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RESEARCH ON THE FORMATION FEATURES AND DEVELOPMENT PROGRESS OF SOME LARGE LANDSLIDES IN THE NORTHERN MOUNTAINOUS AREA (AN EXAMPLE OF IN XIN MAN DISTRICT, HA GIANG PROVINCE)

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SUMMARY OF GEOLOGICAL THESIS

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INTRODUCTION

1. Rationale

According to a 2018 World Bank report, natural disasters in Vietnam may occur more frequently and with increasing frequency in the future. This warning reminds us to pay more attention to extreme natural disasters including landslides. And the fact shows that the phenomenon of landslides tends to be more complicated and leaves more serious damage. According to the statistics of the project "Investigation, assessment and zoning for warning of landslide risk in mountainous areas of Vietnam", the number of small landslides recorded are more than the large landslides (LLs). Although the number of LLs is not much but their appearance causes dangerous destruction, great damage and is much costlier to dealing with the consequences.

The LLs phenomenon is a potential threat to residential areas, traffic infrastructure, terraced fields, and power transmission lines in the Vietnam northern mountains (VNM). Typically, in the rainy season of 2007 & 2008, the phenomenon appeared a lot in the area of Coc Pai town, Xin Man district, Ha Giang (XM-HG), the People's Committee houses were located on landslide area. LLs has a length of 350-500 m, a width of 150-200 m, and needs to be stabilized immediately. LLs at Tan Son markets, Nam Dan, XM-HG appeared at the end of July 2012, destroyed part of the market and collapsed the houses of 5 families. In addition, there are many other LLs in the communes of Ban Diu, Nam Dan, Xin Man, Che La, Quang Nguyen, Na Chi, etc., causing difficulties in the economic development.

Thus, I chose the thesis topic *"Research on the formation features and development progress of some large landslides in the northern mountainous area (an example of in Xin Man district, Ha Giang"* is very important and practical significance.

2. Aims of the study

- Clarifying the current status, factors affecting the formation and development of LLS in VNM area.
- Clarifying the dynamics of development by field monitoring technologies at XM-HG.

3. Objects and scope of research

- *The research object* is the LLs in the VNM area and detailed study of the LLs in the XM-HG area. Limitations of research is not including: debris flood, mud sliding mass and landslide formed by mining activities, construction and site work of hydroelectric and irrigation.
- *Research area*: Vietnam northern mountainous area includes 15 provinces: Ha Giang, Cao Bang, Lao Cai, Bac Kan, Lang Son, Tuyen Quang, Yen Bai, Thai Nguyen, Phu Tho, Bac Giang, Lai Chau, Dien Bien, Son La, Hoa Binh, Quang Ninh, with a total area of 95,264.4 km^2. Detailed study on geodynamics LLs at XM-HG (including 17 communes), an area of 582 km^2.

4. Argument in defense

- The large landslide in the VNM area is characterized by a volume greater than $4.500m^3$, most of which are of the translational and complex type, with the sliding surface coincides with the discontinuity in lithology material or tectonic fissure.
- The tectonics, lithology, slope and human activities were identified as the main factors leading to the formation of LLs in the VNM area based on the synthesis of statistical models and machine learning.
- LLs displacement at XM-HG is a heterogeneous, discontinuous process, in which the displacement increases significantly when the pore water pressure coefficient (r_u) at the sliding surface position over ≥ 0,53.

5. New points of the thesis

- Systematized the main characteristics of LLs for the VNM region based on statistical analysis methods.
- Established a map to assess the susceptibility map of LLs formation in the VNM area by combining statistical analysis and machine learning.
- Developed a process to analyze field monitoring data of geotechnical parameters in accordance with the actual conditions of the LLs at XM-HG.
- Determining the pore water pressure coefficient r_u at the dangerous sliding surface position when there is a significant displacement of the LLs, supporting the early warning of the unstable risk landslide at XM-HG.

CHAPTER I. OVERVIEW OF MAJOR SLIDE STUDIES IN THE WORLD AND IN VIETNAM

1.1. Abroad

David Varnes (1958) gave the first concept of landslide which is quite broad and includes mud, rock, and avalanche. With different natural conditions of each region, the concepts are different. Some authors have introduced the concept of LLs can be mentioned as follows: LLs is a phenomenon of rock and soil moving over a surface area more than 0,1 km^2, sliding material being transported with long distances, is influenced by many environmental and geological factors – according to *Roering & nnk (2005). Agliardi (2012)* described deep sliding as movements with large volume, large sliding surface depth and relatively slow velocity for a long time. *Lo (2017)* suggested that the LLs has a layer surface located in the bedrock, the sliding material is transported with a long distance, the surface area is more than 10 ha, the sliding surface depth is more than 5 m.

Currently, there are many ways to classify landslides, such as: based on the sliding process, type of sliding surface, volume of the sliding mass, movement phase of the landslide, the depth of sliding surface and the lithology material. Summary of research results such as *Fell (1994), V. D. Lomtadze and ICL* gave 7 levels with different volume scales and the results showed quite a large difference.

Table 1.1. Classification of landslides by volume (m3) of some authors

Level	ICL	Fell (1994)	Lomtadze	Description
7	> 10^8	$5x10^6$	>200.000	Huge
6	$10^7 – 10^8$	$10^6 – 5x10^6$		Very large
5	$10^6 – 10^7$	$25x10^4$ - 10^6	1.000-200.000	Large
4	$10^5 – 10^6$	$5x10^4 – 25x10^4$		Large - Medium
3	$10^4 – 10^5$	$5x10^3 – 5x10^4$	200-1000	Medium
2	10^3 - 10^4	500 – 5.000	10-200	Small
1	< 10^2	< 500	< 10	Very small

Fauque (2002), Bobrowsky (2017) and Tanyas (2019) analyzed LLs details in South America, they have shown the LLs formations are related to complex geological structures. These studies all confirmed that tectonic activity and lithology material are the first factors to create a special structure and a large enough volume to form LLS. When analyzing LLs formations on the eastern Alps region, *Agliardi (2001)* demonstrated that the factors forming LLs here converge by 3 factors: geological structure, geomorphological features and rock mechanics.

To assess the risk of landslide formation, there are many methods and techniques proposed by *Guzzetti (1999) and Corominas (2014)* including status assessment, map analysis, statistical methods, probabilistic methods, machine learning methods... In recent times, quantitative approaches have been widely used and dominated. Depend on the purpose, area and scale of the study zone, the accuracy of the methods varies greatly.

LLs dynamic analysis in the world is directed towards 2 directions: model analysis and observational data analysis. With model analysis, the calculus models are quite familiar (ex: Titan, RockScience, Plaxis, Abaqus, GeoStudio), a number of studies by *Hungr (1995)* have focused to analyze the run-out distance of LLs and *Moriwaki (2004)* designed a small physical model with an artificial rain system to simulate the LLs process. In the direction of monitoring data analysis, there are many modern monitoring technologies can be applied: ground monitoring technologies, geotechnical and geophysical technologies, remote sensing technologies.

1.2. Domestic

LLs surveying and drawing in Vietnam has been started very early, since the important construction started. Recently, *Nguyen Van Hung (2002), Do Minh Duc (2013), Phan Trong Trinh (2015)* focused on describing the current site status, assessing the risk based on the relationship with geological structural features. - terrain for some LLs. *Tran Tan Van (2006), Chu Van Ngoi (2008)* have shown a close relationship between the geological structure, the active zone of the fault and the formation of a specific geologic point.

At the regional scale, *Vu Cao Minh (1996), Nguyen Trong Yem (2006)* performed state-level tasks on research on landslides in general. And recently, *Nguyen Quoc Thanh (2015)* has designed a disaster warning maps.

In the dynamic analysis direction, LLs research was raised to a new level when there were first studies on analyzing the effects of rain and groundwater levels in the slopes of *Do Minh Duc (2006), Nguyen Van Hoang (2011), Do Quang Thien (2013), Mai Thanh Tan (2015)*. *Do Minh Duc (2018)* has identified the influence of rain on the phenomenon of landslides and analyzed to provide the thresholds for precipitation that cause water loss. Recently, *Doan Huy Loi (2017)* has applied the theory of liquid particles to analyze the influence of LLs due to heavy rain.

The first site where monitoring equipment was installed was on the Ong Tuong hill, Hoa Binh city. Then, there have been some different monitoring systems installed such as Coc Pai system, Hai Van pass system.

1.3. Research gap

LLs is a complex research object, influenced by many environmental factors to get formation and development, the kinetic process has many different stages, both its own motion and common formation characteristics. Therefore, the research gap is LLs determination, analyze the landslide conditioning factors and assess the susceptibility landslide map in the VNM, analyze the kinetic characteristics of LLs in the XM-HG area towards the proposal of early warning system. Therefore, the research gap need to be studied and clarified include 3 aspects:

a./ The morphological characteristics

Depending on the natural environmental conditions and the research purpose, it is necessary to classify the objects of the sliding phenomenon to clarify the mechanism of formation and development, and it is possible to take appropriate measures and minimize damage. Moreover, with complex natural conditions like in the VNM, the LLs character need to be systematized in order to identify and assess susceptibility landslide map.

b./ LLs susceptibility map

Open database sources for scientific research purposes are now abundant and reliable. Statistical analysis of big data allows to identify dominant factors in assess LLs susceptibility map in the VNM.

The studies show that, depending on the characteristics of each type of landslide and the research rate, the methods of hazard stratification have different levels of accuracy. Statistical methods and machine learning are currently popular methods in landslide research. However, which model is most suitable for predicting the risk of LLs formation needs to be quantified and analyzed.

c./ On the dynamical characteristics of the LLs phenomenon

The evolution movement is a continuous process in many stages, with each stage the velocity is not same and it is difficult for humans to recognize by the senses. In addition, current monitoring technologies can collect different time series (in days, hours or events), so it is necessary to integrate monitoring data over time in one way then we can accurate prediction.

The pore water pressure on the slope affects the effective stress and it is one of the LLs factors triggering. Therefore, pore water pressure monitoring data is considered an important input to analyze LLs stability by the numerical model. Based on the observed data at 2 LLs in XM-HG, it is necessary to give quantification for the dynamic characteristics of LLs.

CHAPTER II. APPROACH, METHOD AND TECHNIQUE SYSTEM

2.1. Approach method

2.1.1. System approach analysis

The systems approach is a methodology used to solve real-world problems on the basis of considering the complete treatment of the object's system characteristics. Within the scope of the thesis, the formation and development of spatial analysis is a complex process in both space and time, so the choice of a systematic approach allows generalization, analyze and predict the displacement of LLs.

When studying the formation and development of landslide in space X and time interval $t_o \leq t \leq t_s$, with the assumption that the initial state is known and the law of impact on u(t) is known, thus determine the state of the system at time t_s, i.e. $x(t_s)$. Then, according to *Hoang Tuy (1987)*, the way to build a general model for the LLs phenomenon is based on the formula:

$$x(t_s) = G(x(t_o), u(.), t_o, t_s)$$

According to the scope of the thesis, U is a set of acceptable input functions, including $u_1(x)$, $u_2(x, t)$ and $u_3(x, t)$, where:

- $u_1(x)$ are natural factors that vary in space, with little/no change in time;
- $u_2(x)$ are natural and anthropogenic factors that change in space and time;
- $u_3(x)$ are natural elements that change very quickly in space and time.

When considering factors affecting the system (including: lithology, tectonics, weathering layer, topography, hydrology, climate, land use and human activities) as a set of statistics, to understand the dynamics and the behavior of the system, the actual movement process, its main trends need to analyze the correlation between factors. Moreover, the factors have the ability to interact with each other as mentioned above, in the analysis process, it is also necessary to consider their multi collinearity. In addition, in order to predict the LLs formation in the VNM, it is not possible to consider all the influencing environmental factors in a short period of time while still ensuring reliability.

2.1.2. Time series integration approach

The time series recording the LLs development is often heterogeneous, discontinuous and has many random factors. The time period for measuring events & displacement LLs characteristics is expressed in many different intervals: hours, days, months, seasons but needs to be repaired according to the order of LLs development. In order to combine into continuous time series, it is necessary to integrate uniformly in order to use of time data series which is the occurrence events of LLs. The time-integrated approach also allows easy addition of different data types of the time series to improve the reliability of the forecasting results.

2.1.3. Logical framework

With the above approach, the researcher aims to analyze the archeology in 3 aspects: the morphological characteristics; the formation law; the kinetic characteristics. The specific logical framework for LLs research is as shown in *Figure 2.1.*

2.2. Research methodology system

2.2.1. Site survey method group

a./ Field survey method: take notes by survey questionnaire, survey and interview, drill and survey the site of the LLs, make a cross-section of the weathering layer of LLs body.

b./ Landscape surveying by UAV and building a numerical model of the land surface.

c/ Mechanical testing of soil samples: Basic characteristic and residual shear resistance of soil samples.

2.2.2. Statistical and machine learning methods

a./ Statistics of geological objects: Spatial objects, directional objects, time data series.

b./ Spatial analysis based on open source software

- Use tools in the open source software QGIS for spatial analysis and RStudio for statistical analysis.
- Statistical analysis of the level of influence through the risk index. For easy observation and assessment, the influence level of the factors is classified into 5 levels and shown in the VNM map with the following levels: no influence, low influence, medium, strong and very strong.
- Optimal statistical model analysis: principal component statistical analysis, Bayesian mean (BMA) model selection statistical analysis, AUC and Kappa statistics.

c./ Data analysis by multivariate statistics and machine learning: logistic regression model, support vector machine model, artificial neural network model, superimposed synthetic model.

d./ Determining the influence of LLS by empirical formula.

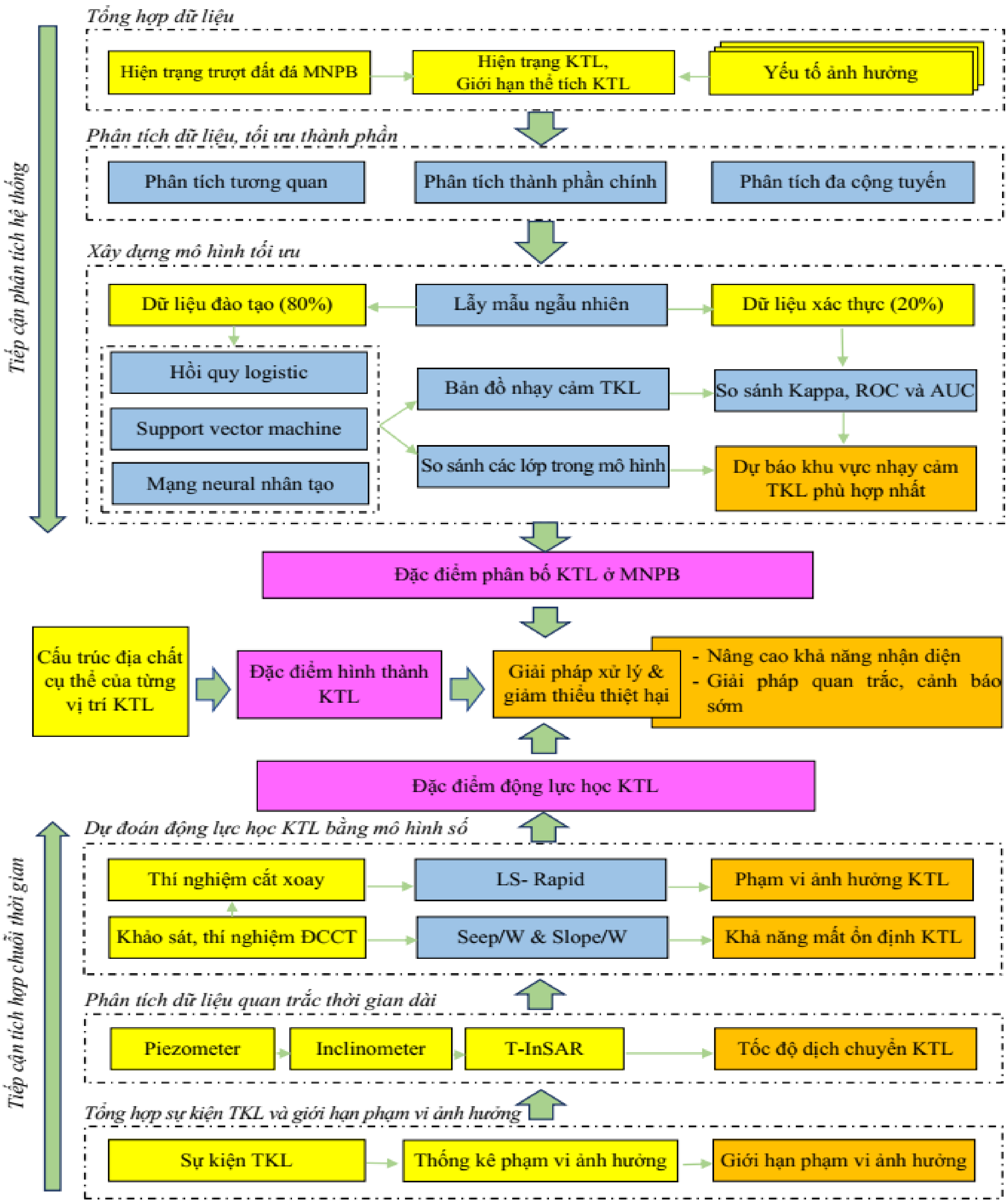


Figure 2. 1. Logical framework to study the LLs formation and development

2.2.3. LLs monitoring methods

The thesis uses field monitoring devices including: rain monitoring, inclinometer and pore water pressure measurement (piezometer), monitoring of surface topographic changes by T-InSAR device.

2.2.4. Application of geotechnical modeling software:

Analysis of LLs stability using GeoStudio 2018 R2 software and analysis of LLs influence using LS-Rapid software.

CHAPTER III. THE FORMATION FEATURES OF LARGE LANDSLIDES IN THE VIETNAM NORTHERN MOUNTAINOUS AREA

3.1. Current characteristics of landslides in the VNM

Landslide is the most common type of geological hazard occurring in the VNM. According to statistics in the period from 1953-2006, Vietnam had 448 flash floods and landslides, an average of 7 events per year. The database of the current state of geomorphology in the VNM area analyzed from 8,304 landslide points is enough for statistical analysis of landslide characteristics in the VNM with the scale 1:200.000.

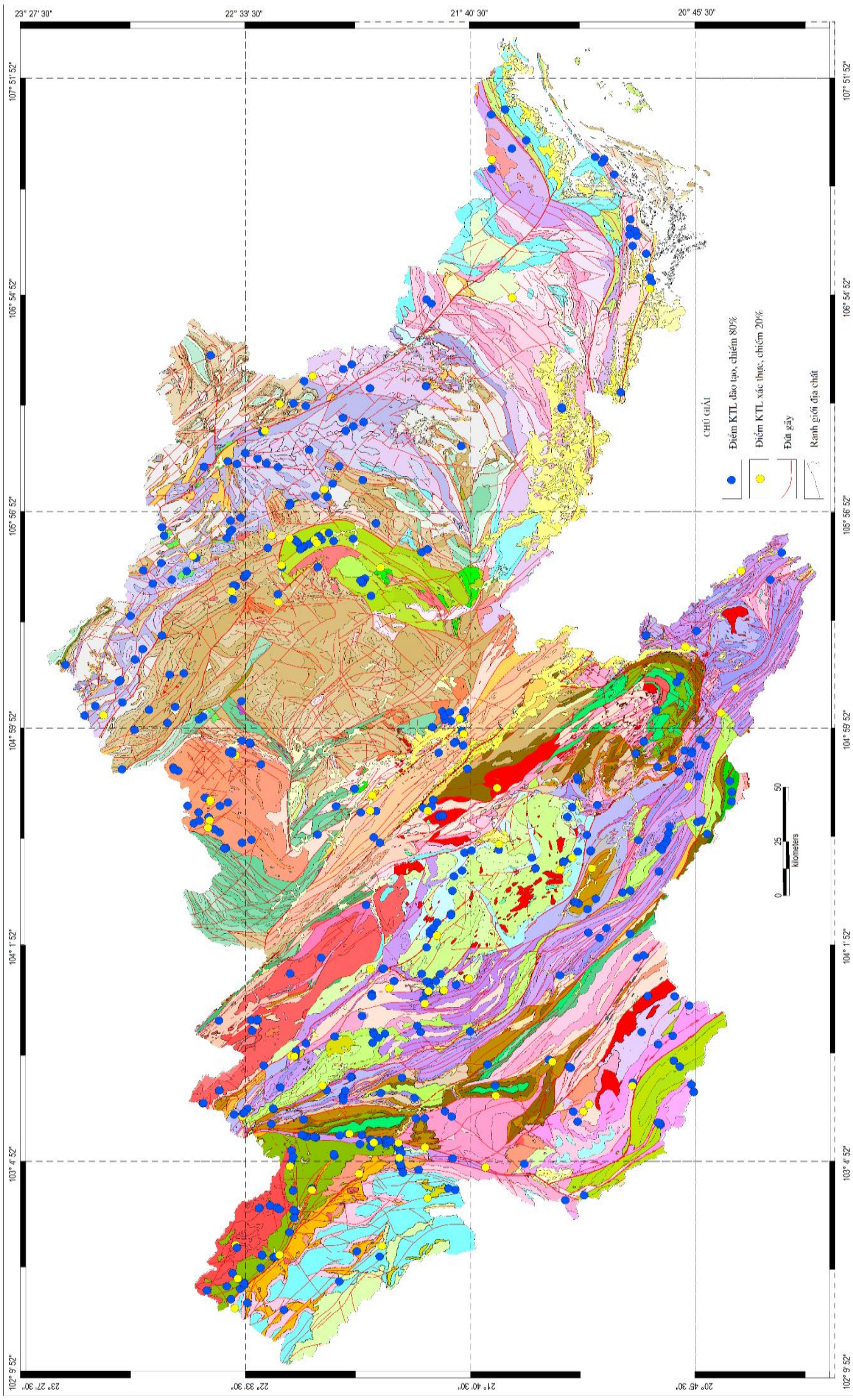


Figure 3.1. The current state map of large landslide in the VNM area on a geological map of the scale 1:200.000

Bảng 3.1 CSDL thống kê các điểm TKL theo các địa phương ở VNM

Province	Area km^2	Landslide amount	Large landslide amount	Max. volume m^3	Density of landslide	Ratio of large landslide to total
Bac Giang	3844.0	106	2	5,593	0.028	1.9%
Bac Kan	4859.4	701	30	178,500	0.144	4.3%
Cao Bang	6709.9	206	27	90,000	0.031	13.1%
Đien Bien	9541.2	672	58	364,500	0.070	8.6%
Ha Giang	7914.9	967	52	494,000	0.122	5.4%
Hoa Binh	4608.7	182	15	43,500	0.039	8.2%
Lai Chau	9068.8	969	113	1,950,000	0.107	11.7%
Lang Son	8320.8	90	9	375,000	0.011	10.0%
Lao Cai	6383.9	531	9	131,250	0.083	1.7%
Phu Tho	3534.6	40	3	4,600	0.011	7.5%
Quang Ninh	6102.4	377	27	50,000	0.062	7.2%
Son la	14174.4	1683	77	98,000	0.119	4.6%
Tuyen Quang	5867.3	246	30	3,000	0.042	12.2%
Thai Nguyen	3531.7	22	3	1,000	0.006	13.6%
Yen Bai	6886.3	1158	48	330,000	0.168	4.1%

3.2. Statistical distribution of the volumes of sliding blocks at VNM area

The probability distribution of the landslide occurrence follows a complex exponential law, so for convenience in analyzing the statistical distribution, the volume value is converted to the logarithmic value of the volume. Then, the frequency distribution graph of landslide occurrence follows the normal log distribution with mean (2,43), variance (0,52), median (2,35). Statistical testing using Cullen & Frey chart (evaluated by the kurtosis index and the skewness of the distribution) shows that the sliding volume logarithm data is best suited to the normal distributions *(Figure 3.4)*.

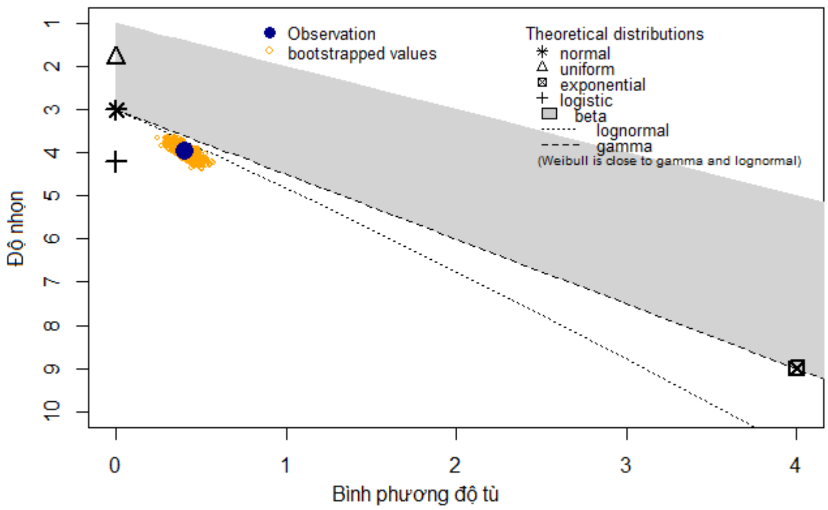


Figure 3.4. Results of testing the statistical distribution according to Cullen & Frey chart

The landslide volume is divided into 5 levels: very small, small, medium, large and very large. The probability of occurrence of Vlog LLs > 3,65 only accounts for 5%, many times smaller than the probability of occurrence of LLs Vlog for 95%, and it is considered to be different. In addition, *Figure 3.5* shows the cumulative probability density curve of variation in slope (inflection point) at the position Vlog=3,65, so this can also be considered as a boundary to distinguish the difference in the volume between the LLs group and the small landslide group. Thus, the volume of the LLs is chosen to be larger than 4.500 m^3.

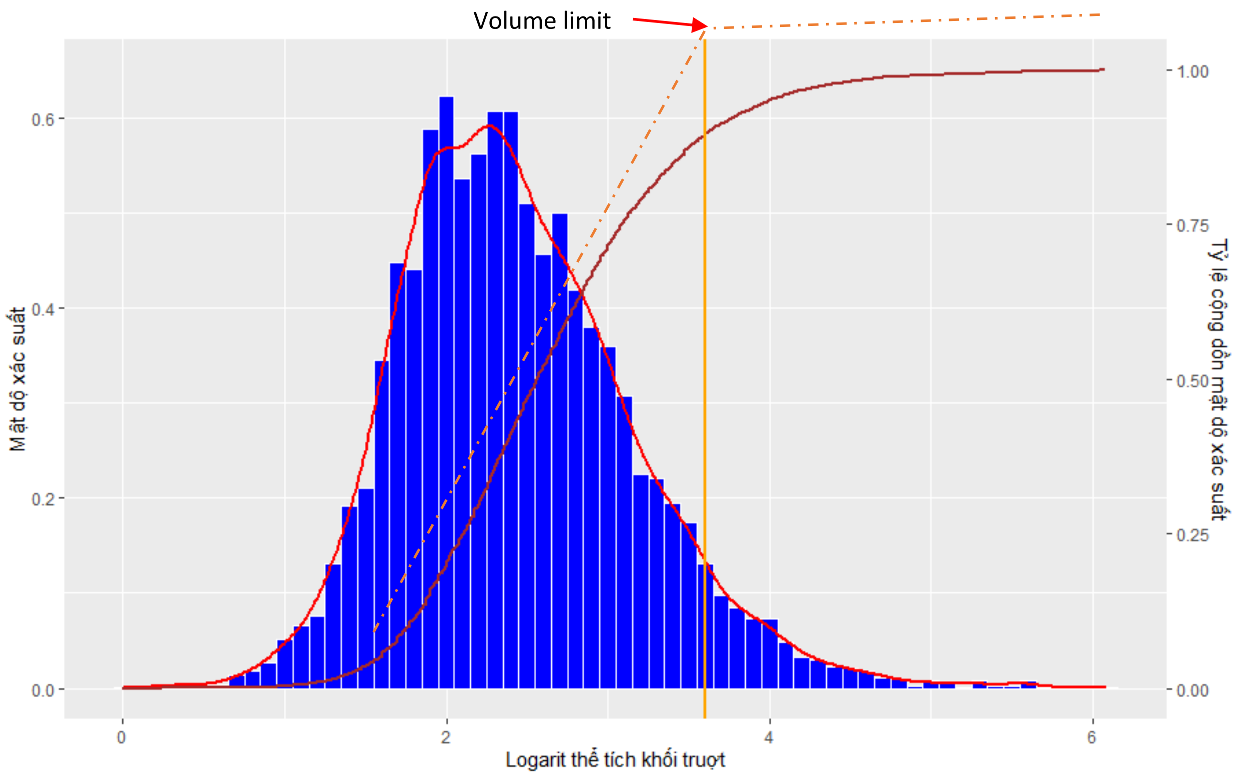


Figure 3.5. Density probability bar plot of landslide occurrence in the VNM according to logarithm of volume

3.3. Morphological characteristics of large landslide

3.3.1. Geometrical features of the LLS

Geometrical features of LLs are described through the main features: main scrap, body, sliding surface, cracks, transverse edges, wet surface, expanding gully, height, width, length.

3.3.2. Sliding surface

Sliding surfaces are discontinuous surfaces with tectonic cracks, which are clearly seen in the Ma Thi Ho-Dien Bien, Bac Yen-Son La, and Coc Pai-XM-HG; Sliding surfaces are transitional surfaces with lithology composition such as in Tan Son market, Thac Khanh waterfall- Hoa Binh, Diu Thuong - XM-HG, Che Cu Nha - Yen Bai. The statistical relationship between the depth of the slip surface and the logarithm of the volume of the 26 detailed investigated LLs follows the linear rule. In addition, the logarithm of the ratio of the depth of the slide surface

- the length of the landslide to the logarithm of the ratio of the width - the length of the landslide also has a similar linear form.

3.4. Various types of large sliding blocks

When considering landslides according to the limit of volume, the LLs that often appears in the VNM area focuses on 2 types:

Translational landslide: translational slip accounts for about 30% of the large landslides occurring in the VNM area. This type of slide can move a considerable distance if the sliding surface is sufficiently long to be continuous, the slip surface is usually discontinuities in lithology composition or tectonic fracture.

Complex landslide: is the type with the most statistics, accounting for about 65% of large block slips appearing in the VNM area. When expanding to the volumetric scale of the LLs, the impact of rotation around the axis or landslide is reduced, the movement of the LLs mainly depends on the effects of gravity and hydrostatic action. Therefore, in the long run, the linear sliding movement prevails over the other types of displacement.

The development dynamics of LLs can be divided into 4 stages: (1) the period before the sliding instability is the phase of gradually decreasing the stability of the rock mass (2) the stage of activating the sliding instability. is the time when the stability strength of the slope soil decreases relatively quickly and very suddenly (3) the period after the sliding instability is the sliding stabilization phase, repeating the stability of the rock mass (4) the period reactivation is the period in which the degree of stability declines and the initial manifestation of slippage begins to appear.

CHAPTER IV. ASSESSMENT OF THE SUSCEPTIBILITY LARGE LANDSLIDE MAP IN THE VIETNAM NORTHERN MOUNTAINOUS

4.1. Condition factor characterization

4.1.1. Lithology factor

The lithology composition: Statistical results show that some types of lithology have a clear influence on the formation of geomorphology, including: magma mafic, foliated metamorphism and some types of metamorphism. Formations that have a strong influence are: River Chay, Ngoi Thia, Phu Si Lung, Tu Le, Yeyesun, Suoi Be, Da Dinh, Chieng Khuong, Ngan Son, Nui Dien, Po Sen, Pu Sam Cap, Xom Giau.

Distance to the lithological boundary: there exist 2 ranges that strongly influence the LLs formation. Within the distance to the lithological boundary of 400 m, the heterogeneity of the lithological composition leading to unstable slopes promoting the LLs formation is easy to see in site. In this range, LLs often has a sliding surface that is formed coincident with a discontinuity with lithology composition. With the distance to the lithology boundary in the range, 1.8 km to 3 km, the statistical results show that only a few geomorphic formations form but dominate more than the formation of small shallow landslide.

4.1.2. Tectonic factor

The tectonic characteristics of the VNM area are considered in the context of geodynamics of 16 structural zones. The fact shows that geomorphological formations are mainly along major fault zones such as: Dien Bien-Lai Chau fault zone, Da river fault zone, Than Uyen fault zone, Chay river fault zone, Yen Minh - Phu Luong fault zone. The influence of tectonic activities on the LLs formation is considered more clearly according to the distance to tectonic factor. Within 400 m around the fault zone, it can be seen that the influence on LLs formation is very strong. The influence of tectonic activities on the formation of geothermal tectonics tends to decrease with the distance to the fault, the further away from the fault, the lower the degree of influence.

4.1.3. Weathering layer

The weathering characteristics on the LLs formation in the VNM not only needs to be analyzed according to the growing thickness of weathering formations, but also needs to analyze the lithological characteristics that determine the most dangerous slip surface formation. the PhD student synthesized weathering layer types based on topographical features combined with lithology composition to divide them into 6 types as follows:

- VPH 1: thickness of fully weathered layer <10 m, sliding surface joins with boundary of medium weathering layer and strong weathering, for example: Diu Thuong and Diu Ha, Ban Diu, XM-HG
- VPH 2: thickness of fully weathered layer <10 m, sliding surface joins with boundary of medium weathering layer and weak weathering, for example: Muong Khoa, Bac Yen, Son La; Ban Ria, Quang Binh, Ha Giang.
- VPH 3: fully weathered layer thickness in the range of 10-15 m, sliding surface joins with boundary of medium weathering layer and strong weathering, for example: Tan Son, XM-HG and QL32 Nam Bung, Van Chan, Yen Bai.
- VPH 4: the thickness of the fully weathered layer is within 10-15 m, the sliding surface joins with the boundary of the medium weathering layer and weak weathering, for example: Thac Khanh, Tan Lac, Hoa Binh.
- VPH 5: the thickness of the fully weathered layer is >15 m, the sliding surface joins with the boundary of the medium weathering layer and strong weathering, for example: Mong Sen Geopark, Lao Cai; LLS village Sang Tung, Sin Ho, Lai Chau.
- VPH 6: the thickness of the fully weathered layer is >15 m, the sliding surface joins with the boundary of the medium weathering layer and weak weathering, e.g. Nam Luc, Ban Ria, Ban Khoang.

4.1.4. Group of topographic factors: terrain elevation, slope, slope direction, curvature, valley depth.

4.1.5. Group of hydrological factors: including topographic humidity index, distance to rivers and streams, average annual rainfall and maximum rainfall.

4.1.6. Group of land use factors: Normalized difference vegetation index.

4.1.7. Human activity factors: distance to slope excavation works (roads, civil and industrial works).

4.2. Assessment of the statistical correlation of condition factors

4.2.1. Paired correlation between condition factors

The factors considered have relative independent correlation and can be considered as independent variables. The multi collinearity results show that all VIF values are satisfied in the range from 1-5, so the 15 factors included in the analysis are not seriously affected by multi collinearity.

4.2.2. Multi collinearity of condition factors

4.2.3. Selection of condition factors for the susceptibility assessment model

BMA analysis shows that first model is capable of simulating the best model including 11 factors: terrain elevation, terrain slope, valley depth, average annual rainfall, maximum rainfall, NDVI, lithology, distance to lithological boundary, distance to fault, distance to road.

The results of main component analysis show that, 5 main factors affecting the LLs formation in the VNM are arranged in order of importance from high to low, including: distance to traffic road, distance to fault fracture distance to lithology boundary, lithological, slope.

Table 4.17. The statistical results of the condition factor analysis

Factor	Model								
	1	2	3	4	5	6	7	8	9
Elevation				0.974	0.208				
Slope direction									-1.0
Slope			0.331						
Valley depth						0.999			
Annual rainfall				0.208	-0.977				
Max rainfall							0.997		
NDVI								-1.0	
Dis to road	0.998								
Dis to lithology boundary		0.993							
Dis to tectonic fault		0.994							
Lithology material			0.353						
Standard deviation	3294.707	1658.118	754.679	448.71	2.672 e+02	5.504 e+01	14.92	10.68	4.739
Variance ratio	0.751	0.190	0.039	0.014	4.942 e-3	2.096 e-4	1.54 e-5	7.895 e-6	1.554 e-6
AUC		0.78	0.837	0.868	0.868	0.885	0.901	0.915	0.92

4.3. Susceptibility assessment result of LLS formation

4.3.1. Susceptibility assessment of LLs formation in the VNM area

4 susceptibility assessment models are formed that need to satisfy the following conditions: complete, practical significance and minimize variables amount.

a./ Logistic regression model: the map shows that the areas along the tectonic fault zones of the Da River, the Fanxipan zone, the Dien Bien Phu zone, the Lo river zone are the areas with high mass shear density with very high risk.

b./ Support vector machine model: The classification results show that the LLs formation is no longer clearly dependent on one main factor but is a combination of many natural and human factors.

c./ Artificial neural network model: The high and very high risk of formation is analyzed in narrow areas and distributed along the main traffic routes.

d./ Stacked ensemble machine learning model: The high and very high formation risk is analyzed in narrow areas and distributed along the main traffic routes. The density of large mass slips is concentrated in large tectonic zones in the northwest (Muong Te zone, Da river tectonic fault zones, Fanxipan zone, Dien Bien Phu zone, Lo river zone) and gradually decreases in northeastern area. Some localities with high hazard density are in the area of Muong Te, Sin Ho, Tam Duong and Than Uyen districts (Lai Chau); Xin Man, Hoang Su Phi, Vi Xuyen Quang Binh (Ha Giang); Sa Pa (Lao Cai); Pac Nam, Ba Be (Bac Kan); Da Bac (Hoa Binh); Moc Chau (Son La); Mu Cang Chai (Yen Bai). *(Figure 4.9)*

e./ Test evaluation results by statistical tools

Table 4.19. Synthesize the evaluation parameters of machine learning models

Model	ACC	95% CI	Kappa	AUC
Logistic regression	0.7784	0.7424 - 0.8115	0.3095	0.911
Support vector machine	0.799	0.7641 - 0.8308	0.3603	0.905
Artificial neural network	0.7852	0.7496 - 0.8179	0.3644	0.883
Stacked ensemble learning	0.7938	0.7586 - 0.826	0.3943	0.920
Stacked ensemble learning with Principal Component Analysis	0.7222	0.6901 - 0.7515	0.4163	0.837

The stacked ensemble learning model is the best model among the considered models. And when reducing the number of variables to 5 main factors, the model still correctly assessed 83.7% of cases of LLs in VNM.

f./ Susceptibility assessment of LLs formation at XM-HG

The results of susceptibility assessment of LLs formation at XM-HG show that a very high risk occurs in the northwest area of XM-HG district, where many fault systems are internship and there are many formations with different lithology here. The geological structure in the northwest region of the district has the Ha Giang formation located unconformable on the Song Chay complex. The southern region is mostly moderate to no-risk, with very few high-risk locations.

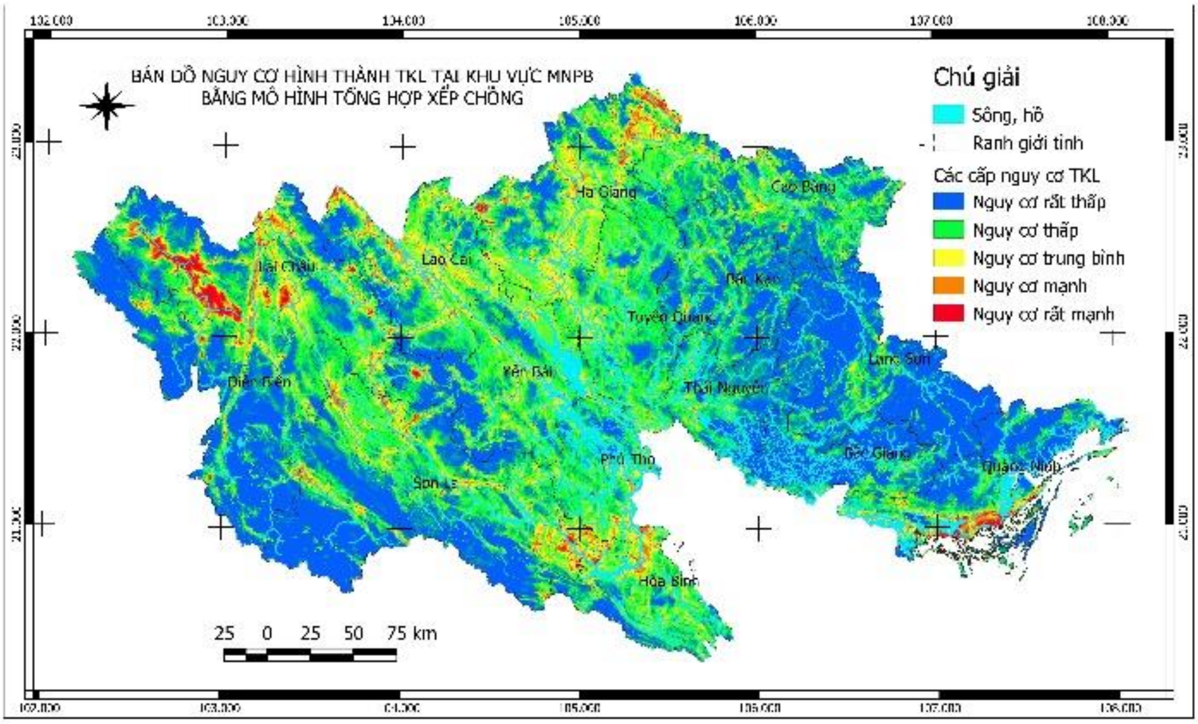


Figure 4.9. The susceptibility assessment map for LLs in the VNM area built with stacked ensemble learning model (reduced at 1:200,000 scale)

4.3.2. Comment on the distribution law of LLs in the VNM

Tectonics, lithology, topographic gradients and human activities are the main factors leading to the LLs formation in the VNM. The possibility of occurrence of LLs tends to prevail when: slope from >25º; the distance to the lithology boundary is in the range of 200-1,000 m; lithology material includes rocks with gabbro, limestone, coal, slate, tuff, shale; located within the influence of the tectonic rupture zone; located close to the lithological boundary.

The difference between the statistical analysis and the state testing are reflected in a number of factors as follows:

- Elevation: LLs is distributed with a large density and is different from a small shallow landslide at an altitude of 400-550 m.
- Slope: in the slope range from >25º, LLs appears much more than shallow landslide, so at this time, shallow landslide appears just as a phenomenon associated with LLs.
- Distance to the lithological boundary: within the range of 200-1000 m, the lithology boundary clearly affects the density of LLs formation more than the shallow types of small landslide.
- The landslide composition: on the graph of *Figure 3.19,* the locations with the difference in the frequency of hydrogeology and the shallow landslide are those with lithology belonging to the group of gabbro rock, limestone, coal, and crushed stone.

- Distance to the fault: LLs is usually located on the fault zone or about 1000-1600 m away from the fault, so at these distances the LLs is likely to appear higher than the small, shallow landslide.
- Distance to the road: within 200 m, the LLs is strongly influenced by human activities, especially the human slope to make roads.

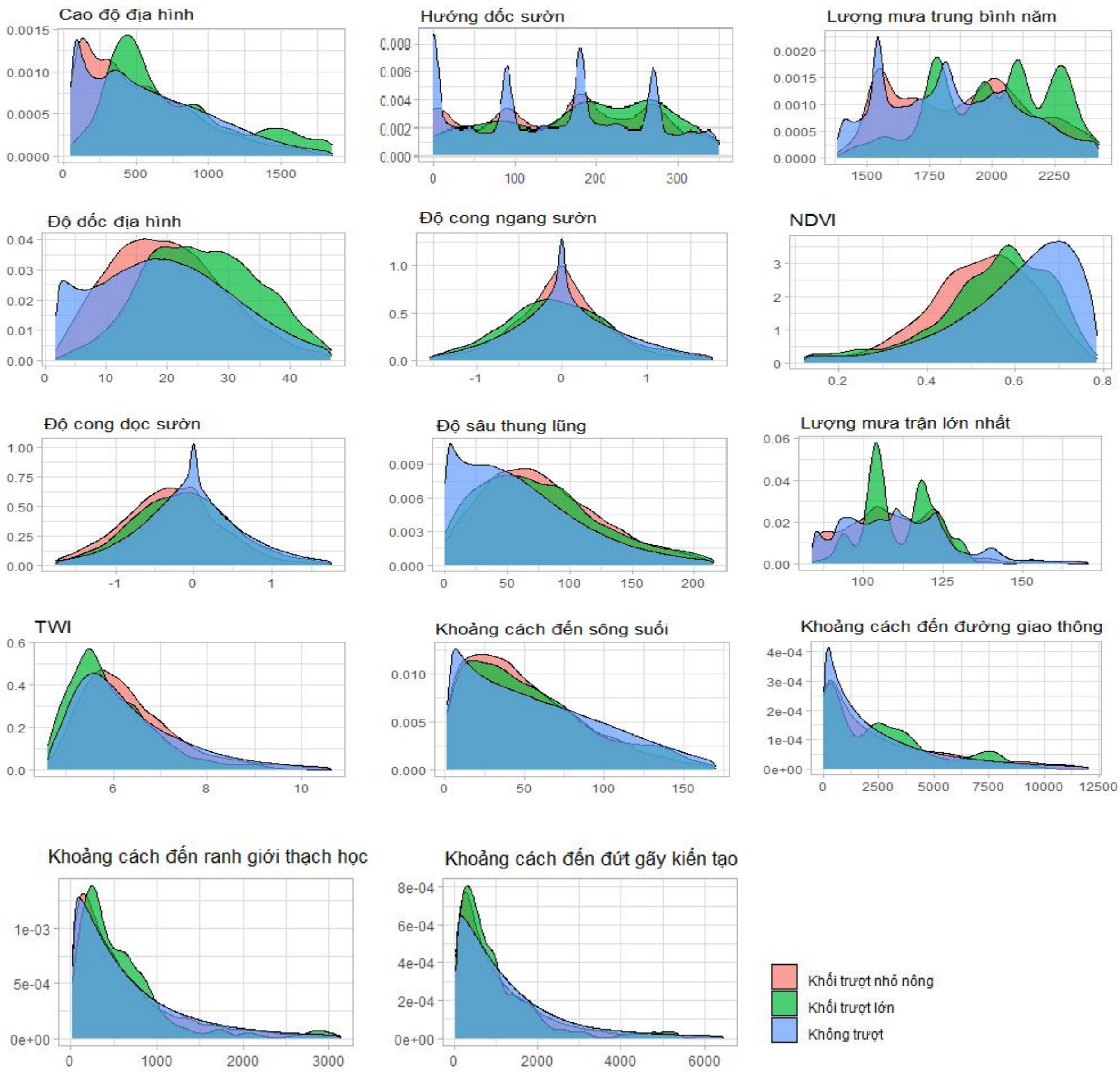


Figure 4.12. Synthesize the probability density distribution correlation between the position of the LLs and the shallow landslide and the unknown points with the condition factors

CHAPTER V. ANALYSIS OF LARGE LANDSLIDE KINEMATIC CHARACTERISTIC IN XIN MAN DISTRICT, HA GIANG PROVINCE

5.1. Dynamic signs

About the process and velocity of LLs: slow motion lasts long and over a wide area, moves with many discontinuous waves, moves fast or very fast when heavy rain occurs.

About signs of surface deformation: rapid and deep gully, LLs transverse edge, small sliding scrap, continuous wet surface, tension cracks.

About impact to human: LLs phenomenon also often causes great economic and human losses, including 3 forms: causing many deaths, causing great loss of economy, developed other damage.

5.2. Site monitoring system of the LLs at XM-HG

Hydrogeological monitoring data in Xin Man district is maintained from 3 types of monitoring: rain gauge, geotechnical monitoring, surface monitoring T-InSar. Due to the technical characteristics of each type of monitoring, the length of the data can be obtained, the data are integrated together and with the time of recording the large landslide event in the study area.

5.2.1. Rain monitoring

Table 5.2. Statistical characteristics of rain among rain monitoring stations around Xin Man district

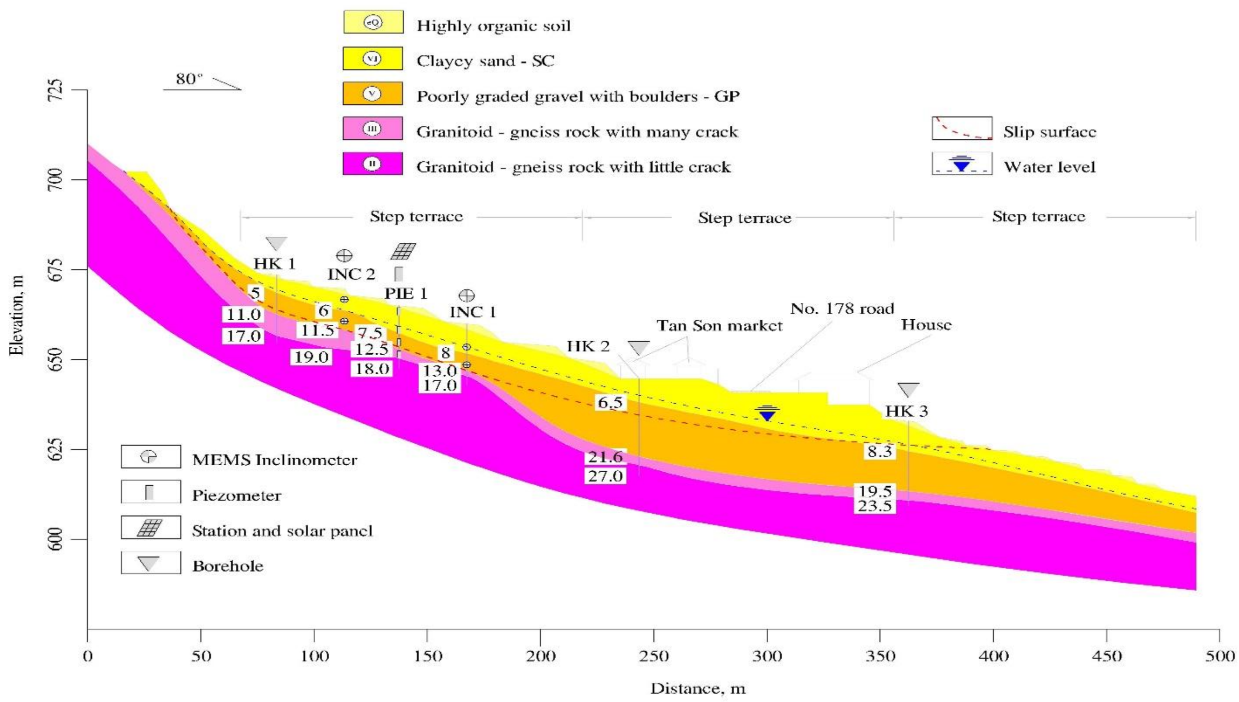
Station	Nam Dan (XM-HG)	Coc Pai (XM-HG)	Vinh Quang (Hoang S. Phi)	Yen Binh (Quang Binh)	Nam Ty (Hoang S.Phi)
Average precipitation (mm)	3444.6	2831.3	3515.5	2940.8	4073.4
Max precipitation (mm)	168	175.3	201.5	171.2	214.8

Rainfall data between stations around XM-HG shows that there is no statistical difference between Nam Dan and Coc Pai stations, so it should be used in the interpretation of other monitoring results and landslide events.

5.2.2. Geotechnical monitoring

Based on the results of geological survey drilling and the dangerous sliding surface, 13 sensors were installed in the body of LLs.

a./ Piezometer: The obtained data shows very clearly the variation according to the seasonal cycle and the day cycle. The rainy season starts around May, the pore water pressure changes continuously and continuously forms peaks depending on each heavy or prolonged rain, and at the end of the rainy season, it tends to decrease gradually starting from May. 11. In the dry season months, the small rains cannot increase the pore water pressure in the soil to form sharp peaks.



Hình 5.1. Geological cross-section of the Tan Son market LLs

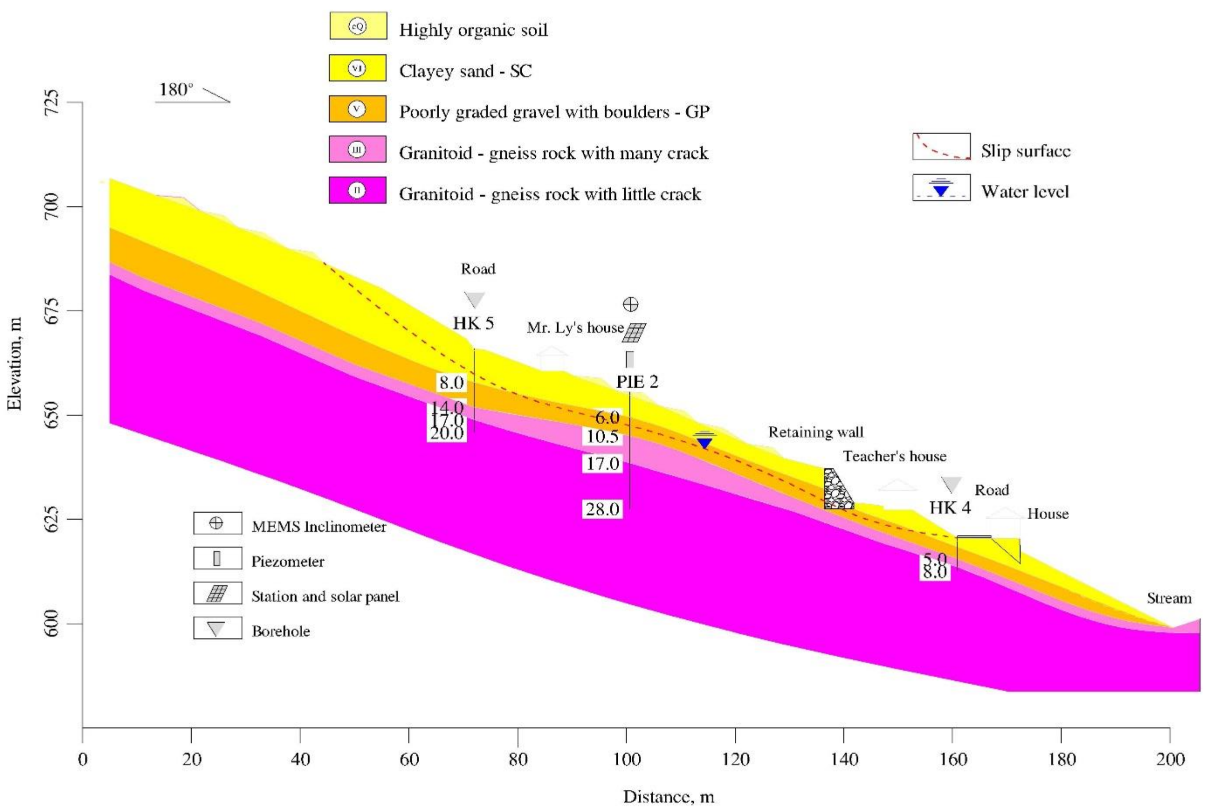


Figure 5.2. Geological cross-section of Diu Thuong LLS

b./ Inclinometer: The accumulated displacement data of sensors at Tan Son market LLs shows that the displacement in the rainy season is mainly. The number of displacements in 2017 is the highest and is also similar to the records of the slip phenomenon occurring around Xin Man district this year. We can see that the trend of decreasing the displacement of the large landslide in Tan Son market is very clear. It seems that Tan Son market LLs is gradually transitioning to a stable state.

5.2.3. T-InSAR: the degree of displacement of LLs slip surface is heterogeneous and discontinuous according to *Saverio Romeo (2020).*

5.3. Analysis of LLs kinetic based on monitoring data

5.3.1. The influence of rain and groundwater level fluctuations on the movement of LLS

To clarify the relationship between pore water pressure and depth, pore water pressure is considered as a function correlated with depth called pore water pressure coefficient (r_u), determined by the formula :

$$r_u = \frac{u}{\gamma * z * 10}$$

Where: u is the pore water pressure (kPa), γ the volumetric mass density (g/cm^3), z the depth determines the pore water pressure (m), 10 is the unit conversion factor

Then, the pore water pressure values at different depths have been converted to the same certain ratio and can be compared between different depths.

Analyzing the hourly monitoring data, it can be seen that the delay between pore water pressure and displacement always has a certain distance. The data at Nam Dan station have shown more clearly, when the pore water pressure coefficient is less than 0,53, no matter whether the pore water pressure coefficient increases, decreases or fluctuates, no horizontal movement can be observed. significantly in the LLs *(Figure 5.8).* When the pore water pressure coefficient increased more than 0,53, the change of the pore water pressure coefficient is always proportional and faster to the horizontal displacement of the sensor near the ground in the borehole from 3 up to 12 hours. At Ban Diu station, the transverse displacement changes on the surface of the slope measured are very small. Therefore, when the pore water pressure coefficient at the position closest to the most dangerous sliding surface exceeds 0,53 is equivalent to exceeding the warning threshold that needs attention.

Consider the times with monitoring values $r_u \geq 0,53$ (July 8th 2017, October 1st 2017, July 25th 2019, July 4th 2020, September 30th 2020), rainfall has been continuous for several days before and is suddenly heavier on the one last day. Some days with very heavy rainfall (July 20th 2017, August 17th 2017, July 30th 2019) also caused the r_u coefficient to increase rapidly exceeding the value of 0,53. These days not only recorded movements in the LLs observed but also recorded landslide events in the area of XM-HG.

5.3.2. Displacement of LLs

Observing the reverse velocity trend after the rain on October 1st 2020 at Tan Son market LLs shows that the landslide has moved to a new stability stage. The reverse velocity value decreases rapidly (from greater than 350 hour/mm) and tends to approach the horizontal axis (time axis) at 18.2 hour/mm. Similar analysis, through the statistics of reverse velocity values at Tan Son LLs, it is found that the reverse velocity values are only asymptote to the horizontal axis and the lowest value is 9 hour/mm.

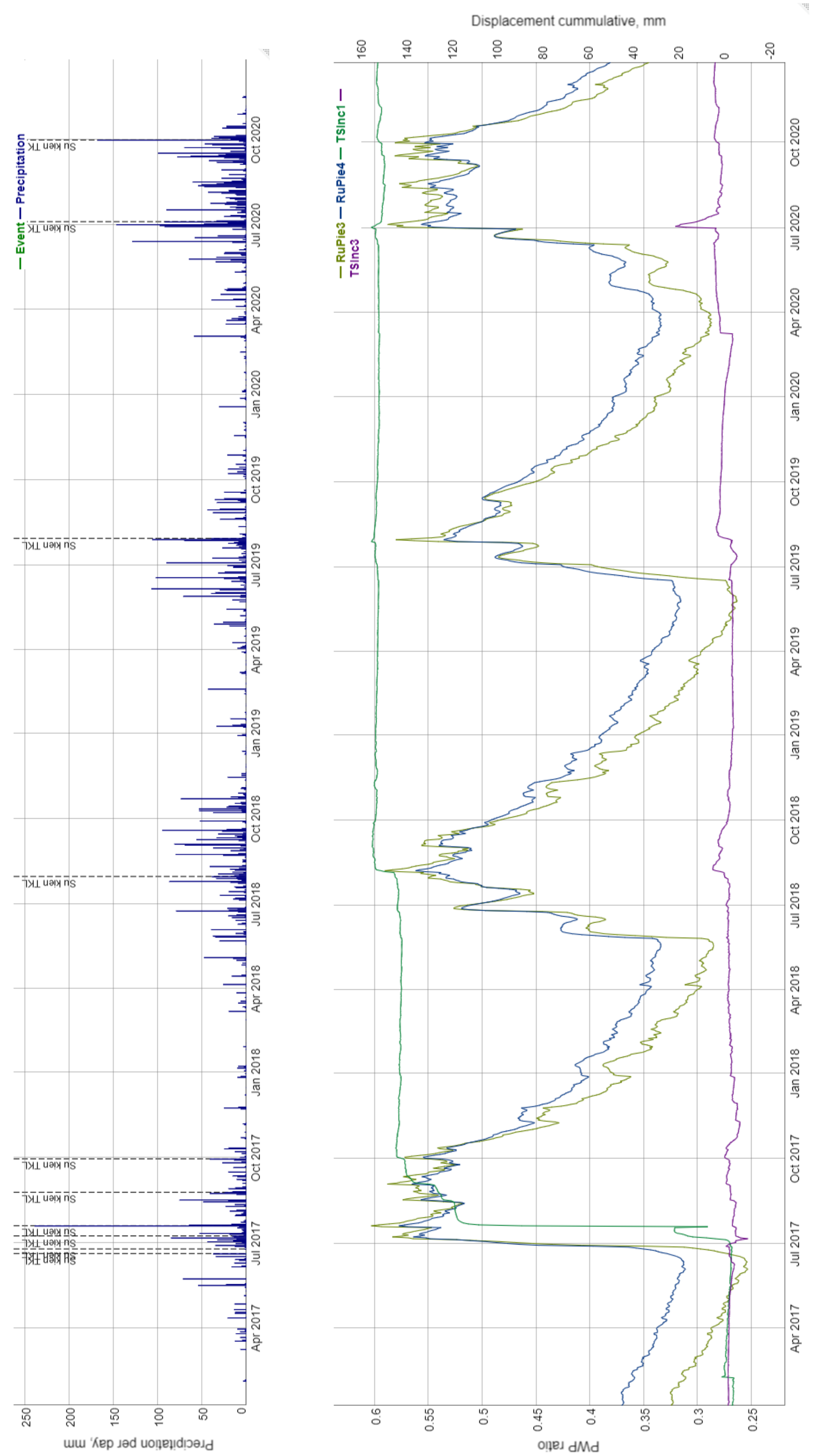


Figure 5.6. The monitoring results of rainfall, pore water pressure and horizontal displacement in at Tan Son station are integrated with landslide events recorded at XM-HG from 2007 to 2021.

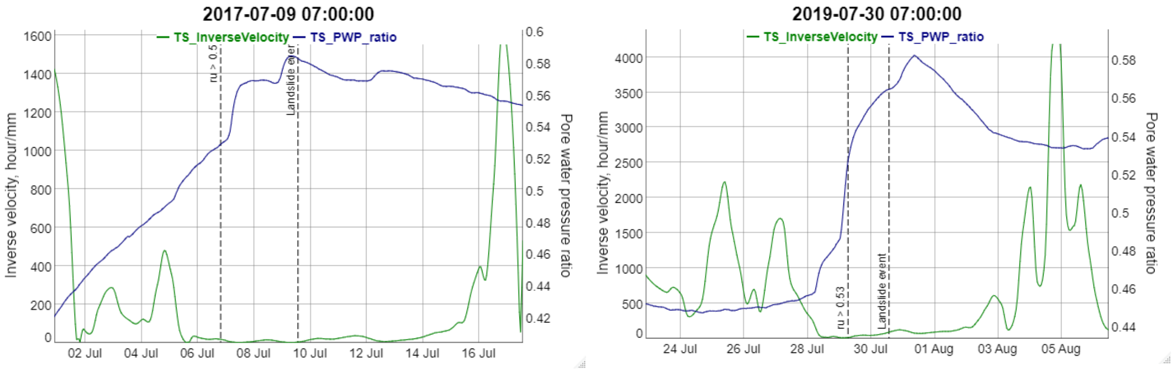


Figure 5.8. Correlation of pore water pressure coefficient when r_u exceeds 0.53 at Tan Son station

Figure 5.8 shows that the intersection between increasing the pore water pressure ratio above 0,53 and decreasing the reverse velocity value below 25 h/mm is considered a dangerous starting point. Then the inverse velocity always tends to be asymptotic to the horizontal axis.

Comparing the correlation between displacement by geotechnical monitoring with T-InSar, the PhD student chose observation point P14 as the installation location of geotechnical monitoring station. shows that the time series of displacement of point P14 corresponds to the displacement of the upper part of the borehole where the inclinometer sensor of the monitoring station is located.

5.4. LLs dynamics analysis based on geotechnical models

5.4.1. Stability analysis

Table 5.5. Synthesize FoS analysis results of Tan Son and Diu Thuong LLs according to different levels of pore water pressure coefficient.

Pore water pressure ratio r_u	Factor of safety	
	Tan Son	Diu Thuong
0,6	1,026	0,998
0,55	1,098	1,094
0,53	1,143	1,132
0,5	1,192	1,183
0,45	1,279	1,245
0,4	1,331	1,382

With the results of stability analysis according to the general equilibrium method as above, it shows that both Tan Son and Diu Thuong LLs are at risk of instability when the ru value exceeds 0,53.

5.4.2. Runout analysis of LLs

The results of run out analysis of LLs Diu Thuong using LS Rapid software showed that, when r_u reached 0,53, the entire landslide was formed and only after about 6,5 seconds, the debris reached maximum speed is 21 m/s. The length of the range of influence is: 190 m.

The results of analyzing the range of motion of Tan Son LLs using LS Rapid software showed that, when ru reached 0.53, the entire sliding block was formed and only after about 8 seconds, the debris reached its motion. speed 20 m/s. The length of the affected area is 210 m.

5.5. Solutions to mitigate LLs damage

Therefore, it is necessary to integrate groups of solutions in an integrate manner suitable to the development stage of LLs and the surrounding environment. In addition, the application of solutions to minimize the impact of LLs should be directed towards the initiative in response and the ability to link between available resources. With the above research results, the researcher proposed 3 groups of basic solutions to minimize the impact of the phenomenon of water loss.

5.5.1. Improve the efficiency of survey work and the ability to identify LLs

5.5.2. Land use planning in high-risk areas for mass slip

a./ Use slope land in high risk area

b./ Run out analyze of LLs

The range of influence is an important feature of kinetics in the study of landslides. According to statistics on the relationship between the influence range (log10(tanα)) and the LLs volume (log10(V)) we see a linear relationship according to the empirical formula:

$$\text{Log10}(\tan\alpha) = -0.0906 * \text{Log10}(V) - 0.1321$$

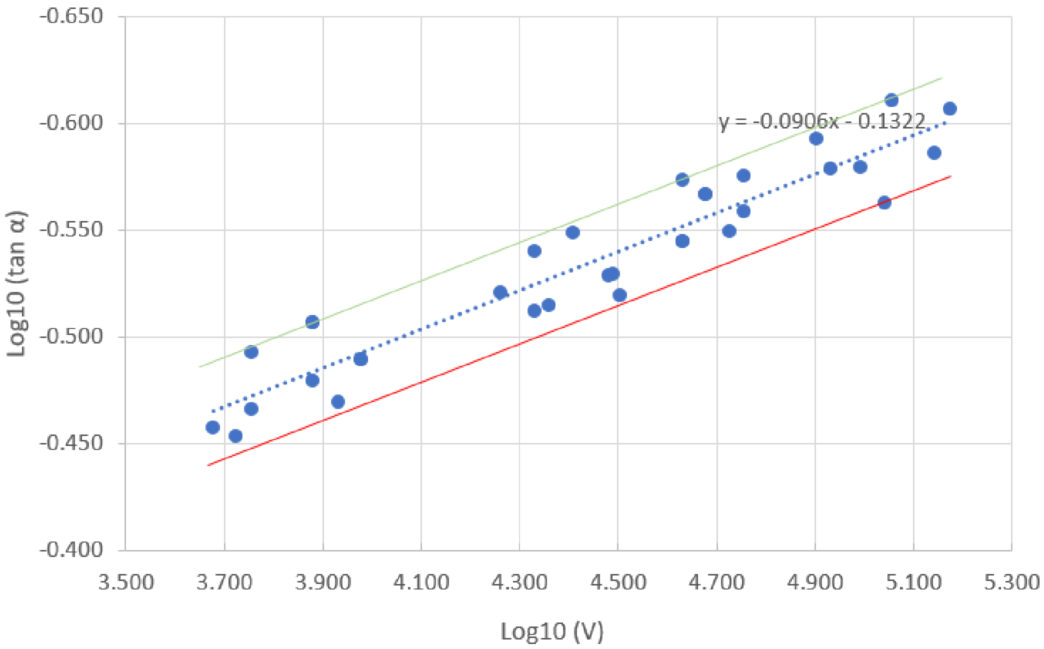


Figure 5.19. 90%, 50%, and 10% probability prediction of runout range (green line, blue dashed, red) based on LLS volume at XM-HG

If we consider the range that 90% of LLs can affect as the margin of safety, the formula for determining the maximum range of influence according to the volume of the sliding mass is:

$$\text{Log10}(\tan\alpha) = -0.0906 * \text{Log10}(V) - 0.1542584$$

This can be considered as a safe limit for the arrangement of civil works in the area affected by the LLs.

5.5.3. Early warning solution

With the monitoring technologies in LLs at XM-HG, the researcher proposes forecasting technology based on a combination of meteorological data, susceptibility maps and monitoring data of the field station for XM-HG. This monitoring process consists of 4 steps: scoping the research area, synthesizing the necessary data, analyzing the risks, and verifying the model.

CONCLUSIONS AND RECOMMENDATIONS

Some conclusions are proposed from the results presented above:

(1) Statistics data of 8.304 landslides in the VNM area shows the landslide occurrence frequency distribution with the volume logarithm is the normal distribution and the volume limit of the LLs is 4.500 m^3 (95% confidence level).

(2) LLs in the VNM area is mostly of complex and translational landslide, the most dangerous slip surface is the discontinuity surface o the boundary of the lithology or the tectonic zone.

(3) The condition factors affect the LLs formation in the natural environment are likely to interact with each other in an regression model. The results of correlation and multi collinearity analysis allow to identify condition factors that are highly correlated with other factors such as: curvature, TWI and distance to rivers and streams.

(4) The LLs formation in the VNM area is influenced by many natural and man-made factors. The combination of statistical analysis and machine learning showed that the stacked ensemble learning method gave the most reliable results, the susceptibility LLs formation was assessed by considering 11 condition factors. The 5 important factors include: distance to road, distance to fault, distance to lithological boundary, lithological material, slope.

(5) Field monitoring system includes observations of surface topographic, hourly rainfall monitoring and pore water pressure monitoring, measuring horizontal displacement at different depths with actual conditions and allows quantitative study of dynamic characteristics of some LLs at XM-HG.

(6) LLs dynamic characteristics at XM-HG are characterized by non-uniform displacement at many different sliding surface positions. LLs displacement follows the process of deformation accumulation and seasonal evolution. The time when the LLs displacement occurs in the rainy season, the pore water pressure increases rapidly at the dangerous sliding surface, and the value of $r_u \geq 0{,}53$.

(7) Base on statistical analysis and run out analysis of LLs, the limit on the run out distance range is determined by the formula based on LLs volume: $\log10 (\tan \alpha) = -0{,}0906 * \log10 (V) – 0{,}1542584$. This is a basis for proposing

solutions to limit the LLS run out in the design of works and has practical significance for disaster prevention work.

With the above contents and conclusions, the PhD student proposes 2 recommendations as follows:

(1) The results of the susceptibility assessment of the LLs formation have a good effect for early warning of catastrophic events, selection of suitable resettlement sites, and relocation of people out of the danger zone. The establishment of susceptibility maps depends on the scale of the study and the scope of the research. For this thesis, the PhD student focuses on analysis at the rate of 1/200.000. For researches at larger scale, it is necessary to analyze with more specific factors such as: weathering crust structure, folds, degree of fracture of bedrock, lying position of bedrock. Therefore, it is necessary continue to study the LLs phenomenon at larger scale.

(2) The early warning system for landslide hazards is a proactive and highly effective solution, but has not been fully invested. The early warning system of landslide hazards in Vietnam has only been tested by some research projects with some advanced foreign technologies. It is necessary to have an approach suitable to Vietnamese conditions and to meet the reliability of warning information. Therefore, it is necessary to have a lot of investment sources, to socialize the equipping of early warning systems for natural disasters.

NEW CONTENTS OF THE THESIS

- Systematized the main characteristics of LLs in the VNM area based on statistical analysis methods.
- Established a susceptibility map to assess LLs formation in mountainous areas by combining statistical analysis and machine learning.
- Developed a process to analyze field monitoring data of geotechnical parameters in accordance with the actual conditions of the LLs at XM-HG.
- Determine the pore water pressure ratio r_u at the dangerous sliding surface position when there is significant displacement of the LLs, supporting the early warning of the LLs instability at XM-HG.

LIST OF RELATED PUBLIC SCIENTIFIC WORKS

1./ Tran Quoc Cuong, Do Minh Duc, Abolfazl Jaafari, Nadhir Al-Ansari, **Dao Minh Duc,** Van Duc Tung, Nguyen Duc Anh, Tran Trung Hieu, Ho Si Lanh, Nguyen Huu Duy, Indra Prakash, Le Van Hiep, Pham Thai Binh (2020). Novel Ensemble Landslide Predictive Models Based on the Hyperpipes Algorithm: A Case Study in the Nam Dam Commune, Vietnam. Applied Sciences No.10(11).

2./ **Dao Minh Duc**, Tran Quoc Cuong, Do Minh Duc, Dang Thi Thuy (2018). Analysis of pore water pressure and slope displacement by historical rain series in Xin Man district, Ha Giang province, Vietnam. Proceedings of the 4th International conference Vietgeo 2018, pages 499-509.

3./ **Đào Minh Đức**, Hoàng Hải Yến, Nguyễn Khắc Hoàng Giang, Đinh Thị Quỳnh (2017). Lựa chọn áp lực cố kết và tốc độ cắt phù hợp trong thí nghiệm cắt xoay nhằm xác định sức kháng cắt dư cho đất sườn tích trên khu vực khối trượt lớn chợ Tân Sơn, xã Nấm Dẩn, huyện Xín Mần, tỉnh Hà Giang. Tuyển tập Hội nghị cơ học toàn quốc lần thứ X, tập 2, trang 728-738.

4./ Do Minh Duc, **Dao Minh Duc,** Do Minh Ngoc (2018). Effects of residual soil characteristics on rainfall-induced shallow landslides along transport arteries in Bac Kan province, Vietnam. Advances and applications in Geospatial technology and Earth resources - GTER 2017, pages 202-223.

5./ Do Minh Duc, Dang Quang Khang, **Dao Minh Duc,** Do Minh Ngoc, Dinh Thi Quynh, Dang Thi Thuy, Nguyen Khac Hoang Giang, Pham Van Tien, Nguyen Huu Ha (2020). Analysis and modeling of a landslide-induced tsunami-like wave across the Truong river in Quang Nam province, Vietnam. Landslides, Vol.17, pages 2329–2341.

6./ Saverio Romeo, Quoc Cuong Tran, Giandomenico Mastrantoni, Duc Do Minh, **Duc Dao Minh**, Huy Thang Nguyen, Duc Anh Nguyen, Paolo Mazzanti (2020). Remote monitoring of natural slopes: insights from the first terrestrial insar campaign in Vietnam. Italian Journal of Engineering Geology and Environment, No.20(1), pages 55-63.

7./ Tran Van Tu, **Dao Minh Duc,** Nguyen Mạnh Tung, Van Duy Cong (2016). Preliminary assessments of debris flow hazard in relation to geological environment changes in mountainous regions, North Vietnam. Vietnam Journal of Earth Sciences, Vol.38, pages 277-286.

8./ Tran Van Tu, **Dao Minh Duc,** Nguyen Manh Tung, Van Duy Cong (2015). Formation and development of debris flows in Vietnam. VietRock 2015 International symposium – Rock mechanics for sustainable development, pages 259-272.