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Landslides Study in Bac Can Province, Vietnam by Analytic Hierarchy Process Method

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Abstract

In recent years, landslides in mountainous provinces have been increasing. Whenever the rainy season comes, landslides occur, causing casualties to people and the infrastructure. Bac Can, which has suffered significant damage from landslides, is a mountainous province in the north of Vietnam. This study introduces the applying the analytic hierarchy process (AHP) to study landslides in Bac Can province, Vietnam. Currently, the earth's temperature is rising, and natural and anthropogenic hazards in the mountain are causing hazards. Integrate elements of the DEM model with component maps and different precipitation scenarios as the basis for the author to issue landslide warnings under the climate change scenario with maximum day rain rainfall for 2025 and 2050.

Keywords: APH, Bac Can, Landslide, Landslide hazard index, Vietnam.

1. Introduction

Landslides in the mountainous provinces of Vietnam are increasing. Whenever the rainy season comes, landslides occur, causing casualties to people and the infrastructure. The mountainous province in the north of Vietnam, with an area of 4,859 km² has suffered significant damage from landslides. One of the factors that directly causes landslides is rainfall. The rainfall from 2014 to 2019 is shown in Figure 1. The higher the rainfall, the stronger the landslide. The Bac Can lies between $20^0$39' – $22^0$02' N and $103^0$11' – $105^0$02' E (Figure 2). Landslides cause significant economic losses for Bac Can province. Particularly in 2021, Bac Can province suffered damage from rain disasters up to 20 billion [1]. Therefore, studying landslides to serve sustainable development is crucial.

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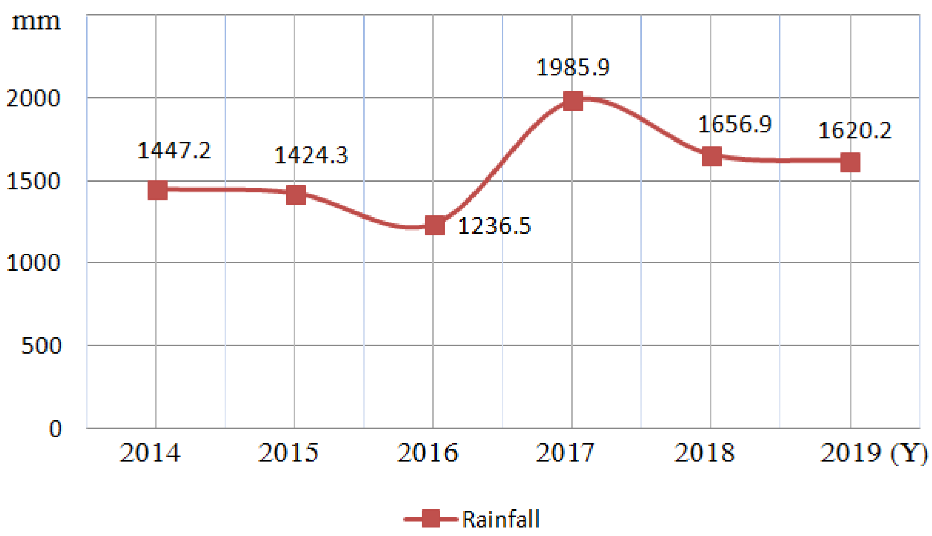

Figure 1. Rainfall evolution of Bac Kan province from 214 to 2019 [2]

Table 1: Landslide statistics of Bac Can province from 2014 to 2019

District	Landslides					
	2014	**2015**	**2016**	**2017**	**2018**	**2019**
Babe	139	121	112	154	151	142
Bachthong, Baccan town	146	156	116	153	132	116
Chodon	86	65	86	86	97	96
Chomoi	88	73	88	69	91	98
Nari	88	90	71	89	86	93
Nganson	91	87	91	91	103	91
Pacnam	62	73	59	78	72	79
Total	**700**	**665**	**623**	**720**	**732**	**715**

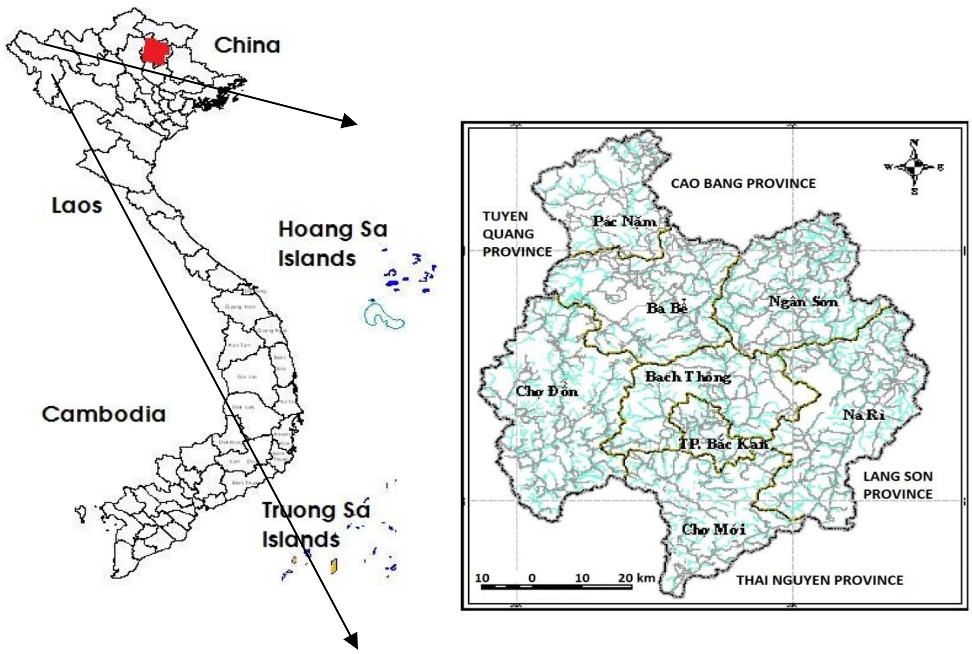

Figure. 1: Map of Bac Can province

2. Materials and methods

2.1. Materials

Data sources for the article include:

- The geological, geomorphological, and hydrogeological documents collected from the Center for Information and Archives of Geology (DGMV) [1, 3-7].
- Research projects on landslides related to Bac Can province [7, 8].
- Documents on hydrometeorology [9].
- Documents on vegetation [10].
- Documents on the current status of landslides [1, 7, 11].
- Research papers of the author from 2011 to the present. Landslides often appear along the traffic road or faults (Plates 1 and 2).

Picture 1. Landslide knocks down People's Wall (E: 589907; N:2458742)

Picture 2. A landslide along the traffic road (E: 584394; N: 2471881)

2.2. Methods

Currently, there are many methods to study landslide risk, some typical research works are [7, 11-28]. Most of these studies radically utilize the role of GIS in data integration. One of the most important data is the DEM. In this paper, we choose the analytic hierarchy process (AHP) to study landslides in Bac Can province. Thomas Saaty developed this analytical method at the Wharton School of Business in the late 1970s. It is a complex, unstructured and multivariable decision aid tool. It provides a flexible, easy-to-use method for analyzing complex problems and allows ideas to be expressed and problem-solving based on hypotheses. Thus, this tool has the potential to structure complexity and implement decisions.

The AHP method was built on three principles: Dissociation, comparative evaluation, and prioritization synthesis [29]. When comparing two values (between classes or parameters within a class), numerical relative ratios are applied as described in Table 2. The difference between the AHP method is the comprehensive integration of the data in the DEM model with the Landslide inventory map. Therefore, the research results will be objective and scientific.

Table 2: Scale of preference between two parameters in AHP

Preference factor	Degree of preference	Explanation
1	Equally	Two criteria result equally in the objective
3	Moderately	Experience and judgment partly favor one criterion over another
5	Strongly	Experience and judgment importantly favor a

7	Very strongly	**factor over another** **A criterion is highly favored over another, and its dominance is shown in practice**
9	Extremely	**The strongest form of an affirmation is when there is evidence that one quality is preferred over another.**
2,4,6,8	Intermediate	**Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9**
Reciprocals	Opposites	**Used for inverse comparison**

In Equation (1), random index (RI) in Table 3 was developed by Saaty (1980). To accept the computed weights, the consistency ratio (CR) must be lower than 0.1; otherwise, the pair comparison matrix must be recalculated. The consistency ratio (CR) is defined as the ratio of the consistency index (CI) and the random consistency index (RI).

$$CI = \frac{\lambda_{Max} - n}{n - 1} \tag{1}$$

Table 3: Random Consistency Index (RI).

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	**1.49**

Saaty (1977) gave the following consistency ratio - CR used as a comparison between CI and RI:

$$CR = \frac{CI}{RI} \tag{2}$$

According to Saaty (1977), if the value of CR O10%, then the inconsistency is acceptable, but if the CR value is > 10%, then the subjective judgment needs to be reconsidered [23].

The application for analytic hierarchy process method for landslide hazards has been successfully applied in many countries, including Vietnam [7, 12, 13, 18, 26, 30]. The landslide hazard map calculated in the GIS for the area is on the formula of Voogd (1983) [31], as follows:

$$LSI = \sum_{j=1}^{n} W_j w_{ij} \tag{3}$$

Where:
- LSI: Landslide susceptibility index.
- W_j: Weight value of parameter j
- w_{ij}: Rating value or weight value of class i in parameter j
- n number of parameters.

The Wij values are the eigenvalues of the matrix that depicts the relationship between all classes in a factor, and the Wj values are produced as the eigenvalues of the pairwise comparisons matrix that displays the relationship between several factors.

Accordingly, the input parameters for us to study landslides in Bac Can province include

09 factors (j=9): Slope; Lithology; Rainfall distribution; Vegetation cover; Fault density; River density; Deep cleavage density; Aspect; Distance to roads.

The input parameters are processed and displayed as raster maps in GIS with a resolution of 30 x 30m for the 01-pixel image map of landslide hazard zoning in Bac Can province based on different LSI values. The process is illustrated in Figure 3.

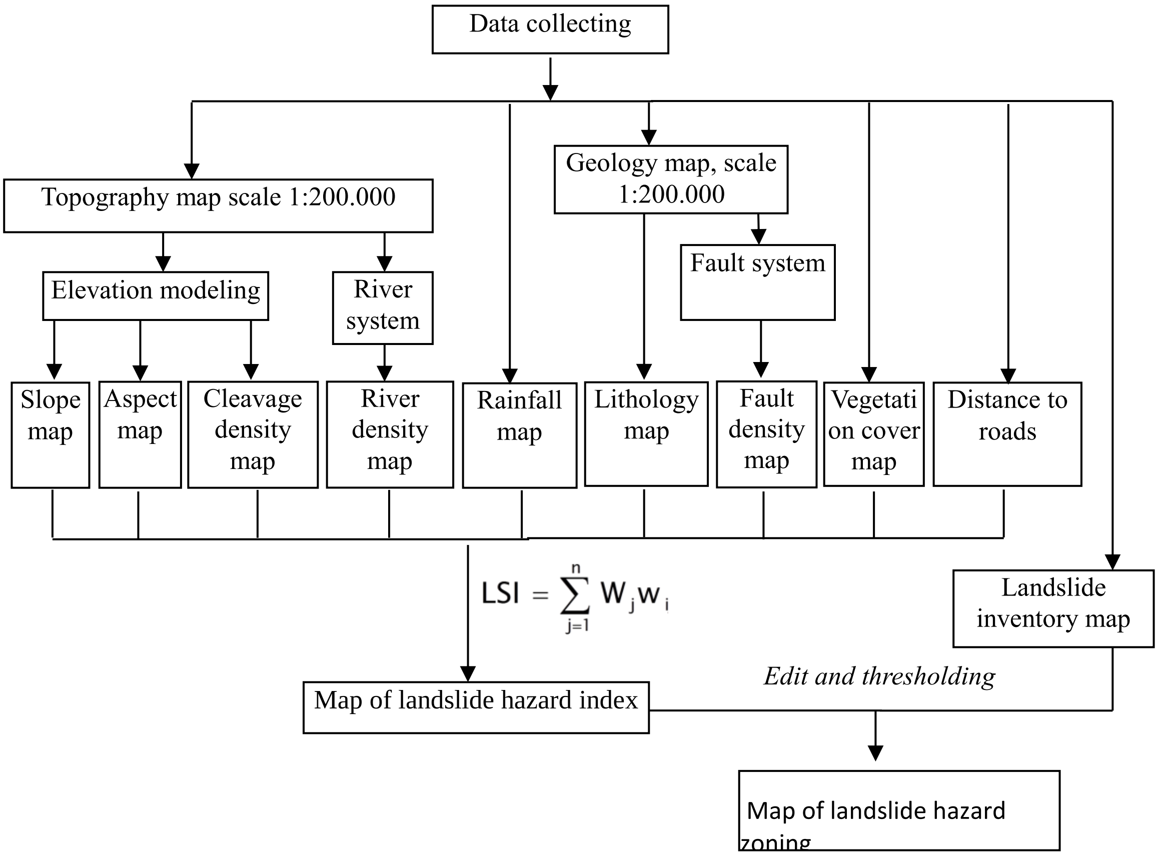

Figure 3: The collecting and processing data to establish a Map of landslide hazard zoning.

Map of landslide risk in Bac Can and component maps built at 1:200,000 scale. The Landslide inventory map was built at 1:50,000 scale, then converted to 1:200,000 scale.

3. Results

3.1. Digital Elevation Model (DEM)

The Digital Elevation Model (DEM- Figure 4) of Bac Can province was freely downloaded from NASA with a resolution of 30mx30m [32].

3.2. Map of slope

The slope map of Bac Can province was created from DEM with a resolution of 30mx30m based on using the SLOPE module available in ArcGIS 10.0 software (ArcGIS User's guide, 2015) (Figure 5).

3.3. Aspect map

Map of aspect of the study area was created from DEM with a resolution of 30mx30m based on using the aspect module available in ArcGIS 10.0 software (ArcGIS User’s guide, 2015) (Figure 6).

3.4. Map of river density

A map of river density was created from ArcGIS 10.0 software. The river density map of Bac Can province has been resolution of 30x30m. (Figure 7)

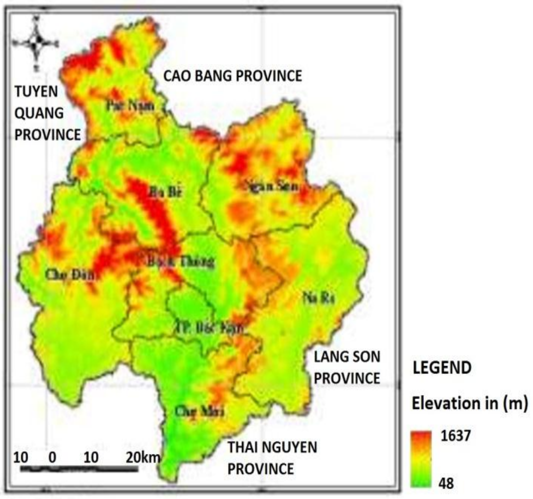

Figure 4: DEM of Bac Can province

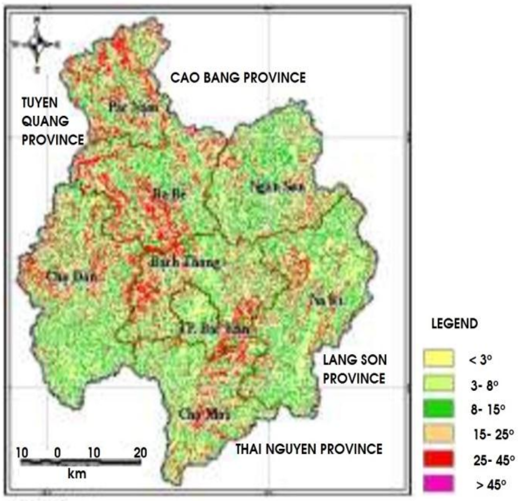

Figure 5: Slope map of Bac Can province

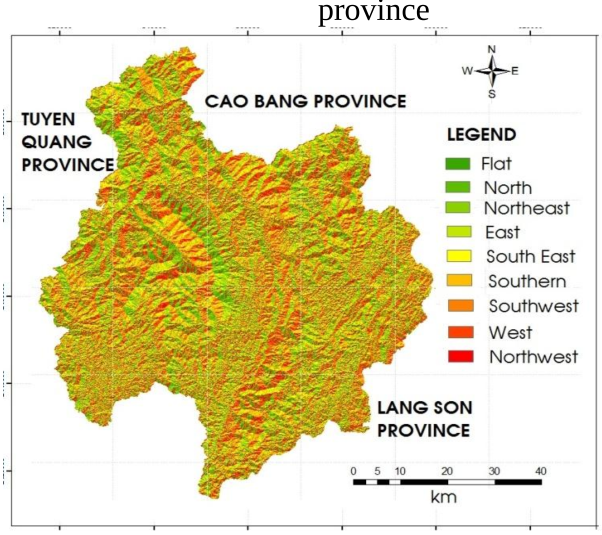

Figure 6: Aspect map of Bac Can province

3.5. Deep cleavage density map

The deep clearance density map of Bac Can province has been resolution of 30x30m. Deep cleavage density map built from DEM and combination of Shuttle Radar Topography Mission (SRTM). (Figure 7)

3.6. Vegetation cover map

The vegetation cover map of Bac Can province was collected from the Vietnam National Institute of Agricultural Planning [10]. The map is built as a shapefile from ArcGIS software (Figure 8).

3.7. Fault density map

The fault density is defined as the total length of faults over an area (usually 1 km^2). The fault density is built from the 1:200,000 scale geological map, combined with satellite image analysis. (Figure 9).

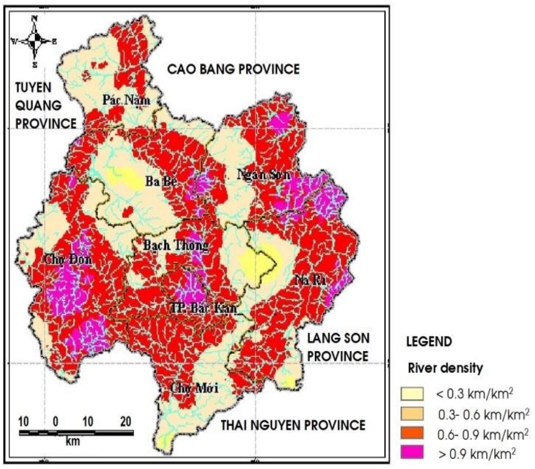

Figure 7: River density map of Bac Can province

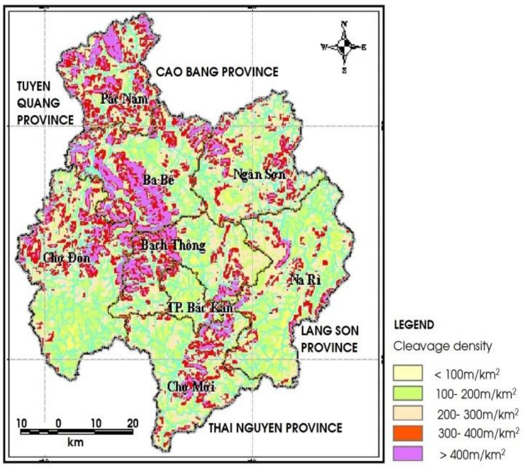

Figure 8: Deep cleavage density map of Bac Can province

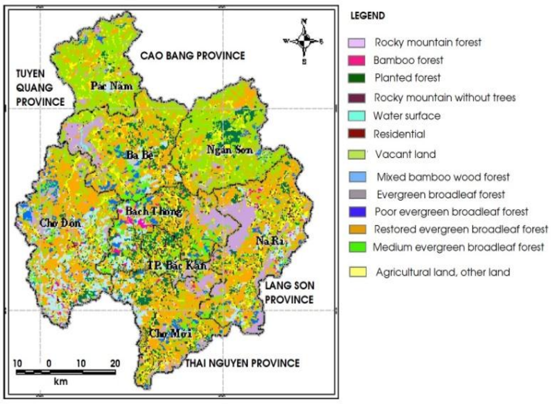

Figure 9: Vegetation cover map of Bac Can province

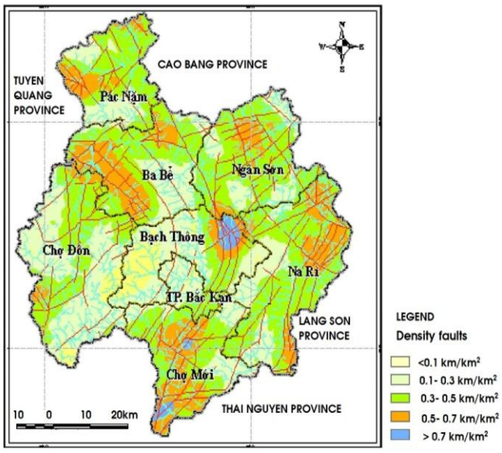

Figure 10: Fault density map of Bac Can province

The results of geological research in Bac Can province have been determined. There are 17 stratigraphic and six magma Complex formations with diverse petrology compositions. According to the degree and natural weathered, The rocks in Bac Can province have six petrology groups: Quaternary sedimentary group; Group of metamorphic rocks and terrigenous deposit; Group of terrigenous deposit and metamorphic rock, limestone-rich in alumosilicate; Carbonate rock; Group of extrusive acid-intermediate rocks; Group of intrusive mafic rocks [3, 6, 8, 11].

- *Quaternary sedimentary group* (Q): including silt, clay, sand, gravel, etc.,
- *Group of metamorphic rocks and terrigenous deposits:* shale, claystone, siltstone, sandstone, grit, conglomerates etc. This rock group includes the following formations: Mo Dong formation, Than Sa formation, Song Hien formation, Phu Ngu formation, Song Cau formation, Khao Loc formation, Ha Coi formation, Van Lang formation, Tam Hoa Formation.
- Carbonate rock group: including limestone, dolomite, marble of Bac Son formation, and Dong Dang formation.
- *Group of terrigenous deposit and metamorphic rock, limestone-rich in alumosilicate* including shale, claystone, siltstone, sandstone, grit, conglomerates etc. This rock group includes the following formations: Tong Ba, Pia Phuong, Mia Le, Na Quan, and Tam Hoa formations.

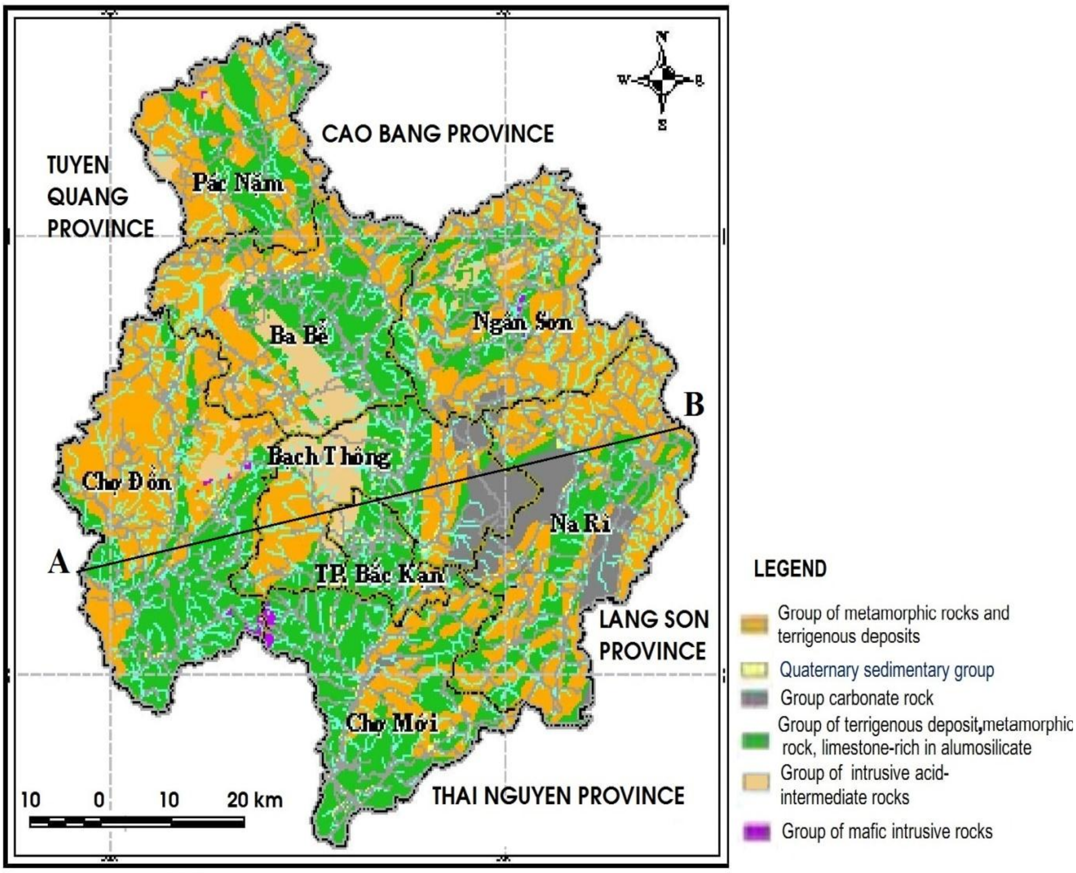

Figure 11: Map of rock groups in Bac Can province

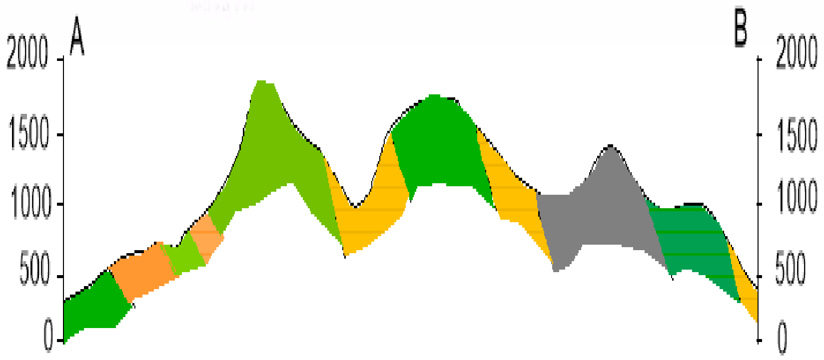

Figure 12: Cross section from A to B

- Group of extrusive acid-intermediate rocks: includes granite rock, syenite rock of PhiaBioc complex formation, Ngan Son complex formation, Cho Don complex formation, Pia Ma complex formation.
- Group of intrusive rocks consists of gabbro rock of Nui Chua complex Formation and diabase dyke.

3.9. Human factors

In the study area, the influence of human activities on landslide induction is diverse. Examples include deforesting, making roads, causing imbalance, and slope stability. We choose the road factor because this is the factor that strongly influences the landslide process. Map of the distance to the road has been using the "buffer calculation" algorithm in ArcGIS software (Figure 13).

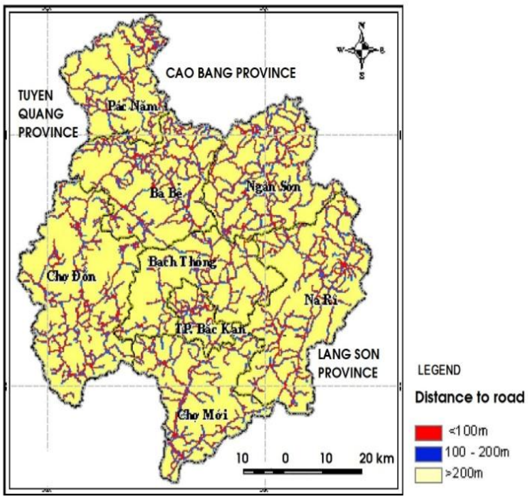

Figure 13: Map of the distance to the road

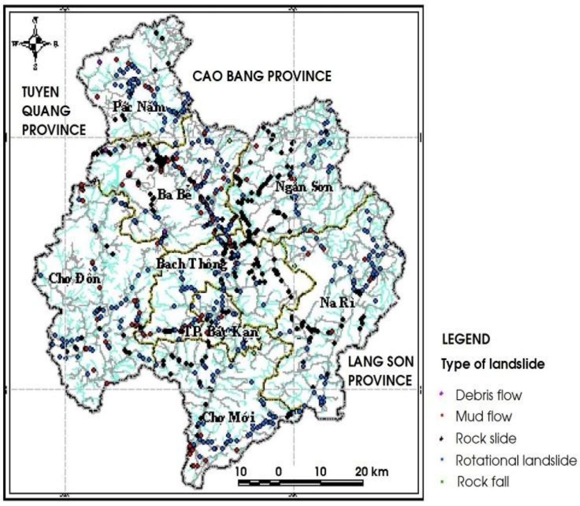

Figure 14: Landslide inventory map of Bac Can province

4. Discussion

4.1. Landslide inventory map of Bac Can province

We collected the landslides from 1996 to 2021. The results of the landslide inventory on projects in Bac Can province show that there are 1342 landslide sites (Figure 13). It was applied the AHP in assessing the critical level of factors that causes landslides in Bac Can province. The corresponding weight values Wj for each landslide factor are determined based on the eigenvector value in the pairwise comparison matrix shown in Table 4.

Table 4: The compare couples matrix, the eigenvector values, and the consistency ratio of the group comparison matrix Factors cause failures in Bac Can province.

Factors groups	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	Eigenvector
[1] River density	1									0.019
[2] Deep cleavage density	2	1								0.024
[3] Distance to roads	4	3	1							0.045
[6] maximum rainfall/day	5	4	2	1						0.068
[5] Fault density	6	5	4	3	1					0.119
[6] Vegetation cover	7	7	6	4	2	1				0.173
[4] Lithology	8	8	7	5	3	2	1			0.254
[8] Slope	9	9	8	6	3	2	1	1		0.268
[9] Aspect	3	2	1/2	1/4	1/6	1/7	1/9	1/9	1	0.030
Consistency coefficient CR = 0.067										

The same comparison of couples has been carried out on the information layers in each factor that causes landslides. These compared couples matrices are the basis for determining the weights for different information layers according to the values Eigenvector in each matrix (Table 5).

Table 5: Matrix compares couples, weight values (Wij /eigenvector), and consistent rate of the information layers comparison matrix in factor groups that causes landslides on Bac Can province.

1. slope	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	Eigen vector
[1] <3^o	1													0.027
[2] 3-8^o	2	1												0.040
[3] 8-15^o	5	3	1											0.091
[4] 15-25^o	7	5	3	1										0.159
[5] 25-45^o	8	7	4	3	1									0.276
[6] >45^o	9	9	5	4	2	1								0.407
Consistency coefficient CR = 0.072														
2. Distance to the road														
[1] < 100m	1													0.557
[2] 100- 200m	1/2	1												0.320
[3] >200m	1/4	1/3	1											0.123
Consistency coefficient CR = 0.020														
3. Maximum daily rainfall														
[1] < 150 mm/day	1													0.122
[2] 150 - 200 mm/day	2	1												0.230
[3] > 200 mm/day	5	3	1											0.648
Consistency coefficient CR =0.005														
4. River density														
[1] <0.3 km/km^2	1													0.043
[2] 0.3 – 0.6 km/km^2	4	1												0.124
[3] 0.6 – 0.9 km/km^2	7	3	1											0.271
[4] > 0.9 km/km^2	9	5	3	1										0.562
Consistency coefficient CR = 0.072														
5. Deep cleavage density														
[1] <100m/km^2	1													0.051
[2] 100-200 m/km^2	2	1												0.082
[3] 200-300 m/km^2	4	3	1											0.150
[4] 300-400 m/km2	5	4	3	1										0.282
[5] >400 m/km^2	6	4	5	2	1									0.435
Consistency coefficient CR = 0.081														

6. Fault density														
[1] < 0.1 km/km^2	1													0.051
[2] 0.1 – 0.3 km/km^2	2	1												0.082
[3] 0.3 – 0.5 km/km^2	4	3	1											0.150
[4] 0.5 – 0.7 km/km^2	5	4	3	1										0.282
[5] >0.7 km/km^2	6	4	5	2	1									0.435
Consistency coefficient CR = 0.081														
7. Vegetation cover														
[1] Rocky mountains without trees	1													0.015
[2] Residential	3	1												0.028
[3] Mixed bamboo, wood forest	5	3	1											0.076
[4] Rich evergreen broad-leaved	4	2	1/2	1										0.050
[5] Poor evergreen broad-leaved	7	5	3	3	1									0.126
[6] Recovery evergreen broad-leaved forest	4	2	1/2	1	1/3	1								0.057
[7] Medium evergreen broad-leaved	3	1	1/3	1/2	1/4	1/2	1							0.033
[8] Water surface	2	1	1/4	1/3	1/5	1/3	1/2	1						0.024
[9] Rocky mountain	2	1	1/4	1/3	1/5	1/3	1/2	1	1					0.024
[10] Bamboo forest	4	2	1/2	1	1/3	1	2	2	2	1				0.046
[11] Plantation forest	5	3	1	2	1/2	1/2	3	3	3	2	1			0.070
[12] Agricultural and other lands	8	6	4	5	2	5	5	6	6	6	3	1		0.187
[13] Vacant land	9	7	5	7	3	7	7	7	7	7	5	2	1	0.264
Consistency coefficient CR = 0.041														
8. Slope direction														
[1] Flat	1													0.021
[2] North	3	1												0.035
[3] Northeast	7	5	1											0.113
[4] East	7	5	1	1										0.113
[5] South East	7	5	1	1	1									0.113
[6] South	7	5	1	1	1	1								0.113
[7] Southwest	7	5	1	1	1	1	1							0.113
[8] West	7	5	1	1	1	1	1	1						0.113

[9] Northwest	5	3	3	3	3	3	3	3	1					0.266
Consistency coefficient CR =0.042														
***9.* Rocks group**														
[1] Carbonate rock group	1													0.016
[2] Group of mafic intrusive rocks	3	1	1											0.037
[3]Group of extrusive acid-intermediate rocks	5	2	2	2	1									0.069
[4] Group of metamorphic rocks and terrigenous deposits	5	2	2	2	1	1								0.069
[5] Group of terrigenous deposit and metamorphic rock, limestone-rich in alumosilicate	7	5	4	4	2	2	1							0.135
[6] Quaternary sedimentary rock group	9	6	6	6	4	4	2	2	1	1				0.232
Consistency coefficient CR = 0.099														

The data in Tables 4 and 5 display:

- *For slope*: The slope increases; the greater the gravity of the rock mass, the higher the risk of landslides. The results of the pairwise comparison showed that weight values or Wij values increased with the larger slope groups from 0.027, 0.040, 0.091, 0.159, 0.276 to 0.407 in the respective terrain groups from "flat" (<3^o) to "hanging cliffs" (> 45^o).

- *Maximum daily rainfall:* Similar to the maximum daily rainfall, the higher the maximum daily rainfall groups, the more favourable the landslide process. The weight values for the groups of maximum daily rainfall < 100mm/day, 100 – 200mm/day, and ≥ 200mm/day increases from 0.122, 0.230 to 0.648 respectively.

- *Human activities* affecting the landslide process are represented by distance to the road, indicating that the closer the road, the higher the risk of landslides. The double comparison of road distances has shown that the weights for groups of road distances from <100m, 100-200m to > 200m are 0.557, 0.320, and 0.123, respectively.

- *Landslide weights for* groups of river density, deep cleavage and fault densities also increase gradually with the density of rivers and streams, deep cleavage density, and the density of faults of the groups, as shown in the eigenvector value of Table 4.

- *For vegetation cover:* Vacant land is the most advantageous factor for the landslide process. The weight of vacant land in the comparison matrix is the highest value of 0.264. Followed by other types of cover such as "Agricultural land and others" (0.187); Plantation forest (0.070); Bamboo forest (0.046); Rocky mountain (0.024) etc. (Table 4)

- *For Slope direction*, The Northwest direction has the highest weight among the slope direction groups with a value of 0.266. This is also wholly consistent with the current statistics of the density of landslides falling on the northwest slope, accounting for 22.5% of the total number of landslides in the study area. Other directions such as Northeast, South, Southwest, and West have a much lower percentage of landslides and are a weight of 0.113. This is followed by the North direction and flat terrain with weights of 0.035 and 0.021, respectively.

- *For rock groups:* Based on origin research, degree of weathering combined with interpolation of analytic hierarchy process (AHP), we have determined the weight of rock groups. The weighted value increases from the carbonate rock group (0.016) to the Group of terrigenous deposit and metamorphic rocks rich in alumosilicate (0.232) (see Table 5)

Our statistics for 2014 show that there are five types of landslides in Bac Can province, including rotational landslide, translational landslide, debris flow, earthflow and topple (Table 6)

Table 6: Type of landslides

District	Type of landslides					Total
	Rotational landslide	Translational landslide	Debris flow	Earthflow	Topple	
Babe	62	51	22	3	1	139
Bachthong, Baccan town	68	65	17	0	0	150
Chodon	52	14	20	0	1	86
Chomoi	49	26	12	0	0	88
Nari	56	28	2	1	1	88
Nganson	28	56	3	0	0	87
Pacnam	47	10	4	1	0	62
Total	362	250	80	5	3	700
%	51.71	35.71	11.29	0.71	0.43	100

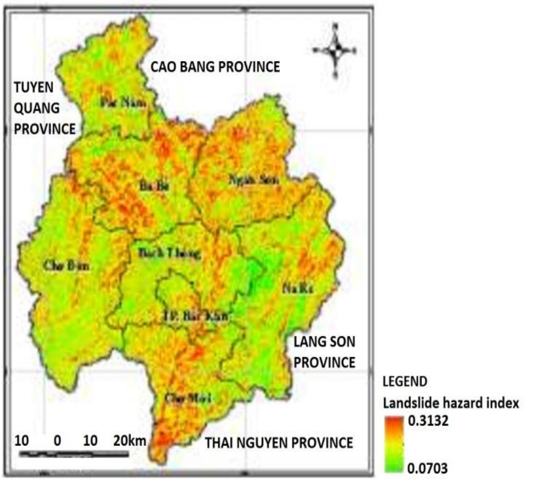

Figure 14: Map of landslide hazard index in Bac Can province climate change maximum day rain scenario for 2025.

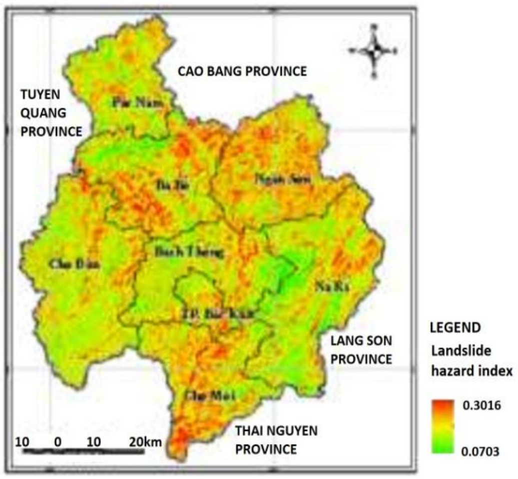

Figure 15: Map of landslide hazard index in Bac Can province climate change maximum day rain scenario for 2050.

Table 4 shows that the consistency coefficients CR are less than 0.1 indicating that the evaluation follows a reasonable and consistent rule. For each slip factor map, a field Wij is created and assigned to a corresponding attribute column, as in Table 4. Based on Wj and Wij values calculated in Tables 3 and 4, using the "Weighted sum" function in ArcGIS software to perform equation (3) for the calculation of the landslide hazard index (LSI). From there, we have the map of the landslide hazard index in Bac Can province (Figures 14 and 15).

4.2. Map of landslide risk in Bac Can

Based on the input source (see 3. results) and comprehensive integration in ArcGIS, a landslide risk zoning map with different scenarios has been obtained. The scenario of climate change with maximum daily rainfall between 2025 and 2050 is selected. On the map of landslide risk zoning of Bac Can province, there are 5 (five) risk thresholds from low to high selected (Figures 16 and 17).

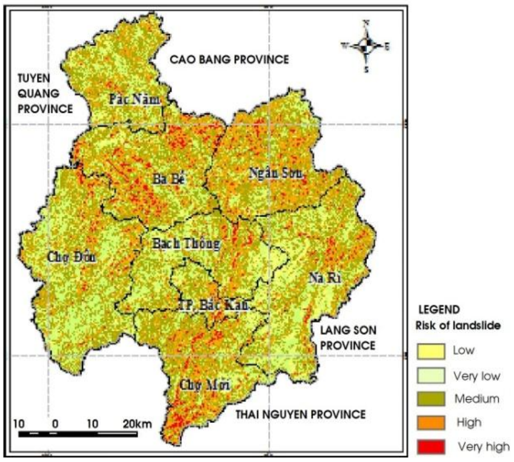

Figure 16: Map of landslide risk in Bac Can province climate changes maximum day rain scenario for 2025.

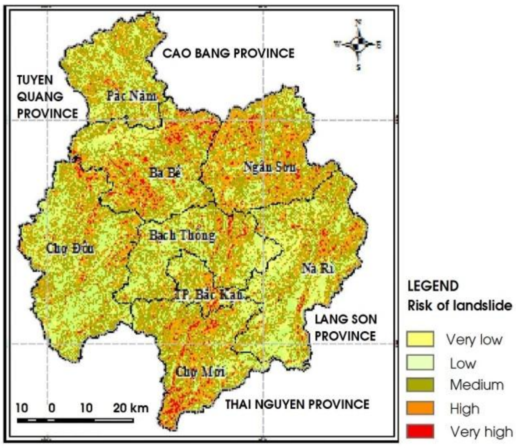

Figure 17: Map of landslide risk in Bac Can province climate changes maximum day rain scenario for 2050.

The analytic hierarchy process (AHP) is one of the landslide research methods successfully applied in many countries worldwide, including Vietnam. The advantage of this method is the Comprehensive integration in ArcGIS; Data sources are selected in order of precedence through pairwise comparison. We hope that this landslide risk zoning map with different scenarios will positively contribute to Bac Can province's sustainable development.

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