Status of landslides and influencing factors in Bao Yen district, Lao Cai province and Quan Hoa district, Thanh Hoa province: A community-based survey

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Thực trạng sạt lở đất và các yếu tố ảnh hưởng tại huyện Bảo Yên, tỉnh Lào Cai và huyện Quan Hoá, tỉnh Thanh Hóa: Khảo sát từ cộng đồng

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ABSTRACT

This study aimed to evaluate the status of landslide incidents and the factors influencing them in two mountainous districts: Quan Hoa (Thanh Hoa province) and Bao Yen (Lao Cai province). The primary method was used by random interviews with selective sampling of local residents and officials in areas frequently affected by landslides. Additionally, the Analytic Hierarchy Process (AHP) method was employed to assess the importance of influencing factors. The main findings showed that in Quan Hoa, over the past five years from 2020 to 2024, there were 36 landslide incidents, occurring along road embankments, in areas with steep slopes, or regions lacking vegetation cover. Similarly, in Bao Yen district, 36 landslide incidents were recorded over the same period. The AHP analysis revealed the order of importance of factors affecting landslides in both areas, from most to least significant, as follows: heavy and prolonged rainfall (A, 42.7%), high and steep terrain (B, 25.0%), overexploitation of resources (C, 10.6%), low vegetation cover with weak soil protection (F, 7.0%), inappropriate agricultural practices (D, 5.7%), improper construction of infrastructure (E, 5.2%), and changing meteorological factors due to climate change (G, 3.7%). Based on these findings, existing local measures and community feedback, the study proposed a comprehensive set of solutions focusing on land management, resource mobilization, and infrastructure reinforcement to mitigate landslide risks and minimize their impacts in these high-vulnerability upland regions.

Keywords:
Bao Yen, community, impact factor, landslide, Quan Hoa.

TÓM TẮT

Bài báo trình bày kết quả nghiên cứu thực trạng sạt lở đất và các yếu tố ảnh hưởng đến sạt lở đất tại hai huyện Quan Hoá, tỉnh Thanh Hoá và huyện Bảo Yên, tỉnh Lào Cai. Phương pháp phỏng vấn ngẫu nhiên, có chọn lọc người dân và cán bộ địa phương – nơi thường xuyên xảy ra sạt lở được sử dụng chủ yếu trong nghiên cứu này. Ngoài ra, phương pháp phân tích thứ bậc (AHP) được sử dụng để đánh giá mức độ quan trọng của các yếu tố ảnh hưởng đến sạt lở. Kết quả nghiên cứu cho thấy, tại Quan Hoá trong từ 2020-2024 có 36 vụ sạt lở xảy ra trên các ta luy đường, khu vực có độ dốc cao, hoặc không có lớp thực vật che phủ. Tương tự, tại huyện Bảo Yên đã có 36 vụ sạt lở trong 5 năm qua. Kết quả phân tích AHP cho thấy các mức độ quan trọng của các yếu tố ảnh hưởng đến sạt lở đất ở hai khu vực đất lần lượt như sau: mưa lớn kéo dài (A, 42,7%), địa hình cao và dốc (B, 25%), khai thác tài nguyên quá mức (C, 10,6%), lớp phủ thực vật thấp (F, 7,0%), canh tác nông nghiệp không hợp lý (D, 5,7%), xây dựng công trình hạ tầng không hợp lý (E, 5,2%), yếu tố khí hậu thay đổi (G, 3,7%). Dựa trên thực trạng các giải pháp mà địa phương đã và đang áp dụng, kết quả phỏng vấn mong đợi của người dân cũng như các kết quả phân tích AHP, nghiên cứu đã đề xuất một số giải pháp nhằm giảm thiểu nguy cơ sạt lở và giảm thiểu các tác động do sạt lở gây nên tại khu vực nghiên cứu.

Từ khóa:
Bảo Yên, cộng đồng, Quan Hoá, sạt lở đất, yếu tố ảnh hưởng.

1. INTRODUCTION

Landslides rank among Vietnam's most perilous natural disasters, particularly in the northern mountainous provinces with steep terrain and frequent heavy rains. Statistics from the Center for Disaster Prevention Policy and Engineering show 162 landslides in 2020 due to rainstorms or runoff, rising to 358 in 2021. In 2024, a record year for disasters, preliminary data indicate 232 heavy rain events causing flooding, flash floods, and landslides, resulting in 514 deaths or missing persons, 2,207 injured, and damages worth hundreds of billions of VND [1]. From 1953 to 2016, an average of 7 landslides occurred annually (totaling 448 incidents), but this number surged to 15–16 per year between 2000 and 2015 due to climate change and extreme weather (General Department of Disaster Prevention, 2019). Areas like Quan Hoa (Thanh Hoa) and Bao Yen (Lao Cai) are heavily impacted, with severe cases such as the hill cracking in Ban Do and the flash flood in Lang Nu in 2024, driven by factors like forest cover changes, steep topography, and intense rainfall. Landslides result from natural and human factors, including geological, meteorological, hydrological, and vegetation influences [2], with triggering factors like rainfall, human activities, and earthquakes [3-5]. Research highlights various methods for assessing landslide risk, often using weighted methods or expert assumptions [6-9], with slope, lithology, slope aspect, and land use as key factors per Dao Viet Long et al. [5]. Ling Zhang et al. (2024) used machine learning to identify 10 critical factors for shallow landslides, including slope curvature and vegetation density, from 17 initial factors [10], while similar studies exist in China [11]. However, no research covers Quan Hoa and Bao Yen. This paper leverages local interviews to analyze landslide factors, laying groundwork for future studies with advanced tools to mitigate damages.

2. RESEARCH METHODS

2.1. The interview method

This method collected data on landslide conditions, contributing factors, and damages in the study areas. A total of 98 people from Quan Hoa district and 60 from Bao Yen district were interviewed, with 80% being household representatives and 20% local officials. Interviews were conducted face-to-face and via Google Form survey sheets, using selective random sampling to ensure randomness while targeting areas with prior landslides or high risk. The interview period spanned from July 2024 to May 2025, focusing on landslide status, impacts, influencing factors, and community-based prevention measures.

2.2. The AHP method

The Analytic Hierarchy Process (AHP), introduced by Iraqi mathematician Thomas L. Saaty in 1980, is a method for weighting multi-criteria decisions to determine criterion importance. In this study, AHP is applied to identify key landslide-influencing factors. The process includes: Step 1: Using references [2-9], seven factors were identified: heavy and prolonged rainfall, high and steep terrain, overexploitation of soil/forests/resources, unsuitable agricultural practices, improper infrastructure, low vegetation cover with weak soil protection, and changing climatic factors (climate change). Step 2: Design interview questions to evaluate the relative importance of these factors using the Saaty scale, e.g. Question 1 "Compared to ‘High and steep terrain,’ how many times more important is ‘Heavy and prolonged rain’ in causing landslides?"

1	3	5	7	9

Corresponding to the 7 proposed criteria, there will be 21 pairwise comparison questions.

Step 3: Conduct interviews with a randomly selected subset of 60 individuals, consisting of 30 from Quan Hoa, Thanh Hoa (10 officials and 20 residents) and 30 from Bao Yen, Lao Cai (5 officials and 25 residents), chosen from a total of 158 surveyed individuals (98 from Quan Hoa and 60 from Bao Yen); Step 4: Construct a matrix consisting of n criteria and n rows. The initial matrix values were calculated using the geometric mean of interview responses from 60 individuals, ensuring the representativeness of the sample; Step 5: Calculate the weights for the criteria; Step 6: Calculate the consistency ratio (CR).

Some formulas used in the AHP method are as follows:

The consistency ratio (CR) is defined as follows:

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Where:

CI is the consistency index;

λmax is the maximum eigenvalue;

n is the size of the pairwise comparison matrix.

$$\lambda_{max} = \sum_{i=1}^{n} wi * \sum_{j=1}^{n} aij \quad (3)$$

aij are the elements in the pairwise comparison matrix with n rows and n columns.

wi is the weight of criterion iii.

RI is Random Index, which is determined from a given table (The RI value for the 7 criteria in this study is 1.32).

2.3. Field survey method

After obtaining interview results, surveys were conducted in areas that experienced landslides or were at risk of landslides, with GPS coordinates recorded using a GPSmap 78s device. The coordinate points were plotted on the area map using QGIS 10.3 software. The purpose was to verify the locations frequently affected by landslides in the area. Additionally, on-site observations helped provide a clearer understanding of the current situation and the mechanisms of landslides in the region.

3. RESULTS AND DISCUSSION

3.1. Current situation of Landslides in Bao Yen district, Lao Cai and Quan Hoa district, Thanh Hoa

The analysis of the current situation of landslides in Bao Yen district (Lao Cai) and Quan Hoa district (Thanh Hoa) is based on interview data and secondary reports. Severe landslide incidents, especially following Yagi typhoon (September 2024), have caused significant damage to both human lives and property. In Bao Yen, the landslide incident in Lang Nu village is typical, while in Quan Hoa, hill cracks have been recorded, such as in Phu Thanh, Phu Le, Trung Son commune. Interview data from local residents and officials clarify the current situation and the extent of the impact of landslides. This analysis provides a practical insight into this type of natural disaster, thereby forming a basis to assess the causes and propose appropriate solutions for the study area.

Table 1. Number of landslide incidents in the research sites from 2020 to 2024

Year	Quan Hoa, Thanh Hoa		Bao Yen, Lao Cai	
	Number of landslide incidents	Locations	Number of landslide incidents	Locations
2020	3	Along transportation routes and residential areas in Trung Son, Trung Thanh, Thanh Son and Phu Xuan communes	5	Along transportation routes and residential areas in Bao Ha, Yen Son, and Xuan Hoa communes.
2021	6	Areas near hills and mountains in Nam Dong and Trung Son communes	7	Areas near hills and mountains in Tan Duong, Kim Son, Cam Con, and Minh Tan communes.
2022	5	Nam Xuan, Xuan Phu, Trung Thanh communes	6	Areas in Tan Tien, Viet Tien, and Dien Quan communes.
2023	8	Hills and inter-commune roads in Hien Chung and Hien Kiet communes	8	Hills and inter-village roads in Bao Ha and Vinh Yen communes.
2024	14	Entire communes, concentrated in Do village (Phu Thanh), Tan Phu village, Hang village (Phu Le), and Xuan Phu, Phu Xuan communes	10	Entire communes, concentrated in Lang Nu, Nghia Do, Viet Tien, Xuan Thuong, Yen Son, Xuan Hoa communes, Pho Rang town, and Tan Tien commune.

Source: Compiled from interview results, 2024, 2025.

The data Table 1 shows a significant increase in the number of landslide incidents in Quan Hoa (Thanh Hoa) and Bao Yen (Lao Cai) from 2020 to 2024. In Quan Hoa, the number of landslides rose from 3 incidents in 2020 to 14 incidents in 2024, primarily occurring in communes with steep terrain such as Phu Thanh, Phu Le, Phu Xuan. Additionally, Xuan Phu, Nam Xuan, Hien Chung, and Hien Kiet are also frequently affected communes (see Map Figure 01). In Bao Yen, the number of incidents increased from 5 in 2020 to 10 in 2024, concentrated in areas like Bao Ha, Yen Son, and Vinh Yen communes. Overall, most communes in Bao Yen have experienced landslides (see Map Figure 02). This increasing trend reflects the impact of heavy rainfall and human activities such as deforestation and construction, especially in Bao Ha, Vinh Yen, and Xuan Hoa communes.

Compared to other studies, the landslide situation in Quan Hoa and Bao Yen is quite similar to the landslide conditions in many mountainous districts in Vietnam, such as Mu Cang Chai (Yen Bai) or Nam Pam commune in Muong La district, Son La province. According to the report by the Ministry of Agriculture and Rural Development (now the Ministry of Agriculture and Environment, 2021), there were over 15 severe landslide incidents in Yen Bai province in 2020, causing significant damage to people and property. In Nam Pam commune, Muong La district, Son La province, a landslide occurred in 2017 in the Nam Pam and Nam Phien river basins, causing heavy losses of life and property, and was considered the fastest and largest landslide and flash flood event in the past 70 years. Landslides in Northern Vietnam are generally attributed mainly to heavy rainfall and forest area reduction, combined with steep terrain and high mountains. However, the damage in Bao Yen (58 deaths in Lang Nu village, Lang Nu commune, Long Khanh, in 2024) is the most severe in the past few decades in northern Vietnam, due to the area's geology being affected by the Earth's fault systems, concentrated heavy rainfall, and various other factors. The map of areas frequently affected by landslides in the study area is presented in Figure 1, 2.

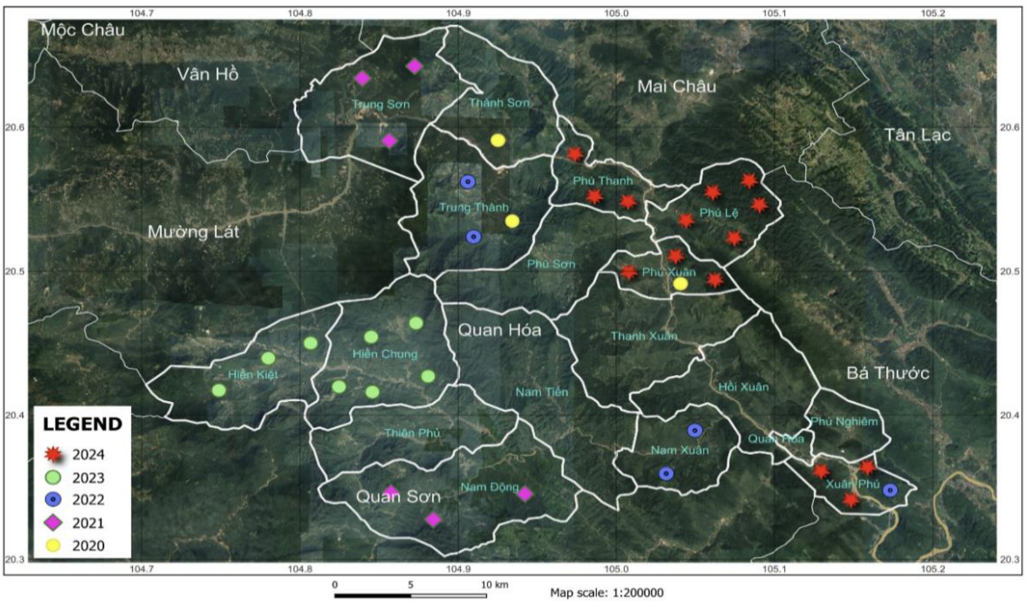

Figure 1. Frequent landslide locations in Quan Hoa district, Thanh Hoa

(Source: Field surveys using GPSmap 78s and mapped with QGIS 10.3)

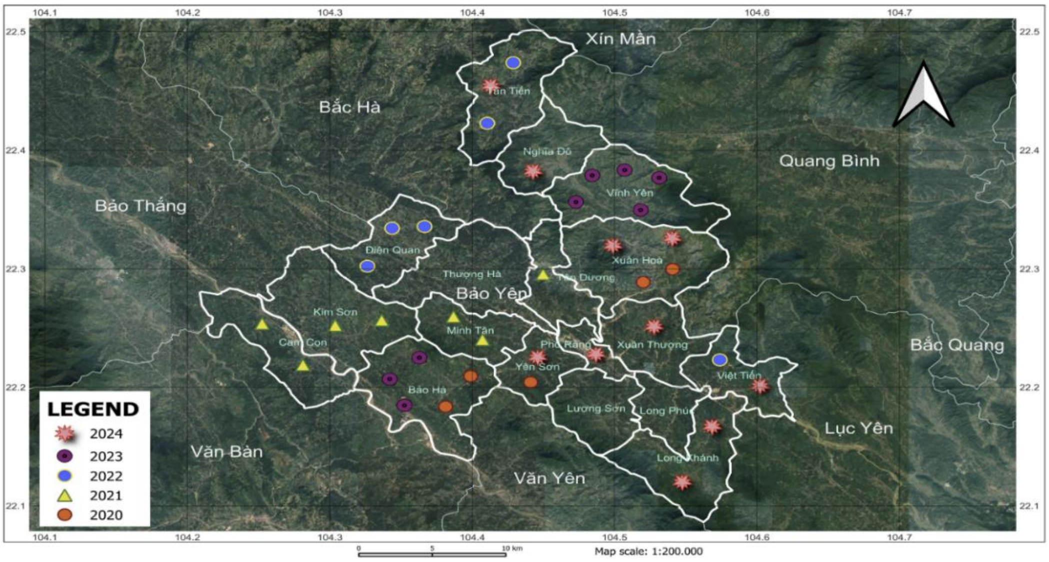

Figure 2. Frequent Landslide locations in Bao Yen district, Lao Cai
(Source: Field surveys using GPSmap 78s and mapped with QGIS 10.3)

Table 2. Percentage of households affected by Landslides (Based on interview results)

Responses	Households affected (%)	
	Quan Hoa	Bao Yen
Affected	82.9	75
Not affected	17.1	25

Source: Compiled from interview results, 2024, 2025

Table 2 shows that, in Quan Hoa, the percentage of households affected by landslides is significantly higher (82.9%) compared to Bao Yen (75%), indicating a higher level of disaster risk in Quan Hoa, based on community interview results conducted locally.

Table 3. Assessment of damages caused by Landslides in the study area from 2020 to 2024

Year	Major damages in Quan Hoa district	Major damages in Bao Yen district
2020	Causing traffic congestion along the Trung Son, Trung Thanh, Thanh Son and Phu Xuan routes, affecting local residents' daily activities, some slopes collapsed, the bases of electric poles were cracked and broken.	In Bao Ha, Yen Son, and Xuan Hoa communes, traffic was locally disrupted, affecting residents' daily activities and travel.
2021	Damage and impact to the housing of 87 households living at the foot of the mountain in Nam Dong commune; 35 households had to be relocated in Trung Son commune.	In Tan Duong, Kim Son, Cam Con, and Minh Tan communes, several houses were damaged.
2022	Soil and rocks spilled onto the fields, causing crop damage in Nam Tien and Nam Dong communes. Collapsed one house, damaged 17 houses, livestock, agriculture, forestry, and housing incurred damages of nearly 3 billion VND.	In Tan Tien, Viet Tien, and Dien Quan communes, crops were affected as mud and rocks from landslides spilled onto the fields.
2023	Severe landslides disrupted traffic on the inter-commune road between Hien Chung and Hien Kiet, The slope eroded at two points, over 70% of fish ponds were affected, over 32 hectares of rice fields and 10 houses were damaged, with no reported human casualties.	In Bao Ha and Vinh Yen communes, transportation routes were affected.

Year	Major damages in Quan Hoa district	Major damages in Bao Yen district
2024	Heavy rainfall caused landslides that damaged 28 houses in various communes, with 5 of them severely affected. Around 6,000 cubic meters of soil and rocks slid at the semi-boarding secondary school in Ban Eo, Phu Xuan commune; the secondary school in Thanh Son is also at high risk of damage due to landslides. Notably, the heavy rain triggered landslides, subsidence, and flooding at multiple locations along National Highways 15 and 16, Provincial Road 521, and 34 inter-commune and inter-village roads.	In Lang Nu, Nghia Do, Viet Tien, Xuan Thuong, Yen Son, Xuan Hoa, Pho Rang town, and Tan Tien, landslides have caused significant damage. Notably, the landslide in Lang Nu in September 2024 resulted in 58 deaths, 9 people missing, and 6 currently receiving medical treatment. The number of deaths in other communes due to landslides was 16 people, with 30 people injured, and many houses, crops, roads, and infrastructure facilities were destroyed

Source: Compiled from interview results, 2024, 2025.

According to Table 3, it can be seen that the damages caused by landslides in the study area include losses of human lives and property, traffic congestion, and crop losses. In Quan Hoa, no specific figures for major damages, unlike those in Bao Yen, have been recorded. From 2020 to 2024, landslides in Quan Hoa mainly caused flooding and minor landslides, with damages concentrated on houses and agriculture, but no large numbers of deaths or missing persons were recorded as in major events. However, in Bao Yen, besides property damage and traffic disruptions, the 2024 landslide in Lang Nu village (Long Khanh commune) caused 58 deaths and 9 missing persons, making it one of the most serious disasters in Vietnam in recent decades. The losses from the Lang Nu landslide accounted for a large proportion of the national damage caused by Yagi typhoon.

Table 4. Assessment of the severity of landslides in the study area

Severity level	Assessment in Quan Hoa district (%)	Assessment in Bao Yen district (%)	Detailed description
Very severe	60.5	25	Landslides cause severe damage, loss of agricultural land, affect houses, lives and health of people, land, and transportation infrastructure. The living area is
Severe	21.1	50	Landslides significantly affect agricultural production and livelihoods but do not cause human casualties. Loss of land and some infrastructure.
Less severe	7.89	16.67	Landslides cause minor damage, affecting part of agricultural land and the environment. No major loss of property or infrastructure.
Normal	9.21	8.33	Landslides rarely occur and have little impact or only causing slight environmental changes or minor effects on the land.
Not occured	1.30	0	No landslides have occurred in the area and there have been no signs or indications of possible landslides.

Source: Compiled from interview results, 2024, 2025

Based on the data regarding the severity levels of landslides in Quan Hoa district (Thanh Hoa) and Bao Yen district (Lao Cai) (Table 4) according to community opinions, more than 60% of respondents in Quan Hoa rated the landslides as very severe, while in Bao Yen, the majority rated the landslides as severe (50%). No respondents in Bao Yen reported that landslides had never occurred or showed no signs of appearing in the area. In contrast, only one respondent out of all interviewed in Quan Hoa believed that landslides did not occur locally.

3.2. Factors affecting landslides

Landslides are a complex natural phenomenon influenced by many natural and human factors. This section presents the results of assessing the main factors affecting landslides based on interviews with local community members in the study area—where landslides frequently occur. The Analytic Hierarchy Process (AHP) method was used to prioritize the influencing factors. The assessment results will provide a scientific basis for proposing measures to reduce landslide risks in the future.

Based on the interview results, Table 5 is summarized as follows:

Table 5. Summary of factors affecting landslides based on interview results

Factors affecting landslides	Agreement percentage	
	Quan Hoa district (%)	Bao Yen district (%)
Heavy and prolonged rainfall	85.4	83.3
High and steep terrain	78.1	75
Overexploitation of soil, forests, and natural resources	66.7	66.7
Unsuitable agricultural practices	41.7	50
Improper infrastructure construction	35.4	41.7
Low vegetation cover and weak soil protection	26	33.3
Changing climatic factors (climate change)	18.7	25

To determine the importance or level of influence of each factor (such as heavy rainfall, terrain, resource exploitation, etc.), this study uses the Analytic Hierarchy Process (AHP) method. The results will serve as a basis for making priority decisions: supporting the selection of factors to focus on, for example prioritizing landslide prevention caused by heavy rainfall if it has the highest weight.

Table 6. Original matrix of evaluation criteria

Criteria	A	B	C	D	E	F	G
A	1	3.5	5.7	7.9	8.0	6.0	5.7
B	0.3	1.0	4.3	5.9	5.9	4.0	5.7
C	0.2	0.2	1.0	3.4	2.3	1.3	3.9
D	0.1	0.2	0.3	1.0	1.2	1.2	2.3
E	0.1	0.2	0.4	0.8	1.0	1.5	1.2
F	0.2	0.2	0.7	0.8	0.7	1.0	3.9
G	0.2	0.2	0.3	0.4	0.9	0.3	1.0
Sum	**2.1**	**5.5**	**12.7**	**20.3**	**19.9**	**15.4**	**23.6**

Evaluation Criteria: *Heavy and prolonged rainfall (A), High and steep terrain (B), Overexploitation of soil, forests, and natural resources (C), Unsuitable agricultural practices (D), Improper infrastructure construction (E), Low vegetation cover and weak soil protection (F), Changing climatic factors (climate change) (G).*

The values in this original matrix table (Table 6) were determined through the geometric mean calculation of interview values from 60 people across two study areas. The results of the hierarchical analysis are presented sequentially in Tables 7, 8, 9 following the steps outlined as follows.

Table 7. Normalized matrix of evaluation criteria

Criteria	A	B	C	D	E	F	G	(Wi) Weight of the criterion
A	0.4860	0.6347	0.4472	0.3903	0.4011	0.3907	0.2407	**0.4272**
B	0.1402	0.1831	0.3380	0.2901	0.2969	0.2624	0.2394	**0.2500**
C	0.0854	0.0426	0.0786	0.1676	0.1147	0.0870	0.1667	**0.1061**
D	0.0612	0.0310	0.0231	0.0492	0.0604	0.0794	0.0965	**0.0573**
E	0.0610	0.0310	0.0345	0.0409	0.0503	0.0989	0.0490	**0.0522**
F	0.0808	0.0453	0.0587	0.0402	0.0330	0.0649	0.1653	**0.0697**
G	0.0854	0.0324	0.0200	0.0216	0.0435	0.0166	0.0423	**0.0374**

To calculate the consistency index (CI), it is nescessary to compute the intermediate results in Table 8.

Table 8. Intermediate table to determine the consistency vector

Wi	(Y) 0.427	0.25	0.106	0.057	0.052	0.07	0.037
Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A	(X) 1	3.5	5.7	7.9	8.0	6.0	5.7
B	0.3	1.0	4.3	5.9	5.9	4.0	5.7
C	0.2	0.2	1.0	3.4	2.3	1.3	3.9
D	0.1	0.2	0.3	1.0	1.2	1.2	2.3
E	0.1	0.2	0.4	0.8	1.0	1.5	1.2
F	0.2	0.2	0.7	0.8	0.7	1.0	3.9
G	0.2	0.2	0.3	0.4	0.9	0.3	1.0

Table 9. Table for determining the consistency vector

Criteria	A	B	C	D	E	F	G	Weight total (T)	(Wi) Weight of the criterion	Consistency vector (T/Wi)
A	(Z) 0.427	0.867	0.604	0.454	0.416	0.42	0.213	3.400848	0.427241	7.960022
B	0.123	0.25	0.456	0.338	0.308	0.282	0.212	1.968918	0.250019	7.875088
C	0.075	0.058	0.106	0.195	0.119	0.093	0.147	0.794409	0.106104	7.487105
D	0.054	0.042	0.031	0.057	0.063	0.085	0.085	0.417869	0.057261	7.297668
E	0.054	0.042	0.047	0.048	0.052	0.106	0.043	0.392004	0.052242	7.503647
F	0.071	0.062	0.079	0.047	0.034	0.07	0.146	0.508933	0.069743	7.297238
G	0.075	0.044	0.027	0.025	0.045	0.018	0.037	0.271731	0.037391	7.267235
Mean (αmax)										**7.526858**

Explain the method of calculating Z in Table 9 from X and Y in Table 8 as follows: Z = X .Y

Check the consistency using formula (2.2) and the Mean(αmax) in Table 9: Consistency Index CI = (7.526858 - 7)/(7 - 1) = 0.088

Consistency Ratio: CR = 0.088/1.32 = 0.067. The Consistency Ratio is less than 0.1, indicating that the aggregated matrix is consistent and the results are reliable.

This suggests that the opinions evaluating the importance of factors affecting landslides have a high level of consistency. In other words, the assessments of the relative importance between factors (e.g., how many times more important one factor is compared to another) do not significantly contradict each other. Therefore, the results of the AHP analysis are considered reliable and can be used for drawing conclusions.

The results of evaluating the importance of factors affecting landslides in the study area are presented in Table 10.

Table 10. Evaluation of the importance level of Factors affecting landslides

Influencing factors (from high to low)	Importance level of factors causing landslides (%)
Heavy and prolonged rainfall (A)	42.7
High and steep terrain (B)	25.0
Overexploitation of soil, forests, and natural resources (C)	10.6
Low vegetation cover and weak soil protection (F)	7.0
Unsuitable agricultural practices (D)	5.7
Improper infrastructure construction (E)	5.2
Changing climatic factors (climate change) (G)	3.7

The results in the Table 10 show that "Heavy and prolonged rain" is the most significant factor affecting landslides (42.7%), followed by "High and steep terrain" as the second most important factor (25%). The group of factors with low importance, below 10%, includes: sparse vegetation cover with weak soil protection, inappropriate agricultural practices, improper construction of infrastructure, and climate change factors. Among these, "Climate change factors" is the least influential, with 3.7%. These research findings align with the community's perceptions of influencing factors as presented in Table 05 and are fairly consistent with studies conducted globally and in Vietnam. Some notable studies include: A study by Thomas A. Stanley and colleagues (2024) developed a Landslide Hazard Index (LHI) based on rainfall and temperature factors, highlighting the role of heavy rainfall, particularly extreme rainfall, which may become more frequent in Asian countries affected by climate change. This study was conducted in the hilly regions of Asia [12]. Several other authors have confirmed the role of heavy rainfall in increasing landslides and flash floods in mountainous regions of Asian countries, such as Mohanty et al., 2019 [13]; Sun et al., 2022 [14]; Chinh Luu and colleagues, 2023 [15]. In Vietnam, Vo Nguyen Duc Phuoc and colleagues (2019) studied the causes of landslides in the mountainous regions of Hue, Quang Nam, Quang Ngai, indicating that, in addition to critical factors such as rainfall, soil type, and slope, other factors like aspect, proximity to roads or streams, and vegetation cover also influence landslides [16]. The research results are quite consistent when compared with studies using machine learning models and algorithms. Ling Zhang and colleagues identified DEM (elevation) as the third most important factor influencing landslides [10]. According to the assessment of Prof. Dr. Tran Hong Thai, Director General of the Vietnam Meteorological and Hydrological Administration (Ministry of Natural Resources and Environment), in the current context of climate change, heavy and extremely heavy rainfall occurs frequently on both widespread and localized scales, causing severe floods, inundation, flash floods, and landslides in many areas across the country. Notable examples include the record-breaking rainfall in Phu Quoc in August 2019, where 1,158 mm of rain fell in just 7 days (accounting for 40% of the annual rainfall), or the three-day prolonged rainfall in October 2022 in Thua Thien Hue and Da Nang, with daily rainfall exceeding 700 mm, causing severe flooding. For these reasons, the frequency and severity of landslides have increased and become more severe in the mountainous regions of Northern Vietnam [17]. Although ranked lowest in terms of direct impact, climate change may amplify other factors such as heavy rainfall.

3.3. Solutions to mitigate landslide damage in the study area

The current awareness and solutions implemented by local authorities to mitigate damage caused by landslides, as well as measures to reduce the risk of landslides, are summarized from interview results presented in Table 11. Accordingly, the majority of residents are well aware of the causes of landslides (75%-89.4%), and local authorities have actively engaged in reforestation and effective forest protection efforts (83.3%-89.8% of responses). These are positive aspects of disaster prevention work that should continue to be promoted. However, only a small number of interviewees agreed that local authorities have developed early warning and forecasting measures for landslides (15-35.7%), and residents have not regularly participated in awareness-raising sessions about landslides. Additionally, not many people have received advice from local authorities or organizations regarding landslides and prevention methods. These are limitations that need to be addressed in landslide prevention efforts in the studied area.

Table 11. Current status of measures applied locally and community awareness of landslides

Current status	Percentage of agreeing opinions in Quan Hoa (%)	Percentage of agreeing opinions in Bao Yen (%)
The locality has effectively protected forests and enhanced reforestation efforts.	89.8	83.3
The locality has implemented measures to raise public awareness.	55.2	43
The locality has maintained close oordination Between local authorities and residents.	59	35
The locality has developed measures for early forecasting and warning of landslides.	35.7	15
Residents clearly understand the causes of landslides.	89.4	75
Residents regularly participate in awareness-raising and educational sessions about landslides.	39.4	33.3
Residents receive guidance from authorities and organizations on landslides and prevention methods.	27.6	25
Residents recognize the damage and consequences caused by landslides.	50	43

Source: Compiled from interview results, 2024, 2025.

Based on the positive aspects and limitations in awareness and actions as shown in Table 11, the study proposes solutions to mitigate the risks and damages caused by landslides for Bao Yen and Quan Hoa, as following: To mitigate landslide risks in Quan Hoa and Bao Yen, the top priority is engaging communities in awareness and training sessions, rated as very necessary in both area to enable proactive self-protection. Next, provincial investment in early landslide forecasting and warning systems is crucial, especially in Bao Yen where it is rated as very necessary, ensuring timely evacuations. Equally important is increasing funding for training officials in management and rescue operations, rated as necessary in both area for effective response. Long-term forest protection and afforestation, though less urgent, support slope stability. Policies supporting funding for infrastructure development and insurance for households in vulnerable areas are lower-priority measures, but remain valuable and should be implemented consistently to complement core prevention and preparedness efforts.

4. CONCLUSION

The study has identified the status of landslides in the two research areas. Over the past five years, Quan Hoa, Thanh Hoa, experienced 36 landslide incidents, causing damage to numerous houses and properties, with annual losses amounting to billions of VND. Similarly, Bao Yen recorded 36 landslide incidents, which, beyond affecting crops, livestock, transportation disruptions, and housing, also resulted in loss of human lives (e.g., the landslide in Nu Village, Long Khanh commune, in 2024). The study also identified frequent landslide-prone locations in the two areas, including Phu Thanh, Phu Le, Phu Xuan, Xuan Phu, Nam Xuan, Hien Chung, and Hien Kiet communes in Quan Hoa, and primarily Bao Ha, Yen Son, and Vinh Yen communes in Bao Yen.

The study evaluated the factors influencing landslides based on community opinions and the use of the Analytic Hierarchy Process (AHP) method. The results indicate a relatively consistent assessment of the importance of these factors. Accordingly, heavy and prolonged rain, high and steep terrain, overexploitation of resources, low vegetation cover with weak soil protection, inappropriate agricultural practices, improper construction of infrastructure, and changing meteorological factors due to climate change are the factors affecting landslides, ranked from highest to lowest importance. Among these, the most significant factors are heavy and prolonged rain and high, steep terrain.

Based on the current situation, the solutions implemented by local authorities, the expectations expressed during resident interviews, and the hierarchical analysis results, the study proposed several solutions to mitigate the risk of landslides and minimize their impacts in the studied areas.

REFERENCES

[1]. Disaster management policyand technology center. Retrieved from: http://www.dmc.gov.vn/thong-tin-thien-tai-pt32.html?lang=vi-VN.

[2]. D. J. Varnes (1984). Landslide hazard zonation: a review of principles and practice. Commission on landslides of the IAEG. Nat. hazards. 3: 61.

[3]. M. J. Crozier (1986). Landslides: causes, consequences and environment, Croom Helm, London. Geogr. Phys. Quat. 7(1): 107–108.

[4]. S. Abuzied, S. Ibrahim, M. Kaiser & T. Saleem (2016). Geospatial susceptibility mapping of earthquake-induced landslides in Nuweiba area, Gulf of Aqaba, Egypt. J. Mt. Sci. 13(7): 1286–1303.

[5]. Doan Viet Long, Nguyen Chi Cong & Nguyen Quang Binh (2020). Assessment of the current situation and research solutions for landslides in Vietnam from 2010 to 2020. Journal of Science and Technology of Irrigation. 61: 119-128.

[6]. P. Reichenbach, M. Rossi, B. D. Malamud, M. Mihir & F. Guzzetti (2018). A review of statistically-based landslide susceptibility models. Earth-Science Rev. 180: 60–91.

[7]. A. Hansen (1984). Landslide hazard analysis. Slope Instab. 523–602.

[8]. A. Hansen, C. A. M. Franks, P. A. Kirk, A. J. Brimicombe & F. Tung (1995). Application of GIS to hazard assessment, with particular reference to landslides in Hong Kong. Geographical Information Systems in assessing natural hazards. 273-298.

[9]. R. K. Dahal, S. Hasegawa, A. Nonomura, M. Yamanaka, T. Masuda & K. Nishino (2008). GISbased weights-of-evidence modelling of rainfall-induced landslides in small catchments for landslide susceptibility mapping. Environ. Geol. 54(2): 311–324.

[10]. Lin Zhang, Zhengxi Guo, Shi Qi, Tianheng Zhao, Bingchen Wu & Peng Li (2024). Landslide susceptibility evaluation and determination of critical factors influencing andslides in the Qinghai-Tibet Plateau: A case study of Qinghai province, China. Ecological Indicators. Available at: https://www.sciencedirect.com/science/article/pii/S1470160X24013682.

[11]. Zang Yeqi, Guo Yonggang, Wang Guowen & Wu Shengjie (2024). Evaluation of landslides susceptibility in Southeastern Tibet, China: An approach based on machine learning algorithms. Heliyon. Available at: https://www.sciencedirect.com/science/article/pii/S2405844024128319.

[12]. Thomas A. Stanley, Rachel B. Soobitsky, Pukar M. Amatya & Dalia B. Kirschbaum Landslide Hazard Is Projected to Increase Across High Mountain Asia. Earth's Future. 12(10): e2023EF004325. DOI: 10.1029/2023EF004325.

[13]. Mohanty, M. Hussain, M. Mishra, D.B. Kattel & I. Pal (2019). Exploring community resilience and early warning solution for flash floods, debris flow and landslides in conflict prone villages of Badakhshan. International Journal of Disaster Risk Reduction. 33: 5-15.

[14]. X. Sun, G. Zhang, J. Wang, C. Li, S. Wu & Y. Li (2022). Spatiotemporal variation of flash floods in the Hengduan Mountains region affected by rainfall properties and land use. Nat. Hazards. DOI: 10.1007/s11069-021-05061-5.

[15]. Hang Ha Chinh Luu, Quynh Duy Bui, Ngoc-Dung Luong, Dong Thanh Khuc, Hung Vu & Dinh Quoc Nguyen (2023). Flash flood and landslide susceptibility analysis for a mountainous roadway in Vietnam using spatial modeling. Quaternary Science Advances. 11: 100083.

[16]. Vo Nguyen Duc Phuoc, Nguyen Quang Binh, Pham Dinh Hung, Doan Viet Long & Nguyen Chi Cong (2019). Studies on the causes of landslides for mountainous regions in central region of Vietnam. Journal of Science and Technology. 17(12): 29-33.

[17]. Ninh Co (2023). Challenges in forecasting landslides and rocks. Nhân Dân Newspaper (People Newspaper) (https://nhandan.vn/thach-thuc-trong-du-bao-sat-lo-dat-da-post752589.html).