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APPLICATION OF THE AHP MODEL TO ESTABLISH A LANDSLIDE PROBABILITY ZONING MAP IN A LUOI DISTRICT, THUA THIEN - HUE PROVINCE, VIETNAM

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Abstract

A Luoi is a mountainous district of Thua Thien Hue province, Vietnam, with rugged terrain, steep slopes, and many valleys. A Luoi district bears many risks of natural disasters such as storms, floods, droughts, and landslides yearly. This study applied the AHP (Analytical Hierarchy Process) model with the GIS tool on the input database of Sentinel-2B Image, DEM, and geographic background data to evaluate the influence of 5 factors: slope, elevation, aspect, land cover, and vegetation to generate a landslide hazard zoning map, scale 1:50,000. The results show that the sites with a high risk of landslides are concentrated mainly in the communes of Hong Kim, Hong Ha, Son Thuy, Hong Thuong, Phu Vinh, and Huong Nguyen. Thereby helping people avoid and minimize vulnerabilities caused by landslides.

Keywords: Landslides; AHP; GIS; Vietnam; Sentinel.

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1. Introduction

Landslides are one of the most famous geological hazards [1]. Landslides often cause loss of life and property and severe damage to natural resources worldwide. Landslides occur due to biological factors or artificial activities. Natural activities include changes in climate, such as heavy rainfall, prolonged rainfall, complex terrain, etc. Human activities include changing land use purposes, cutting down forests for farming, changing slopes, and building infrastructure [2]. Landslide risk mapping is necessary to devise feasible prevention measures and evacuation plans to avoid loss of life and property. Furthermore, landslide hazard maps greatly help planners select suitable areas for economic development in any region [3, 4].

Scientists have been focused on landslide risk topics since the 1970s with many different levels and approaches [5]. Varnes, Guzzetti et al., [6, 7] have divided landslides into 5 levels. Landslide risk assessment methods are divided into 2 groups: Qualitative and quantitative or can be divided into 3 types: Heuristic, statistical, and deterministic. For the heuristic method, investigators rank and evaluate the weights of landslide-causing factors based on the assumption or importance of factors leading to landslides [3, 7, 8]. This is a qualitative method, which

is likely to lead to errors due to its reliance on the opinions of experts in determining the weight of factors causing landslides [4, 9, 10]. The deterministic method belongs to the quantitative method, based on calculating and analyzing the slope's stable or unstable conditions. This is a durable and highly accurate method [3, 10, 11]. The statistical method is a quantitative method based on the spatial distribution of factors causing landslides in the past to analyze and make predictions about the risk of landslides in the future [12]. Among landslide risk assessment methods, deterministic and statistical methods are highly effective and widely used in current research [3]. In particular, the deterministic method can only be applied to small areas because it is necessary to collect detailed information about the slope's topographic, geological, and hydrological characteristics [10, 13]. For large areas, statistical methods are the most common choice [12]. Some qualitative methods become semi-quantitative by combining rankings and weights [14, 15], as is the case with the analytic hierarchy process (AHP), a multi-criteria decision-making method that has been widely applied to solve deterministic problems [16].

This method is based on a hierarchical analysis system of related factors and comparisons between different pairs of factors to assign an appropriate ratio for each factor. Thereby, it is possible to estimate the weight of each considered factor through the linear correlation of each factor with other factors. The correlation among various factors has made this method valuable in establishing landslide hazard maps obtained by correlating and comparing many factors [17].

Therefore, the management of many correlated factors and estimates to determine the extent of landslides is carried out, in most cases, through geographic information systems (GIS) [15]. GIS uses data integration techniques, a highly suitable tool for landslide hazard mapping. Due to the increasing availability of high-resolution spatial data sets, GIS, remote sensing, and high-speed computing, landslide risk assessment and hazard mapping procedures can become partial automation and thus minimize fieldwork [18]. The reliability of these maps depends mainly on the methodology and available data used to estimate disaster risk. Furthermore, GIS is an excellent and valuable tool for mapping the susceptibility of an area at risk of landslides [18]. In Vietnam, landslides mainly occur during the rainy season in the Northern mountainous provinces and the Central-Central Highlands region [19]. Among them, A Luoi, Thua Thien Hue Province, in the Central region, is one of the districts that often suffer from many consequences caused by landslides, causing deaths and damage to plenty of property.

This study aims to establish a landslide risk map for A Luoi district through the AHP model in a GIS environment, based on 5 characteristic factors: slope, elevation, direction, land cover, and vegetation density. Finally, it is possible to zone sites at high risk of landslides and support people and local authorities to minimize vulnerabilities.

2. Study area and data

2.1. Study area

A Luoi is a mountainous district on the western border of Thua Thien Hue province, with an area of about 1,224.63 km^2. A Luoi's terrain is strongly divided, including two parts, East Truong Son and West Truong Son, with an average altitude

of 600 - 800 m above sea level and an average slope of 20 - 25° [20]. The Eastern part of Truong Son has rugged terrain and steep slopes, with high peaks such as Dong Ngai 1,774 m, Co Pung Peak 1,615 m, Re Lao 1,487 m, and Tam Voi 1,224 m [20].

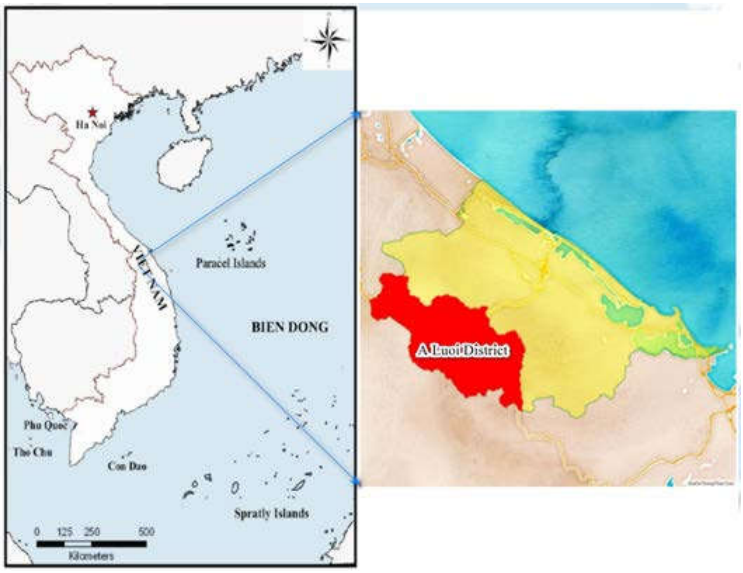


Figure 1: Study area location

In addition, the weathered crust in A Luoi is highly diverse in depth, structure, geomorphology, characteristics, and origin of chemical-mineralogical and geochemical components. The rainy season here lasts about 4 months, from September to December, with 70 - 80 % of the total rainfall in the year; the rainfall in each month ranges from 2,900 - 5,800 mm [20]. The hot and humid conditions of tropical climates strongly affect landslide-related materials, causing rapid weathering processes to take place, weakening and enormously damaging regolith coatings (Guzovski et al., 1989; An et al., 1990; Thai et al., 1991; Van et al., 1995; Van et al., 2001).

A Luoi also possesses ample resources and vegetation; the forest coverage rate in 2010 reached 75 %, with average reserves of 6 - 7 million m^3 [20]. However, in recent years, natural vegetation has also been rapidly changed by local people's deforestation activities or leaving land bare, so the risk of landslides is very high. Therefore, in this study, the authors chose 5 typical factors, including slope, elevation, aspect, land cover, and vegetation density, as input data to build the landslides model in the A Luoi district.

2.2. Data

A data set used in the project includes a Sentinel 2B satellite image (https://scihub.copernicus.eu/) and a Digital elevation model (DEM) with a resolution of 12.5 m (https://search.asf.alaska.edu/#/). The image was acquired on January 15th, 2023, at 10 m of spatial resolution; the ID of the image is S2B_MSIL1C_20230115T032059. Bands 2,3,4,8 of the image are employed to classify land cover and calculate the Normalized Difference Vegetation Index (NDVI). The slope and aspect maps generated by the DEM. Consequently, 5 factors consisting of slope, elevation, aspect, land cover, and NDVI density are ready to put in the landslide model.

3. Methods

3.1. The scheme of zoning landslides

All steps of data processing and model calculation are summarized in Figure 2

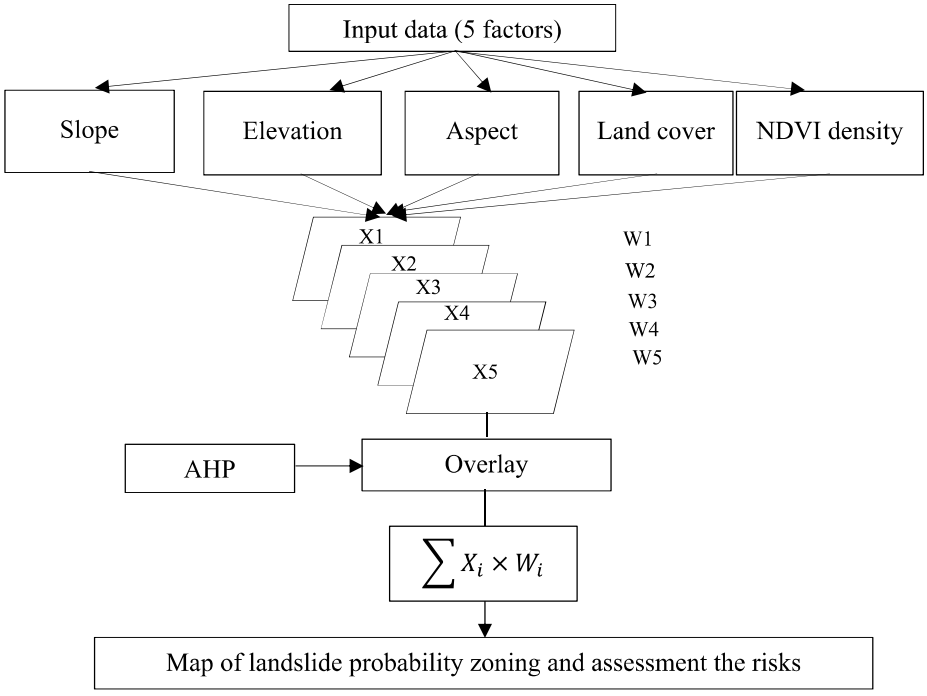


Figure 2: Flowchart of estimate landslide model

3.2. Identifying typical factors to put into the landslide model

Landslides occur due to the resistance of the soil or rock forming the slope against gravity, and landslides occur when gravity is imbalanced. This balance can be changed by both natural and man-made factors. The factors that influence slope stability are diverse and interact in complex and dangerous ways (Varnes, 1984). Besides man-made factors, natural factors affect landslides such as seismicity; soil strength, chemistry, and mineralogy; geology; geomorphology; and hydrology. Identifying the influence of each factor driving landslides or decentralizing the influence of each factor is based on the properties of the drivers.

Based on analyzing the mechanism of landslide formation and identifying the leading causes of landslides, based on analysis of specific characteristics of the study area, and based on previous publications, it is possible to determine qualitatively the main factors affecting the landslide process of the study area as follows: slope, elevation, aspect, geology, weathering crust and soil, geomorphology, fault density, river and stream density, land cover, vegetation density, rainfall and depth of cleavage. From there, we selected 5 typical factors leading to landslides in A Luoi district, Thua Thien Hue province, including slope, elevation, aspect, land cover, and vegetation density to analyze.

Table 1. Scores of priority to the factors (the higher the score, the higher level of priority)

Factors	Slope	Elevation	Aspect	Land cover	NDVI density
Level	1	2	2	3	3

Table 2. Correlated matrix

Factors	Slope	Elevation	Aspect	Land cover	NDVI density
Slope	1	2	2	3	3
Elevation	0.5	1	1	1.5	1.5
Aspect	0.5	1	1	1.5	1.5
Land cover	0.33	0.67	0.67	1	1
NDVI density	0.33	0.67	0.67	1	1
Sum	**2.67**	**5.33**	**5.33**	**8**	**8**

Table 3. Weight matrix of the factors

Factors	Slope	Elevation	Aspect	Land cover	NDVI density	Weight
Slope	0.38	0.38	0.38	0.38	0.38	0.38
Elevation	0.19	0.19	0.19	0.19	0.19	0.19
Aspect	0.19	0.19	0.19	0.19	0.19	0.19
Land cover	0.13	0.13	0.13	0.13	0.13	0.13
NDVI density	0.13	0.13	0.13	0.13	0.13	0.13

3.3. Generating thematic maps according to each element

The scale for assessing the risk of disasters and landslides, in particular, usually has at least 2 levels and at most 7 levels. The number of levels depends on the objectives, data adequatation, and scale of projects. The risk assessment scale is often expressed in increasing levels: Low, medium, and high for a 3-level scale; Shallow, low, medium, high, and very high for a 5-level scale. This project used the latter when producing the maps.

a. Establishing landslide risk maps due to the influence of slope, elevation, and aspect

DEM is essential data for landslide research and supports generating the slope, elevation range, and aspect maps with various tools in GIS.

There are many types of slopes, such as slopes in specific directions, North, South, East, West, and average slope... here we utilize the average slope, and the unit of measurement is degrees. Then, the slope map was thresholded based on the site's physical features. In each slope interval, landslides' weights are calculated according to the model's formulas based on referencing the landslide's existing map. Statistically, the higher the weight, the higher the likelihood of landslides to that factor.

The influence of elevation on landslides is often indirect relationships. Weathering factors play a crucial role in landslides and are closely related to the altitude of the terrain; for example, at high altitudes, more erosion occurs, resulting in less weathering depth. The statistics showed that altitude values in A Luoi district, Thua Thien - Hue province, vary from 22 m to 1,800 m. Terrain with elevation < 300 m accounts for 18.13 %, areas from 300 m - 900 m account for 70.09 %, and areas with elevation from 900 m - 1,200 m account for 8.88 %. Areas with altitudes above 1,200 m account for only 2.9 %. The elevation map, after being established, is statistically divided into 5 classes corresponding to the level of its impact on different landslide risks.

Table 4. The levels of landslide risks according to elevation

Levels	Elevation (m)	Scale of landslide risks	Areas (ha)	Percentage (%)
1	22 - 300	Very low	22,237.26	18.13
2	300 - 600	Low	44,046.02	35.92
3	600 - 900	Medium	41,894.45	34.17
4	900 - 1,200	High	10,883.92	8.88
5	1,200 - 1,800	Very high	3,559.96	2.90

The slop direction indirectly impacts the landslide process through the relationship between terrain and climate. Slopes facing the wind have moisture and vegetation cover that differs from slopes without wind, leading to different slope stability levels. The study area has aspects from the Northeast to the Southeast, accounting for 45.6 %, the South, accounting for 20.78 %, and the direction from the West to the Northwest, accounting for 33.61 %. The aspect map is divided into 5 ranges corresponding to the level of its impact on different landslide risks.

Table 5. The levels of landslide risks according to the aspect

Levels	Aspect	Scale of landslide risks	Areas (ha)	Percentage (%)
1	North East	Very low	27,630.86	22.56
2	South East	Low	28,218.51	23.04
3	South	Medium	25,447.67	20.78
4	West	High	20,724.33	16.92
5	North	Very high	20,436.81	16.69

Slope statistics in A Luoi district, Thua Thien - Hue province, show slope values vary from 0 - 75^o. Areas with a slope <18^o accounts for 43.78 %, areas from 18 - 25^o accounts for 23.54 %, and areas above 25^o account for 32.68 %. The slope retrieved map is divided into 5 threshes corresponding to the level of its impact on different landslide risks.

Table 6. The levels of landslide risks according to slope

Levels	Slope (^{o})	Scale of landslide risks	Areas (ha)	Percentage (%)
1	< 3^o	Very low	6,088.33	4.97
2	3 - 8^o	Low	12,077.87	9.85
3	8 - 18^o	Medium	35,502.18	28.96
4	18 - 25^o	High	28,858.75	23.54
5	>25^o	Very high	40,061.8	32.68

b. Establishing landslide risk maps due to vegetation density

Studying landslides, the vegetation cover plays a very important role, it is closely related to the stability of slopes. For areas covered with dense vegetation, large coverage, and developed root systems, the probability of landslides is low and vice versa. Thus, establishing a vegetation map is critical to landslide research. In this study, vegetation was evaluated through NDVI density maps; NDVI is calculated based on the red band and near-infrared band of the Sentinel 2B satellite image as shown below.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

Different NDVI values reflect different plant quality in each pixel. The NDVI index in the area interested varies from - 0.22 to 0.62. It is thresholded into 5 levels corresponding to the landslide risk levels, in which areas with little or no vegetation have a high likelihood of landslides and vice versa.

Table 7. The levels of landslide risks according to NDVI density

Levels	NDVI	The scale of landslide risks	Areas (ha)	Percentage (%)
1	0.42 - 0.62	Very low	31106.43	25.30
2	0.34 - 0.42	Low	46258.13	37.63
3	0.24 - 0.34	Medium	30006.18	24.41
4	0.09 - 0.24	High	13146.83	10.69
5	(-0.22) - 0.09	Very high	2421.64	1.97

c. Establishing landslide risk maps due to land cover

Sentinel images are used for land cover classification. There are two main classification methods: supervised classification and unsupervised classification. The authors used a supervised classification method in the study and performed classification with types, including Forests, Bare soils, Water bodies, Impervious surfaces, and Agricultures.

In the study area, forest and agricultural areas dominate 54.66 %. Bare soil and impervious surfaces, especially traffic systems, mainly cause landslides, accounting for up to 33.42 %. Recently, natural vegetation has been drastically altered by human activities such as agriculture and timber production; local people clear forests and leave bare soil, so the risk of landslides is very high. Levels of landslide risks corresponding to land cover classes are presented in Table 8.

Table 8. The levels of landslide risks according to land cover

Levels	Land cover classes	Scale of landslide risks	Areas (ha)	Percentage (%)
1	Water bodies	Very low	14,656.85	11.91
2	Forests	Low	31,789.87	25.84
3	Agricultures	Medium	35,462.9	28.82
4	Impervious surfaces	High	28,511.12	23.17
5	Bare soils	Very high	12,609.15	10.25

3.4. Establish a landslide probability zoning map

Many factors affect the landslide process; however, their roles are not similar. Therefore, determining the weight of each driver is very necessary. This study determines the weights by comparing the correlation among influencing factors. Intermediate maps and weight value maps showing the relationship between the landslide process and each factor are integrated into GIS to produce a landslide risk zoning map for the study area. The probability of landslide is calculated in the GIS system for an area based on the following Van Westen formula:

$$LSI = \sum_{j=1}^{n} X_{ij} W_j \qquad (2)$$

where: LSI: Landslide risk index;

Wj: Weight of the factor j;

Xij: is the score of class i in the factor j;

n: Number of agents causing landslides in the study area.

After considering and evaluating the level of landslide risk, we classify the level of landslide risk from low level to hazardous level (determine the level of no landslide risk, low risk, high risk... corresponds to value ranges), then group the values in the same range together. Then, all sites on the map in a range face the same landslide risk level.

The above formula adapted for A Luoi district to result in the below equation:

$$LSI = 0.38\times A + 0.19\times B + 0.19\times C + 0.13\times D + 0.13\times E \quad (3)$$

where: A is slope, B is elevation, C is aspect, D is land cover, and E is NDVI density.

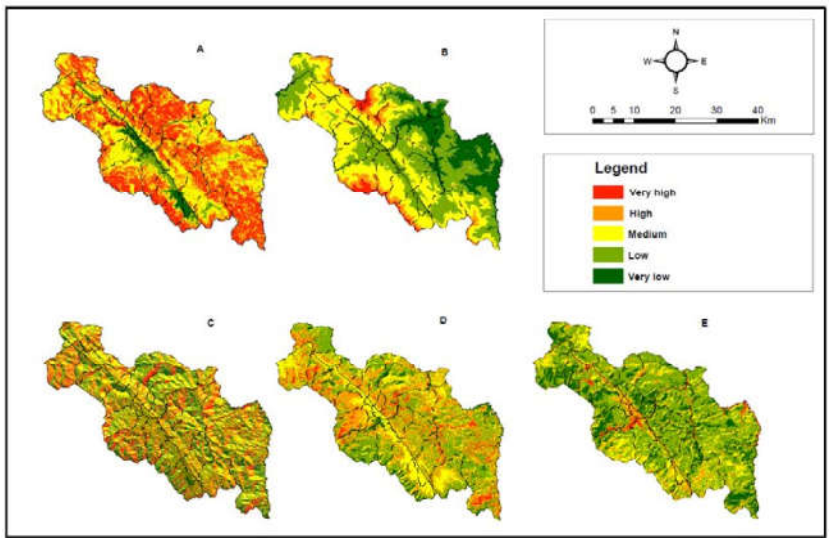
The result is a map of landslide probability with different values on each pixel, then the map is reclassified as 5 corresponding risk levels consisting of very low, low, medium, high, and very high. The thresholds are selected based on statistical value resulting in a cumulative probability curve with the following parameters: $LSI_{min} = 1.15$; $LSI_{max} = 4.84$

The intervals are calculated according to the below formula:

$$\Delta_{TL\text{Đ}} = \frac{\text{LSImax - LSImin}}{n} = \frac{4.84 - 1.15}{5} = 0.74$$

4. Results and discussions

The products of the project are 5 landslide risk maps due to the separate factors and a map due to integrating all drivers in the A Luoi district, as shown in Figures 3 and 4.



A: Landslide risk map due to slope; B: Landslide risk map due to elevation; C: Landslide risk map due to aspect; D: Landslide risk map due to land cover; E: Landslide risk map due to NDVI density

Figure 3: Landslide risk maps due to each factor in A Luoi district

As shown in Figure 4, the landslide probability zoning map in A Luoi district, Thua Thien - Hue province, Vietnam, includes 5 levels of landslide risk: Deficient in dark green, low in light green, medium in yellow, high in orange, and very high in red.

Statistical results in Table 9 show that areas with meager landslide risk account for 19.86 % (corresponding to 24,297.5 ha) of the entire district area, and low landslide risk accounts for 19.86 % (corresponding to 24,297.5 ha) of the entire district. 2.15 % (equivalent to 2,635.11 ha), the medium risk of landslides accounts for 46.55% (equivalent to 56,954.02 ha), the high risk of landslides is 30.02%

(36,726.14 ha), the exceptionally high is about 1.41%, accounting for 1,724.37 ha).

The results of landslide risk zoning in the district A Luoi show that the communes identified as having a very high risk of landslides are Hong Thai, with an area of 495.91 ha, followed by Hong Kim, accounts for 243.93 ha, Hong Trung 197.61 ha, Dong Son 129.31 ha, Hong Thuong 100.69 ha, etc.

Areas with high risk of landslides concentrated in several communes, mostly in Huong Nguyen (4,869.4 ha), Hong Ha (4,130.97 ha), Hong Trung (2,871.23 ha), Hong Kim (2,043.71 ha), A Roang 1,625.71 ha, followed by A Luoi, Dong Son, Hong Bac, Hong Thuy, Hong Thai, Hong Thuong, Hong Van, Phu Vinh, Hong Lam,...

+ Landslide risk at medium level distributed in 3 communes, including Huong Nguyen commune accounts for 8,748.33 ha, Hong Ha commune accounts for 7,018 ha, and Hong Thuy commune accounts for 6,164.07 ha. In addition, there are several communes with large areas of moderate risk of landslides, such as A Roang, Hong Thai, Hong Trung, Hong Van, Huong Lam, Huong Phong, and Nham.

+ Communes with low risk of landslides are Huong Nguyen, Dong Son, and Huong Lam, and shallow risk such as Huong Nguyen, Hong Ha, Huong Phong, and Huong Lam. The project's products are 5 landslide risk maps due to the separate factors and a map for integrating all drivers in A Luoi district, as shown in Figure 3 and Figure 4.

Table 9. Areas according to levels of landslide risks in A Luoi district

Levels	Scale of landslide risks	Point distance	Area (ha)	Percentage (%)
1	Very low	1.15 - 1.89	2,4297.5	19.86
2	Low	1.89 - 2.63	2,635.11	2.15
3	Medium	2.63 - 3.36	56,954.02	46.55
4	High	3.36 - 4.10	36,726.14	30.02
5	Very high	4.10 - 4.84	1,724.37	1.41
			122,337.14	100

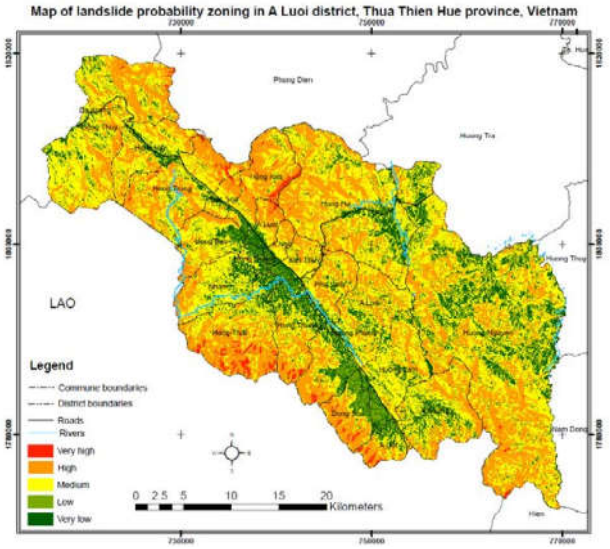


Figure 4: Map of landslide probability zoning in A Luoi district

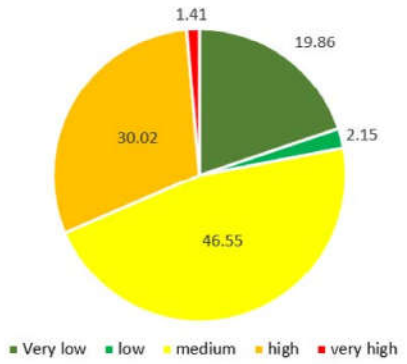


Figure 5: Percentage of area by levels of landslide risks

Table 10. Area of landslide risk zones by commune in A Luoi district

Commune	Area of landslide risk zones (ha)				
	Very low	Low	Medium	High	Very high
A Dot	444.67	53.93	583.19	499.29	99.00
A Luoi	285.64	52.40	435.40	546.77	51.31
A Ngo	196.09	45.82	359.08	292.87	3.74
A Roang	1179.79	93.06	2703.19	1625.71	9.29
Bac Son	128.67	9.72	462.63	466.16	39.27
Dong Son	591.17	281.13	677.80	1023.18	129.31
Hong Bac	607.88	68.39	1515.64	927.54	4.38
Hong Ha	2493.48	178.38	7018.96	4130.97	68.98
Hong Kim	378.06	40.81	1474.24	2043.71	243.93
Hong Quang	302.33	71.13	194.39	34.26	0.24
Hong Thuy	1385.32	49.45	6164.07	4082.45	93.67
Hong Thai	872.18	77.63	2526.11	2911.42	495.91
Hong Thuong	1171.12	209.31	1521.05	1043.76	100.69
Hong Trung	656.55	24.52	2846.44	2871.23	197.61
Hong Van	606.46	36.99	2020.92	1371.19	54.92
Huong Lam	1405.05	272.96	2501.03	924.40	1.00
Huong Nguyen	3839.21	327.51	8748.33	4869.40	93.73
Huong Phong	1861.32	256.27	3664.91	2290.07	69.81
Nham	829.11	40.63	2125.43	815.75	3.41
Phu Vinh	535.46	34.81	1330.52	900.87	1.36
Son Thuy	410.92	101.36	773.55	446.76	1.33

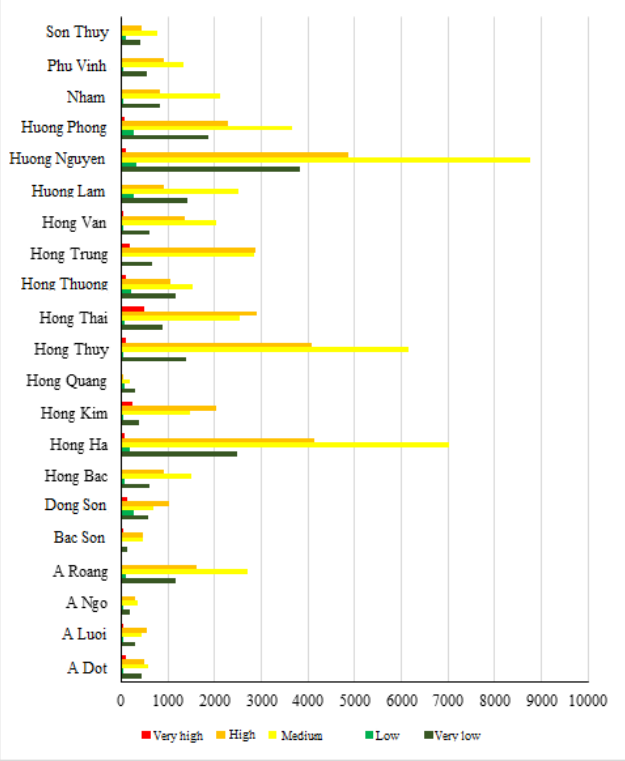


Figure 6: Area chart of landslide risk zones by commune in A Luoi district

According to the landslide risk map (Figure 4), sites with a very high risk of landslides are distributed to the East of the Truong Son range, where the terrain is rugged, has steep slopes, high mountain peaks, and the upstream area of three large rivers consists of Da Krong river, Bo River and Ta Trach river, specifically in Hong Thai, Hong Thuong, Dong Son and A Dot communes. This result is entirely consistent with the practical situation mentioned below.

Historical documents indicated that landslides at many mountainous rivers and stream sites in A Luoi district became more severe after annual rainstorm seasons, threatening people's lives and damaging property. Landslide risk points occurred along Highway 49A, passing through Hong Ha, Phu Vinh, and Hong Thuy communes; A Co pass area, along Ho Chi Minh road through communes Hong Thuy, Hong Van, Trung Son, Hong Kim, A Ngo, Quang Nham, Son Thuy, A Luoi town, Phu Vinh, Huong Phong, Dong Son, Lam Dot, A Roang; On the banks of A Sap and Bo rivers. In addition, there are very high-risk points for landslides on the sides of the Ho Chi Minh road, the segment through the Peke Pass area (Hong Thuy commune), Hong Kim commune, A Roang commune, and border Quang Nam province; Landslide area behind Bot Do market (Phu Vinh commune), critical points on A Co Pass,...

In recent years, landslides have been increasing, and the consequences to people, property, and the environment are serious as some following events:

- On September 19, 2013, heavy rains in A Luoi district caused landslides at several sites:

+ Ho Chi Minh road: 8 points were eroded, with a volume of soil and rock of about 1,000 m^3.

+ National Highway 49A from Hong Ha commune to Bot Do intersection: Landslides at 03 points are at Km 67 + 700, Km73 + 100, and Km75 + 150, causing traffic jams long time, with a volume of soil and rock of estimated 1,500 m^3.

+ 03 bridges in Dong Son commune (Khe Chai bridge, Khe Triet bridge, Ti Nghieu bridge) collapsed.

+ Underwater dam from village 4 to village 6 in Hong Thuy commune was swept away.

- On October 28th, 2021, due to prolonged heavy rain, more landslides occurred on the sides of Ho Chi Minh road. Preliminary statistics showed approximately 80 landslide locations, with soil and rocks spilling onto the road surface, causing traffic jams, including many locations that have collapsed 4 - 5 times.

- On October 10th, 2022, landslides happened at Km75 + 150 on National Highway 49, hundreds of cubic meters of soil and rock flowed from the slopes, covering most of the road surface. Many roads were flooded in the mountainous communes of Dong Son, Hong Thuy, and A Roang, and some villages in Hong Thuong and Hong Quang communes, and water swept soil and rocks onto the road surface.

- In September 2023, A Luoi district currently has 18 landslide risk points in mountains, rivers, and streams, with hundreds of households affected. Among them, the 4 most critical and dangerous sites include the Bot Do market area, A Luoi hydropower resettlement area, Tru Phi village, Hong Thuy commune, and behind the People's Committee headquarters of Quang Nham commune,

affecting the lives of 200 households. Notably, many deep and wide cracks appeared and stretched hundreds of meters on the high mountain, affecting 105 households living in Tru Phi village, Hong Thuy commune, two years ago.

The results also indicated that landslides in A Luoi district caused tremendous consequences in every aspect of life, such as loss of farmland, damage to transportation systems, schools, hospitals, communication systems, and many other facilities, particularly many deaths. The map of zoning landslide probabilities supports local authorities and people to minimize vunarabilities. We recommend some solutions, such as enhancing local people's education on landslide awareness, such as recognizing the signatures before a landslide occurs, prevention measures, evacuation, and possibly building an early warning system in sites with high risk of landslides. Besides, it is necessary to actively green up bare land and reduce human activities that probably cause landslides.

5. Conclusions

This study has established a map of zoning landslide probabilities in A Luoi district, Thua Thien - Hue province, Vietnam, due to the influence of 5 typical factors, including slope, elevation, aspect, land cover, and NDVI density, based on the application of the AHP model and integrating GIS-remote sensing technology.

The landslide risk map classified according to the natural fault method consists of 5 risk levels: deficient, low, medium, high, and very high, corresponding to an area of 19.86 %, 2.15 %, 46.55 %, 30.02 %, and 1.41 % of the total area of A Luoi district. High and very high-risk areas are distributed along Highway 49A, rugged terrain, bare land, and spare vegetation cover areas.

The landslide risk zoning map is a valuable tool for the authorities to provide measures guiding people in responding and minimizing damage when landslides occur in A Luoi district. Furthermore, the research results are also an essential reference in land use planning and environmental resource management, aiming for sustainable development and reducing the risk of landslides in the locality.

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