of landslides and affected 3,189.13 ha of land (3%), which was distributed mainly in the east. The lowest risk of landslide occurred in yellow-brown soil on ancient alluvial and was largely seen in the west (19,788.60 ha or 16% of the total area). The yellow-red soil on acid igneous had low landslide risk level and accounted for 15 percent of the total area of A Luoi district, which was distributed mainly in the northwest. The yellow-red soil on clay had medium landslide risk and was sparsely distributed in the northeast edge of the district, which accounted for 13 percent of the total district area. Figure 9 shows the soil map in A Luoi district.

Building a Landslide Hazard Map for A Luoi District

The landslide hazard map was built on the basis of a spatial analysis approach in ArcGIS 10.22 software. The thematic maps developed from the factors causing landslides were analyzed. The rates of landslide risk were classified into five levels: very high, high, medium, low, and very low. All thematic maps were then overlaid by using raster calculator algorithm (Spatial Analyst)

Figure 8. Land cover map of A Luoi District

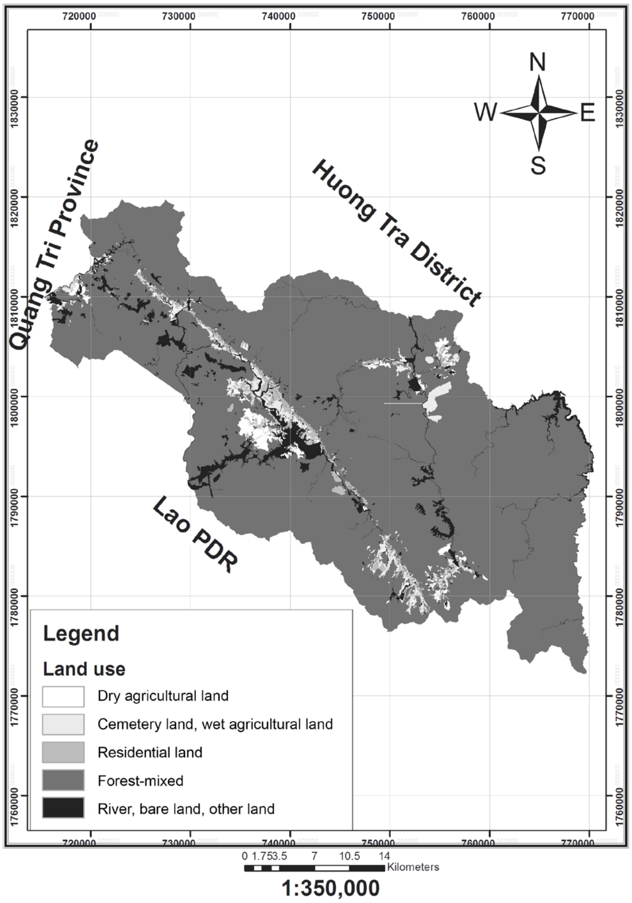


Table 12. Landslide risk levels by land cover

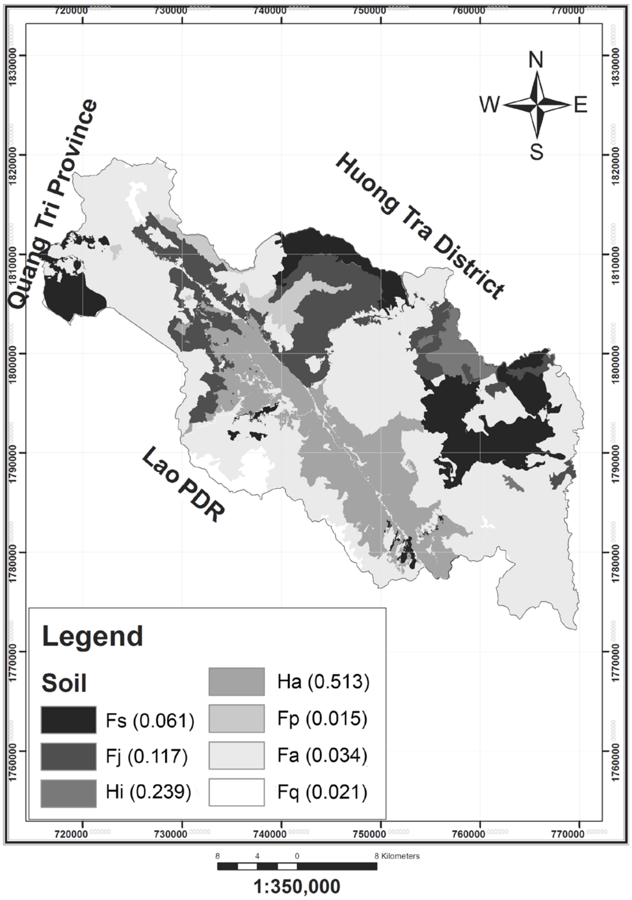
Level	Land cover	Landslide Risk Level	Area(ha)	Percentage(%)
1	L5	Very low	108,232.60	88.38
2	L4	Low	1,777.47	1.45
3	L3	Medium	2,289.37	1.87
4	L2	High	3,314.36	2.71
5	L1	Very high	6,849.80	5.59
		Total	122,463.60	100.00

Table 13. Landslide risk levels by soil type

Level	Soil type	Landslide Risk Level	Area (ha)	Percentage (%)
1	FRu-a, FRu	Very low	19,788.60	16.16
2	ACf-l	Low	18,608.32	15.19
3	FR1	Medium	15,623.29	12.76
4	FRac, FRa	High	65,254.26	53.28
5	FRf	Very high	3,189.13	2.60
		Total	122,463.60	100.00

Notes: FRu-a: Acrivi-Humic Ferralsols; FRu: Humic Ferralsols; Acf-l: Lixi-Ferralic Acrisols; FR1: Lixic Ferralsols; FRac: Acrivic Ferralsols; FRa: Arsenic Ferralsols; FRf: Fluvic Ferralsols

Figure 9. Soil map of A Luoi District



in ArcGIS to calculate the landslide hazard index using the following formula:

(2)

*Landslide hazard = Slope map*0.217 + Soil type map* 0.050 + Aspect map* 0.053 + River density map* 0.104 + Land cover map* 0.05 + Rainfall map* 0.417 + Road density map* 0.107*

Based on the overlaid map (Figure 10), the landslide hazard index was determined and was classified into five levels: very high (>9), high (7–9), medium (5–7), low (3–5), and very low (1–3). The hazard value is used to identify the severity of the potential effects of landslides and other natural disasters. The higher the hazard index, the higher the potential of landslide risk.

As can be seen from Table 14, the very high risk of landslide hazard had the lowest percentage (12% in area total) at an area of 14,231.35 ha with an index over nine. Conversely, the low risk of landslide hazard had the highest percentage (34% in total area) at an area of 41,036.2 ha with index from 3 to 5. The risk of landslide hazard occurred at high, medium, and very low levels at the rate of 22 percent, 18 percent, and 14 percent in area total, respectively. The high risk of landslide hazard occupied an area of 27,176.99 ha, with index from 7 to 9. The medium risk of landslide hazard had an area of 22,380.84 ha, with index from 5 to 7. The very low risk of landslide hazard was present in an area of 17,638.22 ha, with index from 1 to 3.

Figure 10. Landslide hazard map of A Luoi District

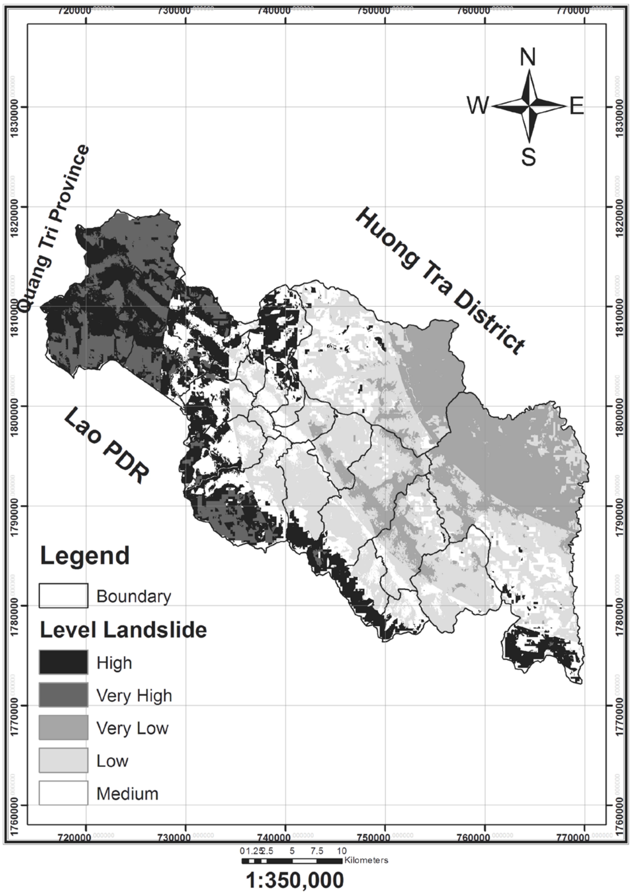


Table 14. Landslide hazard risk

Level	Area (ha)	Percentage (%)
Very high (>9)	14,231.35	11.62
High (7–9)	27,176.99	22.19
Medium (5–7)	22,380.84	18.28
Low (3–5)	41,036.20	33.51
Very low (1–3)	17,638.22	14.40
Total	**122,463.60**	**100.00**

The map in Figure 10 shows that the area of some communes (such as Hong Ha, Hong Thuong, Hong Phong, Hong Nguyen, and Hong Thai) had hazard indices from 1 to 5, where the land was covered by forest. Therefore, the risk of landslide ranged from low to very low rates. In contrast, other communes (such as Hong Thuy, Hong Trung, Hong Van, Hong Kim, Bac Son, Nham) had high hazard indices; therefore, landslides occurred frequently. Hong Thuy commune had a hazard index of 7 to 9. Other places had hazard indices over 9 (such as PeKe pass) where heavy rain occurred regularly during the rainy season.

The results indicated that among the factors, rainfall and slope were the most influential factors in landslides. A Luoi district is a mountainous area. If land cover is improperly distributed and soil is degraded because of over cultivation, the landslide hazard would increase.

CONCLUSION

The research applied GIS, remote sensing, and AHP techniques to build a landslide hazard map in A Luoi district (digital map). Calculated results showed that rainfall was the most influential factor in landslides (42%). Other factors were slope (21.7%), road density (11%), river density (10%), and aspect (5%). Land cover and soil type were the least influential factors (5%). The results also indicated that landslide hazard index could be divided into five levels: very low (1–3), low (3–5), medium (5–7), high (7–9), and very high (>9). Landslide hazards mainly occurred in low, high, and medium rates at 34 percent, 22 percent, and 18 percent, respectively. According to the research results, landslide hazard at high and very high risks will occur in some communes such as Hong Thuy, Hong Trung, Bac Kim, Hong Van, and Nham. On the other hand, the landslide hazard at medium risk will occur in Hong Ha, Hong Thuong, Hong Phong, Hong Nguyen, and Hong Thai communes, while landslide hazard at low and very low risk will occur in the remaining regions. Hence, conducting assessments and building landslide hazard maps are necessary for monitoring and preventing landslides in the future.

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